UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Global
Green Growth
Institute

GLOBAL GREEN GROWTH:
Clean Energy Industrial Investments and Expanding Job Opportunities

Overall Findings

The Global Green Growth Institute
United Nations Industrial Development Organization

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April 2015

United Nations Industrial Development Organization (UNIDO)
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Foreword

It has become abundantly clear that fossil fuel powered industrialization as we have known it has had unanticipated adverse environmental impacts. One of the most significant challenges faced by global leaders today is how to achieve inclusive and sustainable industrial development, hereby creating jobs and reducing poverty, while combating climate change and resource depletion. As the world gears up for common actions to meet this end, one must ask whether current 'green growth' efforts towards low-carbon resource-efficient industrial development will lead to the sustained generation of new jobs.

The present paucity of policy-related information on the impact of green industrial investment on employment prevents policy makers and businesses from obtaining a full picture of the potential benefits of such investments, and thus to undertake investments that will be successful in terms of achieving both environmental protection and job creation. The absence of this information might cause the great expectation for green industries to dwindle. Indeed, it might jeopardize the global efforts to meet the emission reduction targets set by the Intergovernmental Panel on Climate Change (IPCC) to control climate change.

This project comes at a time when policy makers are focusing their national strategies on employment creation while they face a still faltering global economy with slow and uneven recovery. Against this background, there is a pressing need to combine the objectives of green growth with the broader targets for economic development in order to achieve a sustainable, low-carbon trajectory. Developing countries in particular will have to balance these objectives so as not to sacrifice opportunities to expand decent employment opportunities and reduce poverty. Designing and implementing effective industrial policies within all countries at all levels of development and effective international coordination will be critical for expanding green investments and hence facilitating the transformation to a global low-carbon economy.

The project has resulted in two reports. Volume I focuses on the employment generation opportunities of measures to reduce carbon dioxide emissions through investments in renewable energy and energy efficiency, and reviews some of the main considerations with respect to advancing effective industrial policies. The report concludes that if most countries devote about 1.5 percent of their economy's GDP to such investments each year, it will be possible for the global economy to meet the IPCCs' 20-year intermediate emission reduction target, while also enjoying energy security for supporting sustainable growth rates.

Volume I also shows that there are clear net-gains in employment generation in shifting from conventional energy sources to renewable energy sources and enhancing energy efficiency. These gains have wider societal implications, as decent job opportunities are likely to open up for people in the informal sector with low educational attainment levels. Targeted industrial policies will need to help these groups realize such opportunities as well as providing the training and skill acquisition needed for other positions created through green investments.

Volume II examines the specific industrial policy measures promoting a low-carbon transition in five focus countries, specifically Brazil, Germany, Indonesia, the Republic of Korea and South Africa, through a compilation of expert review studies. Across all levels of development, major attention is being paid to the threats of climate change and opportunities of pursuing a low-carbon development path, and dedicated efforts are presented to operate efficient industrial policies to enhance green growth. However, it is clear that the major focus in developing countries will need to be on green investments and on creating an enabling environment for such investments if the global economy is to effectively combat climate change.

It is our pleasure to note that the reports are the result of a major effort that has brought together the expertise of UNIDO and GGGI as well as experts from around the world. We hope that the findings of this project will provide policy makers, other global actors and businesses with a bigger picture of the employment generation opportunities of investing in green energy sources. At the same time, we hope that the specific attention to industrial policy will inspire countries when they formulate their own industrial development strategies and approaches, so that they are prepared to make their own effective contributions to the transformation to a global clean energy economy.

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Director General of UNIDO

Yvo de Boer

Director-General of GGGI

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Abbreviations and Acronyms

BAU	Business As Usual
BTU	British Thermal Unit
CCS	Carbon Capture and Sequestration
CFL	Compact Fluorescent Light
CGE	Computable General Equilibrium
CO2	Carbon dioxide
EIA	Energy Information Administration (U.S.)
EPA	Environmental Protection Agency (U.S.)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt (1x10^9 watts)
GWh	Gigawatt-hour
HVAC	Heating, Ventilation, and Air Conditioning
I-O	Input-Output
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KW	Kilowatt
KWh	Kilowatt-hour
Mmt	Million metric tons
Mt	Metric tons
MW	Megawatt (1x10^6 watts)
MWh	Megawatt-hour
NAS	National Academy of Sciences (U.S.)
OECD	Organization for Economic Cooperation and Development
PV	Photovoltaic (Solar)
Q-BTU	Quadrillion BTU (1x10^{15} BTU)
R&D	Research and development
ROK	Republic of Korea
UNFCCC	United Nations Framework Convention on Climate Change

SUMMARY OF MAIN FINDINGS

As of 2010, total world greenhouse gas (GHG) emissions amounted to about 45,000 million metric tons (mmt). In order to control climate change, the Intergovernmental Panel on Climate Change (IPCC) estimates that total emissions will need to fall by about 40 percent as of 2030, to 27,000 mmt, and by 80 percent by 2050, to about 9,000 mmt.

Of the 45,000 mmt of total GHG emissions, about 82 percent are generated by energy-based sources. This includes 33,615 in CO_2 emissions from energy sources, equaling about 75 percent of total GHG emissions itself.

This report focuses on measures to reduce CO_2 emissions from energy-based sources. Expressed on a per capita basis, global CO_2 emissions in 2010 averaged 4.6 metric tons (mt). We can express our intermediate emissions reduction goals in terms of this measure, within the framework of reducing the absolute level of carbon emissions by 40 percent, to around 20,000 mmt, within 20 years. With global population expected to rise to about 8.4 billion by 2030, this means that carbon emissions will need to be at no more than 2.4 mt per capita within 20 years.

The purpose of this report is to examine policy frameworks through which these CO_2 emission reduction targets can be met, without inhibiting the opportunities for economies to grow and expand well-being for their citizens. We are especially concerned that developing countries be able to grow at healthy rates as the global clean energy transition advances. For developing countries to sacrifice economic growth as a means to reverse climate change will also entail sacrificing opportunities to expand decent employment opportunities and dramatically reduce poverty. Limiting opportunities for countries to proceed on a healthy economic growth trajectory will also face formidable political resistance. This resistance will in turn create unacceptable delays in proceeding with effective policies to control climate change.

The core arguments of this report are simple. We argue that the global economy is capable of meeting the IPCCs' 20-year intermediate emission reduction target if most countries - including especially most countries with either large GDPs or population - devote about 1.5 percent per year of their economy's GDP to investments in energy efficiency and clean renewable energy sources. These clean renewable sources include solar, wind, geothermal, and small-scale hydropower, as well as low-emissions bioenergy sources. They exclude corn ethanol and other high-emissions bioenergy sources, whose use generates CO_2 emissions at levels equivalent to oil. We conclude that, as a general proposition, countries that sustain this 1.5 percent of GDP level of annual investments in energy efficiency and clean renewables will also be able to maintain economic growth at healthy rates while providing a sufficient supply of energy resources to undergird growth. These investments in energy efficiency and renewable energy will also be a net new source of job opportunities. More specifically, new investments in energy efficiency and renewable energy will generate more jobs for a given amount of spending than maintaining or expanding each country's existing fossil fuel sectors.

Global GDP in 2013 was $87 trillion. Thus, 1.5 percent of global GDP is about $1.3 trillion at current GDP levels. This would mean channeling about $650 billion each for clean renewables and energy efficiency investments, if new investment funds were divided evenly between these two sectors. If spending were instead divided at something closer to 1 percent for renewables and 0.5 percent for energy efficiency, as will probably be appropriate in most country settings, that entails devoting about $870 billion for renewables and $435 billion for energy efficiency at the current global GDP level. These clean energy investment figures would also increase annually, corresponding with the growth of each country's GDP.

As of the most recent credible data, total global renewable investments were at $227 billion in 2011 and energy efficiency investments were between $150 and $300 billion. This totals between $377 and $527 billion, or between 0.4 and 0.6 percent of global GDP. In other words, current global investments in clean energy are at roughly 30-40 percent of where they need to be to reach the 1.5 percent of GDP level. It is clear that a great deal needs to be accomplished to reach the 1.5 percent figure. At the same time, with the current investment level already at between 0.4 and 0.6 percent of global GDP, getting to a 1.5 percent of GDP figure is not so far out of reach as to appear implausible.

Industrial Policies for Clean Energy Transition

To bring global clean energy investments up to about 1.5 percent of global GDP will certainly require the development of effective industrial policies for countries at all levels of development. This begins with governments playing a leading role in adapting clean energy technologies. As the UNIDO 2013 *Industrial Development Report* usefully summarized specifically with respect to uptake of green technologies in manufacturing, "technological change rarely takes place in a vacuum, and often requires incentives. Success stories of new energy technologies are the product of forward-thinking ambitious government policies," (UNIDO, 2013, p. 124). Governments will also need to play a leading role in delivering affordable and flexible financing arrangements for clean energy investments to be sustained on a large-scale basis.

In conjunction with the need for a major expansion in clean energy investments worldwide, it is also the case that the burning of oil, coal and natural gas will need to contract substantially in absolute terms throughout the globe to achieve the IPCC's emissions reduction targets. This conclusion is unaffected by whether new fossil fuel reserves are discovered, such as the so-called "pre-salt" deposits in Brazil or elsewhere. It is also unaffected by whether new technologies, such as hydraulic fracturing - i.e. "fracking" - are employed to produce fossil fuel energy more cheaply. This means that, over the next generation and further into the future, all owners of fossil fuel assets, including public sector entities as well as private oil, coal, and natural gas corporations, will, by necessity, experience a major decline in the value of these fossil fuel holdings.

Workers tied to the oil, coal, and natural gas industries will inevitably face job losses as a consequence. Economic policies are therefore needed in all countries to assist these workers, as well as their families and communities, with transitional support into new areas of economic activity, where decent job opportunities are expanding. In most countries, the energy efficiency and clean renewable energy sectors will be among the most important new areas of expanding job opportunities.

Country-Specific Perspectives

As of 2010, total global energy consumption amounted to about 510 quadrillion BTUs (Q-BTUs) from all energy sources - including fossil fuels, all renewable sources and nuclear power. This is while total CO_2 emissions were at 33,615 mmt, or 4.6 mt per capita. The two leading countries in terms of both energy consumption and CO_2 emissions are China and the United States (U.S.). Their respective levels of energy consumption were nearly identical in 2010, with China at 100.9 Q-BTUs and the U.S. at 98 Q-BTUs. Together, China and the U.S. account for nearly 39 percent of world energy consumption. In terms of carbon emissions, China is at a higher level, at 7,997 mmt, or 6 mt per capita. The U.S. produces 30 percent fewer emissions overall, at 5,637 mmt, but three times more emissions on a per capita basis, at 18.2 mt. Together, they account for 43 percent of all global carbon emissions. Obviously, we must give major attention to developments in the U.S. and China - both the specifics within both countries and their impact in combination - in terms of mounting an overall project for controlling climate change.

But the cases of the U.S. and China also underscore another fundamental fact. Despite their obvious centrality, they are still, in combination, contributing well less than half to the overall level of global carbon emissions. This therefore means that we must be at least equally concerned to develop policies that apply to all other countries. This report focuses in particular on the challenges faced by five specific countries: Brazil, Germany, Indonesia, South Africa, and the Republic of Korea (ROK).

Economic conditions obviously range widely between these five countries. But they are all, in their own distinctive ways, leading economies within their respective regions of the world. It is also notable that with all five selected countries, policymakers have already proposed clean energy/emissions reduction policy frameworks ranging between 1-2 percent of their country's GDP. Our proposal for a clean energy project sustained at about 1.5 percent of GDP therefore builds from the perspectives developed within our five selected countries. In examining these individual cases in some depth, we will also clearly be able to gather insights on a broader set of countries at various levels of development.

Consider, for example, the case of Indonesia, which is defined as a lower-middle income economy according to the World Bank. Indonesia aims to grow rapidly over the next 20 years - i.e. in the range of 6-7 percent per year - following the examples in recent decades of the ROK, China, India and other fast-growing Asian economies. However, the Indonesian government's own estimates show that the country's CO_2 emissions will increase by more than 500 percent by 2030 relative to 2010 if the economy's GDP growth is fueled primarily by oil, coal, and natural gas. By contrast, we estimate that, under reasonable assumptions, a significant share of Indonesia's energy needs for fueling a rapid growth trajectory can be met through investments in energy efficiency and clean renewable energy, as long as Indonesia channels about 1.5 percent of GDP annually into these clean energy areas. We also estimate Indonesia's investments in energy efficiency and renewable energy can also be a significant new source of job creation within the country.

Valuable perspectives also emerge through our explorations of our four other selected countries. Brazil is important because it is the world's best-performing upper-middle income economy in terms of maintaining low emissions levels amid a healthy GDP growth trajectory. Germany, similarly, has an excellent record in terms of emissions levels relative to other high-income countries. Germany's clean energy agenda for the next 20 years is also highly ambitious and innovative. South Africa is critical because it is the largest and most advanced economy in Sub-Saharan Africa. At present, it also depends heavily on its major coal reserves, both to meet its domestic energy needs and to generate export revenues. A clean energy transition is nevertheless still realistic for South Africa. The case of the ROK is unique because, in 2009, the previous government of President Lee Myung-bak established a project of "Green Growth" as a major national development objective. Consistent with the goals of the ROK's Green Growth project, our research finds that, in fact, the ROK could realistically reduce its absolute level of CO_2 emissions per capita by roughly 50 percent within 20 years without having to lower the economy's GDP growth rate. We reach this conclusion based on a set of relatively conservative assumptions about the ROK's prospects for integrating energy efficiency and clean renewables into the country's energy mix.

Global CO2 Emissions Projections for 2030

We can obtain valuable perspective on the magnitude of the challenges ahead by considering the CO_2 emission level projections for 2030 by the International Energy Agency (IEA), which publishes an annual *World Energy Outlook*. The IEA provides projections under three scenarios: a Reference case; a "New Policies case" and a 450/Low Carbon case. The IEA describes its New Policies case as taking into account "broad policy commitments and plans that have already been implemented to address energy-related challenges as well as those that have been announced…." But this New Policies case also "assumes only cautious implementation of current commitments and plans." The IEA describes its 450/Low Carbon case as setting out "an energy pathway that is consistent with a 50 percent chance of meeting the goal of limiting the increase in average global temperature to 2^oC compared with pre-industrial levels," (IEA, 2013a, p. 645). That is, the IEA believes that its 450/Low Carbon case provides a 50 percent chance for the world to control climate change.

Under the IEA's 2030 Reference case, global CO_2 emissions are at 40,825 mmt, which is more than twice as high as the IPCCs' 20,000 mmt 2030 target level. The situation is only modestly improved in the IEA's New Policies case, in which they project 2030 CO_2 emissions to total 36,493 mmt. Even under the 450/Low Carbon case, the IEA still projects global emissions to be 24,663 mmt. Of course, this is a dramatic improvement relative to the other two cases. But it is still 23 percent higher than the 20,000 mmt 2030 target. It is critical to underscore, moreover, that the IEA describes the 450/Low Carbon case as offering only a 50 percent chance of the world succeeding in controlling climate change.

It cannot be a satisfactory situation when, even under the most aggressive policy framework for controlling climate change modeled by the IEA, we still face only a 50 percent chance of achieving success.

Options for Reducing Carbon Emissions

Notwithstanding the wide differences in levels of development among Brazil, Germany, Indonesia, South Africa and the ROK, and more broadly, across the globe, the fact remains that there are only a limited number of ways in which any country, regardless of its level of development, can control its carbon emissions while still consuming energy resources to an extent sufficient to support rising average living standards. These are (listed in no particular order of significance):

1. Raise the economy's level of energy efficiency through the operations of buildings, industry and transportation systems;

2. Among fossil fuel energy sources, increase the proportion of natural gas consumption relative to coal, since carbon emissions from burning natural gas are about one-half those from coal;

3. Invest in the development and commercialization of some combination of the following technologies:

   a. Clean renewables, including solar, wind, hydro, geothermal and some types of bioenergy;

   b. Nuclear power;

   c. Carbon Capture and Sequestration (CCS) processes in generating coal, oil, and natural gas-powered energy.

We conclude through our review of these alternative approaches that, considering all factors within a long-term perspective, there are only two truly viable options. These are: 1) Investments to raise energy efficiency levels; and 2) Investments to expand capacity in clean renewables. Pursuing these two options should therefore constitute the core of the 1.5 percent of GDP clean energy investment project. The reasoning behind these choices becomes clear through comparing the relative prospects for non-renewable energy sources moving forward versus those for clean renewable and efficiency investments.

Prospects for Non-Renewable Energy Sources

By far, the major source of global CO_2 emissions is burning oil, coal, and natural gas to produce energy. Emissions do vary significantly between these three sources. Coal emissions, at roughly 100 mmt per Q-BTU, are, respectively, about 50 percent higher than those for oil and 80 percent than those for natural gas. Oil emissions are therefore also about 20 percent higher than those for natural gas. Yet, despite the fact that oil, and still more, natural gas, are cleaner burning than coal, there are still no scenarios through which the IPCC's 20-year global emissions target is achievable if consumption levels increase over this time period through any combination of oil, coal, and natural gas usage. This includes an implausible scenario in which natural gas substitutes for 100 percent of global coal usage.

Following from this finding, we then also consider the alternative ways to continue utilizing non-renewable energy sources while still reducing emissions. Nuclear power is the first option, since it does generate electricity without producing CO_2 emissions. But nuclear power does also create major environmental and public safety concerns, which have only intensified since the March 2011 meltdown at the Fukushima Daiichi power plant in Japan. Similarly, CCS technologies present hazards. These technologies aim to capture emitted carbon and transport it, usually through pipelines, to subsurface geological formations, where it would be stored permanently. But such technologies have not been proven at a commercial scale. The dangers of carbon leakages from flawed transportation and storage systems would, in any case, only increase to the extent that CCS technologies are commercialized.

Prospects for Clean Renewables

It will be necessary to create a rapidly expanding and successful clean renewable energy sector in order to achieve both the IPCC's 20-year emissions reduction target as well as its target for 2050. In fact, it is realistic to allow that renewables could provide in the range of 30 percent of all global energy supplies within 20 years. The main driver here is that the trajectory for prices and costs for renewables is becoming increasingly favorable. In a wide range of conditions - though of course not under all circumstances - renewable energy from most sources will be at cost parity with non-renewables within the next 5–10 years. Costs for renewables become still more favorable relative to fossil fuels through the establishment of either carbon tax or carbon cap policies that reflect the environmental costs of carbon emissions. Either measure would raise the prices of emissions-generating energy sources.

There are certainly areas of concern with renewables, as with non-renewables. The most significant is that, as mentioned above, some bioenergy sources, including corn ethanol and woodburning, offer little to no improvement on emissions relative to burning coal or oil. A rapidly expanding bioenergy sector could also create strains on global agricultural resources and, thereby, global food prices. Also, large-scale hydro projects, under most circumstances, will generate serious environment problems. We conclude that, even while recognizing these specific concerns, the prospects are quite favorable for the large-scale expansion of solar, wind, geothermal, small-scale hydro as well as clean bioenergy. These renewable sources constitute the core of what we term the *clean* renewable options.

Prospects for Energy Efficiency

Significantly raising energy efficiency levels in all three major areas of energy usage - i.e. buildings, industry and transportation - offers major opportunities for all countries at all levels of development. This is why, along with investments in clean renewables, it needs to be one of the cornerstones of a global clean energy investment project. One major area of support for this conclusion is the evidence we review from a range of studies as to the costs of large-scale gains through energy efficiency investments. These cost estimates vary widely. But even at the highest cost estimates, of around $30 billion in investments per Q-BTU of energy savings, these investments are cost effective, in that they still generally pay for themselves within three years. UNIDO's 2011 *Industrial Development Report* shows that, in a wide range of specific settings, returns from efficiency investments only increase further over time. The main challenge for enabling the global energy efficiency investment market to grow rapidly is to develop more effective systems of financing and risk-sharing.

It is possible that efficiency investments may not have their intended effect of reducing energy consumption at all. This would be due to the "rebound effect," whereby better energy efficiency encourages consumers to expand their energy-using activities. However, we conclude that any rebound effect that may emerge as a byproduct of an economy-wide energy efficiency investment project will not be large enough to counteract their significant benefits in terms of both cost savings and emissions reductions. Still, the most effective way to limit rebound effects is to combine efficiency investments with complementary measures to greatly expand the supply of clean renewables and to raise the prices of oil, coal, and natural gas through either a carbon tax or carbon cap.

Industrial Policy and Domestic Content

As we have discussed above, operating effective industrial policies within all countries at all levels of development will be critical for expanding investments in renewable energy and energy efficiency to the scale necessary to achieve the IPCC's emissions reduction targets. Such policies would be fully complementary with establishing a carbon price through either carbon tax or carbon cap measures. Effective industrial policies will also be needed to effectively manage the unavoidable major retrenchments in the oil, coal and natural gas industries.

In addition to presenting general perspectives on the role of industrial policies in the clean energy investment project, our particular focus is on the question of how much, in each of our five selected countries, expanding clean energy investments can be accomplished through utilizing domestic resources versus relying increasingly on imports. To the extent that a country runs up against domestic productive capacity constraints while expanding its investments in energy efficiency and clean renewable energy sources, it then faces two alternatives: either scale back the clean energy investment strategy or rely increasingly on imports to maintain the ambitious investment agenda. Our particular concern for this report is employment effects. That is, to what extent will changes in the domestic content of the country's output in the relevant sectors affect the overall job-generating prospects of its clean energy investments? For each of our five selected countries, we develop estimates of employment creation through clean energy investments based on two scenarios. In the first scenario, domestic content remains stable in the relevant sectors as clean energy investments expand, while in the second scenario, we assume domestic content declines by 20 percent in the relevant sectors.

We then also consider the extent to which countries currently rely on fossil fuels to both meet their energy consumption needs, and, potentially, to also generate export earnings. Within this context, the experiences of a wide range of countries with respect to the "curse" of operating as a resource-rich economy offers useful perspectives for our analyses, especially for Indonesia and South Africa, which are currently both major coal exporters.

Job Creation Estimates from Clean Energy Investments

We present two sets of estimates of the employment impacts of large-scale clean energy projects in Brazil, Germany, Indonesia, South Africa, and the ROK. The first is the aggregate level of new employment generated through investments in various types of renewable energy and energy efficiency. We generated these figures directly from national survey data of public and private economic enterprises and organized systematically within each country's national input-output (I-O) model. We recognize that there are limitations with our use of the I-O model.

But we nevertheless conclude that this is the most reliable methodology for our purposes.

We then disaggregate these country-specific employment estimates according to four criteria: gender balance; the share of self-employment versus wage employment; the share of jobs created in micro-enterprises versus larger enterprises; and the educational attainment levels associated with each type of job linked to clean energy activities. These disaggregated employment statistics enable us to gain clarity as to which groups in society are likely to benefit from new employment opportunities generated by clean energy investments.

Aggregate employment effects. With these country-level aggregate figures, we focus on the levels of employment generated through spending $1 million within the various specific energy sectors. Overall, we find that, per $1 million in spending in each country (converted at current exchange rates), clean energy investments generate, on average, about 37 jobs in Brazil, 10 jobs in Germany, 100 jobs in Indonesia, 70 jobs in South Africa, and 15 jobs in the ROK. Critically, we also find that the clean energy investments create more jobs in all five countries than spending the same amount of funds within each country's fossil fuel sectors. In the cases of Brazil, Indonesia, and South Africa, the net employment gains for clean energy investments are substantial. They are more modest in Germany and especially the ROK. Still, in all cases, we find that investing in building a clean energy economy will also be a net positive source of job creation.

Disaggregated Employment effects. The disaggregated employment creation patterns also vary substantially by country. We observe, for example, a high proportion of employment in informal sectors in Brazil, Indonesia, and South Africa, as indicated by our figures on both self-employment and micro-enterprise employment. This is less significant in the ROK and a negligible factor for Germany. The high rates of informal employment in Brazil, Indonesia, and South Africa are tied, first, to the large proportion of agricultural employment that will be generated by the growth of clean bioenergy production. It is also associated with the large increase in construction work that would result through the expansion of energy efficiency building retrofit projects. The major increase in investment funds flowing into construction and agriculture should also provide opportunities to raise the level of formalization for these sectors. This should entail increased mechanization and productivity growth.

In its current composition, employment in clean energy areas is heavily male dominated in all five countries. This is due to the significant role played by both manufacturing and construction in overall clean energy investments. Advancing major clean energy initiatives in all five countries (and elsewhere) could therefore be seen as an opportunity to open up decent job opportunities for women in these heretofore male employment strongholds.

The levels of educational attainment in the clean energy areas are generally not especially high. Indeed, if anything, they are somewhat lower than those for workers in the fossil fuel sectors. This suggests that, at least at the level of general educational levels, there should not be major challenges in finding qualified workers to cover the rising employment needs for expanding clean energy activities. At the same time, some of these new employment activities will entail new activities and skills. For example, installing solar panels on roofs and wiring these panels so they supply electricity are distinct tasks relative to the jobs that are traditionally performed by either roofers or electricians. As one important component of its clean energy industrial policy agenda, countries will need to make provisions for these and similar areas that demand new types of training and skill acquisition.

We are not able to observe directly the possible ways in which a large-scale expansion of clean energy investments can contribute toward reducing poverty per se. But our disaggregated employment figures can provide relevant data for better understanding the interconnections between the two fundamental projects of reducing global poverty and fighting global climate change. In general, people who work in informal employment with low educational attainment levels also tend to receive low earnings. Creating new employment opportunities for people in these circumstances - including creating more formal employment jobs operating at higher productivity levels - should also provide opportunities for better pay and more job security. In addition, the expansion of employment generally through the clean energy investment project will help reduce poverty resulting from mass unemployment.

Country-Specific Analyses

In this section of our report, we present estimates of the overall effects on emissions reductions and employment expansion through clean energy projects in each of our five selected countries. For Germany, Indonesia, South Africa, and the ROK, we assume clean energy investments at 1.5 percent of GDP every year over the 20-year cycle. With Brazil, we assume clean energy investments at lower rate, at 0.9 percent of GDP annually. This is first of all because Brazil is already a strong performer in both its reliance on renewable energy and its level of energy efficiency. In addition, CO_2 emissions in Brazil, uniquely among our five selected countries, account for less than 40 percent of the country's total GHG emissions. As such, for roughly the next decade at least, Brazil should devote a relatively large share of its resources to controlling methane and nitrous oxide emissions from non-energy sources.

We generated our estimates on emission reductions and employment expansion on the basis of: 1) our cost estimates for investments in clean energy and energy efficiency; 2) our estimates of employment creation per dollar of expenditure in each of the five countries; and 3) our assumptions for average GDP growth in each country over the 20-year cycle. We deliberately work with conservative GDP growth assumptions, derived from projections by the IEA, IMF and the countries' own forecasting models. Our purpose in working with these conservative GDP growth forecasts is not that they should necessarily be accurate but that, if anything, they err on the low side. If our five selected countries experience faster GDP growth than we assume, they then have more resources to channel towards clean energy investments.

In Table S.1, for each of our five selected countries, we summarize the impact of our 20-year clean energy investment project on emissions levels and employment creation as of Year 20. As the table shows, in all cases, the clean energy investment strategy generates major gains in emissions reductions relative to both 2010 levels and Business-as-Usual (BAU) assumptions as of Year 20. Brazil is at 2.0 mt per capita emissions under the clean energy strategy. This is a 38 percent improvement over the BAU model, even while Brazil is devoting only 0.9 percent of GDP to the project. Germany is at 5.5 mt per capita emissions through our clean energy investment strategy. This is a 43 percent improvement relative to 2010 and a 29 percent improvement relative to Germany's 2030 BAU scenario. Indonesia is at 2.6 mt at the end of the 20-year investment strategy. This figure is is 67 percent lower than Indonesia's BAU framework for 2030. This result for Indonesia underscores how Indonesia can proceed on a rapid GDP growth path without increasing its per capita emissions. The situation is similar for South Africa. We show that South Africa can support a 4 percent GDP growth trajectory while still lowering its emissions within 20 years by 50 percent relative to its 2030 BAU scenario. Our estimates for the ROK are equally impressive. Here again, we find that the ROK could reduce its CO_2 emissions per capita by 56 percent relative to its 2030 BAU scenario over the 20-year investment cycle, while still maintaining an average annual GDP growth rate over this period of 3.3 percent.

Table S.1: Summary of emissions reduction and employment expansion effects through 20-year country-specific clean energy investment projects

	Brazil	Germany	Indonesia	South Africa	ROK
Emissions reductions					
Year 20 per capita emissions	2.0 mt	5.5 mt	2.6 mt	8.7 mt	5.9 mt
Year 20 per capita emissions relative to 2010	-13.0%	-43.3%	+52.9%	-8.4%	-49.1%
Year 20 per capita emissions relative to 2030 BAU	-37.5%	-28.6%	-66.7%	-49.7%	-55.6%
Employment expansion					
Clean energy jobs per $1 million	37.4 jobs	9.5 jobs	103.3 jobs	66.2 jobs	15.1 jobs
Clean energy *minus* fossil fuel jobs per $1 million	16.2 jobs	1.9 jobs	81.3 jobs	33.1 jobs	1.5 jobs
Midpoint Year 20 employment through clean energy investments	806,000	352,000	1.8 million	398,000	276,000
Midpoint Year 20 employment as share of labor force	0.7%	0.9%	1.3%	1.9%	1.0%

Source: For emissions figures, Tables 1.4, 8.4 9.3, 10.5, 11.6, and 12.6. For employment figures, Tables 7.1, 7.5, 7.9, 7.13, 7.17, 8.7, 9.5, 10.7, 11.8, 12.8.

In conjunction with these major across-the-board gains in emissions reductions, we also see in Table S.1 that clean energy investments will be a positive source of net job creation for all five countries. These positive job effects are proportionally larger for South Africa, Indonesia, and, operating on a smaller scale, Brazil. They are relatively modest in Germany and the ROK, because the levels of employment creation per dollar of expenditure are more similar to those in the fossil fuel sectors in these countries. Therefore, for Germany and the ROK, the job increases generated by clean energy investments will be more closely matched by the job losses produced by retrenchments in the oil, coal and natural gas sectors.

The most critical point of our report nevertheless remains valid for all five selected countries and emerges clearly from the results in Table S.1. In all five cases, our research finds that the clean energy investment project is capable of achieving dramatic reductions in CO_2 emissions while overall job opportunities are expanding and GDP growth proceeds along a healthy long-run growth trajectory.

CHAPTER 1: THE GLOBAL CLEAN ENERGY CHALLENGE

This report addresses the profound challenge now facing humanity to control climate change. The climate scientist Professor Kerry Emanuel recently summarized some of the consequences of failing to control climate changes as follows:

- "There will be more frequent and intense heat waves, previously fertile areas in the subtropics may become barren, and blights may seriously affect both natural vegetation and crops."

- "Comparatively small shifts in precipitation and temperature can exert considerable pressure on governments and social systems whose failure to respond could lead to famine, disease, mass emigrations, and political instability."

- "Were the entire Greenland ice cap to melt, sea level would increase by 22 feet, flooding many coastal regions, including much of Southern Florida and lower Manhattan. Eleven of the fifteen largest cities in the world are located on estuaries and all would be affected."

- "The 2005 hurricane season was the most active on record, corresponding to the record warmth of the tropical Atlantic….Globally, tropical cyclones cause staggering misery and loss of life," (Emanuel, 2012, pp. 55-57)."

As of 2010, total world GHG emissions amounted to about 45,000 mmt. In order to control climate change, the Intergovernmental Panel on Climate Change (IPCC) estimates that total emissions will need to fall by about 40 percent as of 2030, to 27,000 mmt, and by 80 percent by 2050, to about 9,000 mmt.

Of the 45,000 mmt of total GHG emissions, about 82 percent are generated by energy-based sources. This includes 33,615 in CO_2 emissions from energy sources, equaling about 75 percent of total GHG emissions itself. It also includes about 3 mmt in energy-based methane emissions and 0.4 mmt energy-based nitrous oxide emissions.

This report focuses on measures to reduce CO_2 emissions from energy-based sources. In advancing an overall global project for controlling climate change, it will of course be necessary to undertake policies to control emissions from methane, nitrous oxide and other sources at the rate at which CO_2 emissions are also being reduced. But we do not consider these parallel issues regarding non- CO_2 emission sources in this report. With respect to CO_2 itself, we establish the goal that global emissions will need to fall at the same rate as overall GHG emissions, by 40 percent as of 2030 and 80 percent as of 2050 relative to 2010. This means that global CO_2 emissions will need to be no more than about 20,000 mmt by 2030 and 6,700 mmt by 2050.

Our aim in this report is to explore the pathways through which these CO_2 emission reduction targets can be met, without sacrificing the opportunities for economies to continue growing and expanding well-being for their citizens. We are especially concerned that developing countries be able to grow at healthy rates as the transformation to a global clean energy economy proceeds. For developing countries to sacrifice economic growth as a means to reverse climate change will also entail sacrificing opportunities to expand decent employment opportunities and to dramatically reduce poverty. Limiting opportunities for countries to proceed on a healthy economic growth trajectory will also face formidable political resistance. This in turn will create unacceptable delays in proceeding with effective policies to control climate change.

Overall then, the purpose of this research is to develop economic policy agendas through which a global clean energy transition can proceed in a mutually supportive way with measures to expand decent employment opportunities and reduce poverty.

At the same time, to be clear at the outset, it is *not* the purpose of this report to explore policy ideas that are most capable of promoting economic growth or expanding decent employment *independent of* their impact on reducing CO_2 emissions. This report is rather focused on advancing policies capable of achieving the IPCC's global emissions targets within the next 20 years and by 2050, and, *within that context*, to develop strategies capable of also supporting economic growth and expanding employment opportunities.

This general approach applies in particular to our focus on the provision of sufficient energy resources within each country as it seeks to meet its appropriate emissions reduction targets. Within all country settings, there is, of course, a wide range of issues that need to be explored in behalf of the goals of promoting economic growth and employment opportunities. Many of these issues are not particularly concerned with a country's energy sector. For example, there are good reasons for countries to consider the potential economic benefits of promoting specific economic sectors such as electronics, textiles, or food processing. However, given that this report is focused on achieving CO_2 emissions reduction targets, we need to concentrate our attention on how this can be accomplished while also providing economies with sufficient energy resources for supporting a healthy growth trajectory.

To be more specific, this report does not consider the merits of investments that can reduce CO_2 emissions versus investments that can, for example, promote a successful high-tech sector. Correspondingly, it is only within the context of reducing CO_2 emissions that we explore the impact of a clean energy investment agenda on generating decent job opportunities. Once again, we do not consider, for example, whether expanding a country's electronics sector is more conducive to promoting decent job opportunities than investing in clean energy resources. This is because it is only through investing in clean energy resources that we are able to deal with the challenge of achieving a country's emissions reduction targets.

This report ranges widely and presents large amounts of data, calculations, and detailed examinations of particular problems. At the same time, our core arguments are simple. That is, we argue that the global economy is capable of meeting the IPCCs' 20-year intermediate emission reduction target if most countries—including especially most countries with either large GDPs or population — devote about 1.5 percent per year of their economy's GDP to investments in energy efficiency and clean renewable energy sources. These clean renewable sources include solar, wind, geothermal, and small-scale hydropower, as well as low-emissions bioenergy sources. They exclude corn ethanol, woodburning and other high-emissions bioenergy sources, whose use generates CO_2 emissions at levels equivalent to coal or oil. We conclude that, as a general proposition, countries that sustain this 1.5 percent of GDP level of annual investments in energy efficiency and clean renewables will also be able to maintain economic growth at healthy rates while providing a sufficient supply of energy resources to undergird growth. These investments in energy efficiency and renewable energy will also be a net new source of job opportunities. More specifically, we find that new investments in energy efficiency and renewable energy will generate more jobs for a given amount of spending than maintaining or expanding each country's existing fossil fuel sectors.

It will be useful here to briefly place this 1.5 percent of GDP figure in context. Global GDP in 2013 was $87 trillion. Thus, 1.5 percent of global GDP is about $1.3 trillion at current GDP levels. This would mean channeling about $650 billion each for clean renewables and energy efficiency investments, if new investment funds were divided evenly between these two sectors. If spending were instead divided at something closer to 1 percent for renewables and 0.5 percent for energy efficiency, as will probably be appropriate in most country settings, that will entail devoting about $870 billion for renewables and $435 billion for energy efficiency at the current global GDP level. These clean energy investment figures would also increase annually, corresponding with the growth of global GDP.

As of the most recent credible data, total global renewable investments were at $227 billion in 2011 and energy efficiency investments were between $150 and $300 billion.[1] This totals to between $377 and $527 billion, or between 0.4 and 0.6 percent of global GDP. In other words, current global investments in clean energy are at roughly 30-40 percent of where they need to be to reach the 1.5 percent of GDP level. It is clear that a great deal needs to be accomplished to reach the 1.5 percent figure. At the same time, with the current investment level already at between 0.4 and 0.6 percent of global GDP, getting to a 1.5 percent of GDP figure is not so far out of reach as to appear implausible.

To bring global clean energy investments up to about 1.5 percent of global GDP will certainly require the development of effective industrial policies for countries at all levels of development. In Chapter 5, we review some of the main considerations with respect to advancing effective industrial policies. The core project is described well by Mazzucato (2013), when she writes that "Governments have a leading role to play in supporting the development of clean technologies past their prototypical states through to their commercial viability. Reaching technological 'maturing' requires more support directed to prepare, organize, and stabilize a healthy 'market,' where investment is reasonably low risk and profits can be made" (2013, p. 136). UNIDO's 2013 Industrial Development Report usefully examines this theme in the specific context of uptake of green technologies in manufacturing, writing that "technological change rarely takes place in a vacuum, and often requires incentives. Success stories of new energy technologies are the product of forward-thinking ambitious government policies," (UNIDO, 2013, p. 124).

In conjunction with the need for a major expansion in clean energy investments worldwide, it is also the case that the burning of oil, coal and natural gas will need to contract substantially in absolute terms throughout the globe if the world economy is going to achieve the IPCC's emissions reduction targets. As we will show, this conclusion is unaffected by whether new fossil fuel reserves are discovered, such as the so-called "pre-salt" deposits in Brazil or

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[1] The figure on global renewable energy investments is from the Frankfurt School-UNEP Collaborating Centre's 2014 report *Global Trends in Renewable Energy Investment 2014, Key Findings*, p. 11. The figures on global energy efficiency investments are from the International Energy Agency's 2013 *Energy Efficiency Market Report*, pp. 47-50. The IEA study provides an extensive methological discussion on the challenges involved in "measuring the market for energy efficiency," (Chapter 2 of study). Through this discussion, they do nevertheless conclude that "the IEA estimates that total global investment in energy efficiency measures in 2011 was up to USD 300 billion," (p. 49). But they also provide, as a range, $147-$300 billion (p. 47).

elsewhere. It is also unaffected by whether new technologies, such as hydraulic fracturing - i.e. "fracking" - are employed to produce fossil fuel energy more cheaply. Workers tied to the oil, coal, and natural gas industries will therefore inevitably face job losses as a consequence. Economic policies are needed in all countries to assist these workers, as well as their families and communities, with transitional support into new areas of economic activity, where decent job opportunities are expanding. In most countries, the energy efficiency and clean renewable energy sectors will be among the most important new areas of expanding job opportunities.

This report presents a global perspective on the challenges of controlling climate change through strategies that will concurrently expand employment opportunities and contribute toward reducing mass poverty. At the same time, we focus in particular on the challenges faced by five specific countries: Brazil, Germany, Indonesia, South Africa, and the ROK. As we will discuss throughout this report, and as should be apparent in any case, economic conditions range widely between these five countries. But they are all, in their own distinctive ways, leading economies within their respective regions of the world. It is also notable that with all five selected countries, policymakers have already proposed clean energy/emissions reduction policy frameworks ranging between 1 and 2 percent of their country's GDP. Our proposal for a clean energy project sustained at about 1.5 percent of GDP therefore builds from the perspectives developed within our five selected countries. In examining these individual cases in some depth, we will also clearly be able to gather insights on a broader set of countries at various levels of development.

Consider, for example, the case of Indonesia, which is defined as a lower-middle income economy according to the World Bank. Indonesia aims to grow rapidly over the next 20 years - i.e. in the range of 6-7 percent per year - following the examples in recent decades of the ROK, China, India and other fast-growing Asian economies. However, the Indonesian government's own estimates show that the country's CO_2 emissions will increase by more than 500 percent by 2030 relative to 2010 if the economy's GDP growth is fueled primarily by oil, coal, and natural gas. By contrast, we estimate that, under reasonable assumptions, a significant share of Indonesia's energy needs for fueling a rapid growth trajectory can be met through investments in energy efficiency and clean renewable energy, as long as Indonesia channels about 1.5 percent of GDP annually into these clean energy areas. We also estimate Indonesia's investments in energy efficiency and renewable energy can also be a significant new source of job creation within the country. In short, we show how Indonesia's goal of sustaining a rapid economic growth trajectory can be accomplished through relying to an increasing extent on clean energy resources. The Indonesian case also has broader implications. It shows that low- and lower-middle income countries can achieve rapid economic growth without their growth having to depend heavily on oil, coal, and natural gas. This in turn means that Indonesia and similarly situated economies can achieve rapid growth without having to increase their country's CO_2 emissions as a necessary, if unfortunate, byproduct of sustained growth.

Valuable perspectives also emerge through our explorations of our four other selected countries. The case of Brazil is important because, as we will see, it is the world's best-performing upper-middle income economy in terms of maintaining low emissions levels amid a healthy GDP growth trajectory. Germany, similarly, has an excellent record in terms of emissions levels relative to other high-income countries. Germany's clean energy agenda for the next 20 years is also highly ambitious and innovative. South Africa is critical because it is the largest and most advanced economy in Sub-Saharan Africa. At present, it also depends heavily on its major coal reserves, both to meet its domestic energy needs and to generate export revenues. It is therefore a major challenge to consider how South Africa can reduce its dependence on coal while still growing at a healthy rate. But a clean energy transition is also realistic for South Africa.

The case of the ROK is especially important because, in 2009, the previous government of President Lee Myung-bak established a project of "Green Growth" as a major national development objective.[2] Consistent with the goals of the ROK's Green Growth project, our research finds that within 20 years, the ROK could realistically reduce its per capita emissions by roughly 50 percent relative to 2010 levels without having to lower the economy's GDP growth rate. We reach this conclusion based on a set of relatively conservative assumptions about the ROK's prospects for integrating energy efficiency and clean renewables into the country's energy mix.

In short, by focusing on the cases of Brazil, Germany, Indonesia, South Africa, and the ROK, we are able to develop new perspectives on the global challenges presented by climate change. We believe we are also able to provide a realistic framework for controlling climate change while, concurrently, expanding job opportunities and supporting long-term economic growth. It is, more specifically, realistic to expect that most countries can devote about 1.5 percent of their GDP annually to investments in renewable energy and energy efficiency. It is correspondingly realistic to expect that when countries commit to this clean energy investment agenda, they will also be able to support a healthy GDP growth trajectory and an increase in overall job opportunitites.

Total Energy Consumption and Carbon Emissions

As an initial step in developing our research framework, it will be useful to review some basic evidence on energy consumption and CO_2 emissions on a global scale, and within our five selected economies. We begin this review with Table 1.1, which provides relevant data as of 2010. As Table 1.1 shows, as of 2010, total global energy consumption amounted to about 510 Q-BTUs from all energy sources - including fossil fuels, all renewable sources and nuclear power. This is while total CO_2 emissions were at 33,615 mmt.

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[2] World Bank (2012).

Table 1.1: Energy consumption and CO2 emissions levels for world and selected countries, 2010

	Energy consumption		CO_2 emissions	
	Total primary energy consumption	Per-capita energy consumption	Total CO_2 emissions	Per capita CO_2 emissions
	(Q-BTUs)	*(M-BTUs)*	*(mmt)*	*(mt)*
World	510.5	74	33,615	4.6
China	100.9	75.4	7,997	6.0
U.S.	98	316.9	5,637	18.2
Brazil	11.3	58	450.9	2.3
Germany	13.9	170.4	793.3	9.7
Indonesia	6.0	25.2	414.6	1.7
South Africa	5.6	111.8	473.2	9.5
ROK	10.8	218.2	581	11.7

Sources: U.S. Energy Information Administration, "International Energy Statistics," (for energy consumption and per capita emissions); World Bank (2014), "World Development Indicators," Table 3.9: Trends in greenhouse gas emissions (for total emissions).

The two leading countries in terms of both energy consumption and CO_2 emissions are China and the U.S. As Table 1.1 shows, their respective levels of energy consumption were nearly identical in 2010, with China at 100.9 Q-BTUs and the U.S. at 98 Q-BTUs. Together, China and the U.S. account for nearly 39 percent of world energy consumption. In terms of carbon emissions, China is at a higher level, at 7,997 mmt, while the U.S. is at 5,637 mmt. Together, they account for 43 percent of all global carbon emissions. Obviously, we must give major attention to developments in the U.S. and China in terms of mounting an overall project for controlling climate change.

But even from this first set of statistics in Table 1.1, it is also clear that the challenges in terms of a clean energy agenda are dramatically distinct for the U.S. and Chinese cases. The U.S. is an advanced industrial economy in which energy consumption per capita is among the highest in the world for large population countries, at 316.9 million BTUs (hereafter M-BTUs) per capita. China, by contrast, despite its historically unprecedented growth experience over the past 35 years, is still a developing country, in which energy consumption per capita, at 75.4 M-BTUs, is one-fourth that of the U.S. A major part of the challenge for advancing a viable global agenda for controlling climate change in the most effective ways is to recognize the distinctive issues and industrial development needs facing the U.S. and China.

The cases of the U.S. and China also underscore another fundamental fact. As important as they are to grasping the overall global climate change challenge, they are still, in combination, contributing well less than half to the overall level of global carbon emissions. This therefore means that we must be at least equally concerned to develop policies that apply to all other countries - including, of course, Brazil, Germany, Indonesia, South Africa and the ROK. Moreover, as with the comparative situations for the U.S. and China, the differences among our five selected countries are dramatic. For example, the current energy consumption levels are even more different than those between the U.S. and China. We can obtain a first basic picture of these differences through the data in Table 1.1. As we see there, per capita energy consumption in Germany is 170.4 M-BTUs. This is 45 percent below the level of per capita consumption in the U.S. But it is also nearly seven times greater than the per capita consumption level for Indonesia.

Considering another pair of countries, per capita energy consumption as well as emissions are actually higher now in the ROK than Germany, even while their overall level of energy consumption, at 10.8 Q-BTUs, is about 20 percent below that of Germany. Brazil is nearly at the same consumption level as Germany, but its per capita level of consumption and emissions are in the range of 20-30 percent that of Germany. Another notable comparison that we see in Table 1.1 is that South Africa's per capita emissions level is roughly equal to that in Germany. This reflects the greater use by Germany of clean energy sources. South Africa, in particular, remains heavily dependent on burning coal to generate electricity. Coal, in turn, is the most emissions-intensive source of fossil fuel energy. Per BTU of energy, CO_2 emissions from coal are roughly 50 percent higher than those from oil and 80 percent higher than those from natural gas.

Specifying the Climate Change Challenge

Table 1.1 shows us world per capita carbon emissions in 2010 at 4.6 mt, with figures ranging in our selected countries between 1.7 mt for Indonesia and 18.2 mt for the U.S. This ratio will provide an important measure for clarifying the scale and types of policy initiatives that will be necessary for controlling climate change.

Thus, we can express our intermediate emissions reduction goals in terms of this measure, within the framework of reducing the absolute level of carbon emissions by 40 percent, to around 20,000 mmt, within 20 years. With global population expected to rise to about 8.4 billion by 2030, this means that carbon emissions will need to be at no more than 2.4 mt per capita by 2030. The question will be how to achieve this in a way that is also supportive of rising average living standards and declining poverty.

This challenge becomes especially sharp when we consider the current pattern in the relationship between per capita GDP levels and emissions. Not surprisingly, there is a strong direct correlation between rising per capita GDP and rising per capita emissions. This is evident even through the basic figures shown in Table 1.1. As we see, Indonesia has the lowest per capita emission level of our selected countries, at 1.7 mt.

We can see this pattern more generally in Table 1.2, which divides all countries into four broad income categories, and shows the emissions per capita for each of the four income categories. Starting with the upper panel of Table 1.2, we see that low income countries, averaging $592 in per capita GDP and with a total population of 709 million people, operate with emissions level of 0.3 mt per capita. Per capita emissions then rise to 1.6 mt for lower income countries, 5.4 for upper-middle income countries and 11.6 for high-income countries. That is, on average, the 1.3 billion residents of high-income countries generate 7.2 times more emissions than the 2.5 billion people living in lower-middle income countries, and 38 times more emissions than the 709 million people living in low-income countries.

Table 1.2: World income-level groupings and CO2 emissions levels, 2010

a) Per capita income, population and emissions

Income Categories	**Average GDP per capita** *($2005 PPP)*	**Total population**	**Average emissions per capita** *(mt)*
Low	$592	709 million	0.3 mt
Lower middle	$1,920	2.5 billion	1.6 mt
Middle	$4,560	4.9 billion	3.4 mt
Upper middle	$7,340	2.4 billion	5.4 mt
High	$37,720	1.3 billion	11.6 mt

b) Countries with low, medium, and high per capita emissions

	Number of countries	**Average GDP per capita**
Countries with per capita CO_2 emissions below 2.4 mt	60	$1,768
Countries with per capita CO_2 emissions below 4.6 mt	74	$3,058
Countries with per capita CO_2 emissions above 10.0 mt	13	$33,700

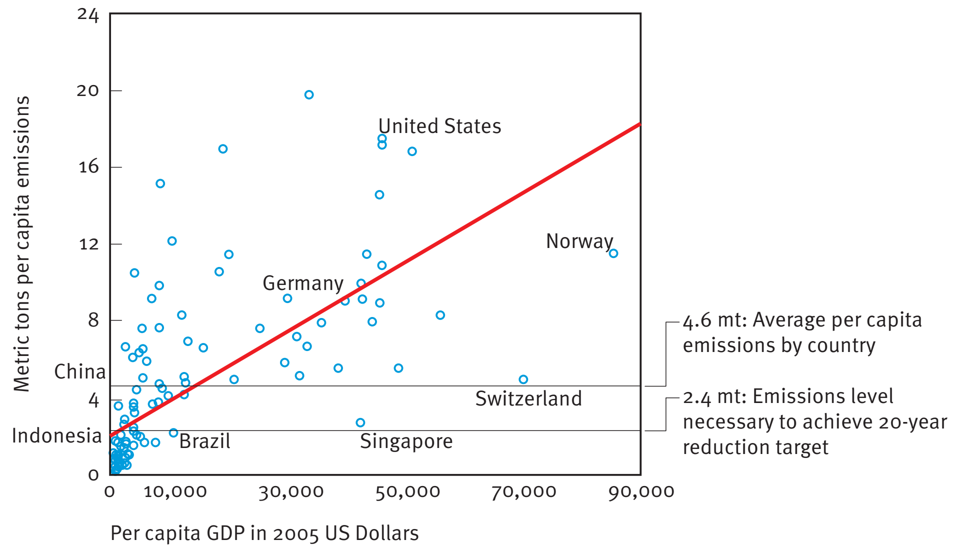
Source: Authors' calculations based on World Bank (2014), "World Development Indicators," Table 1.1: Size of the economy, 3.8: Energy dependency, efficiency and carbon dioxide emissions, 3.9: Trends in greenhouse gas emissions.

Note: Sample includes countries with over 5 million in population

The lower panel of Table 1.2 gives further perspective on this relationship. Of the total of 60 countries in which emissions per capita are currently below 2.4 mt - the average level for all countries that the world needs to reach within 20 years - average GDP per capita was $1,768. Further, of the 74 countries in which per capita emissions was below the current world average of 4.6 mt, average GDP per capita was $3,058. By contrast, of the 13 countries in which per capita emissions were above 10 mt, average GDP per capita was $33,700.

At the same time, we do see some significant outliers. This is evident from Figure 1.1, which plots the relationship between per capita GDP levels and per capita emissions. The positive correlation is clearly strong. But we do still see large outliers on either side of the regression line. As the figure shows, the low emissions countries in the high-income category include Norway, Switzerland, Sweden and Singapore. Among countries whose per capita GDP ranges between $10,000 and $30,000, the best performer is Brazil, one of our five selected countries. Brazil is also important among the full set of countries, since it is the only large economy that is operating at significantly below the regression line in terms of lower emissions. As we see, the U.S. and China are both substantially above the regression line. We of course consider the case of Brazil more fully in later chapters.

Figure 1.1: Country-by-Country per Capita CO2 Emissions and GDP, 2010



Source: World Bank (2014), "World Development Indicators," Table 3.8: Energy Dependency, Efficiency, and Carbon Dioxide Emissions.

Global CO2 Emissions Projections for 2030

We can obtain further perspective on the magnitude of the challenges ahead by considering the CO_2 emission level projections for 2030 by two of the largest and most influential organizations that have developed models that address this question. These are the U.S. Department of Energy's Energy Information Agency (EIA), which produces an annual *International Energy Outlook*; and the OECD's International Energy Agency (IEA), which publishes an annual *World Energy Outlook*.

In Table 1.3, we show the most recent projections of the EIA and IEA for world CO_2 emissions levels under various scenarios. The EIA reports a world emissions projection for 2030 only under its Reference case[3]. As we see in Table 1.3, under this 2030 Reference case, the EIA projects that total global CO_2 emissions will be at 41,468 mmt - i.e. at a level that is more than twice as high as the 2030 target level for climate change control of 20,000 mmt.

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[3] In addition to its Reference case, with projections for 2030, as well as through 2040, the EIA also reports results for four other scenarios - both high and low economic growth cases and both high and low oil price cases. But they do not report on CO_2 estimates under 2030 under these four other scenarios.

Table 1.3: Projected world CO2 emissions levels for 2030 by U.S. Energy Information Administration and OECD International Energy Agency

	2030 CO_2 emissions projections
U.S. Energy Information Administration (EIA) Reference case	41,468 mmt
OECD International Energy Agency (IEA)	
• Reference case	40,825 mmt
• New Policies case	36,493 mmt
• 450/Low Carbon case	24,663 mmt

Sources: Authors' compilation based on U.S. Energy Information Administration, "International Energy Outlook 2013."; International Energy Agency (2013) "World Energy Outlook 2013," Tables for Scenario Projections, pp. 574-575.

The IEA provides projections under three scenarios: a Reference case; a "New Policies" case and a 450/Low Carbon case. The IEA describes its New Policies case as taking into account "broad policy commitments and plans that have already been implemented to address energy-related challenges as well as those that have been announced...." But this New Policies case also "assumes only cautious implementation of current commitments and plans." The IEA describes its 450/Low Carbon case as setting out "an energy pathway that is consistent with a 50 percent chance of meeting the goal of limiting the increase in average global temperature to 2°C compared with pre-industrial levels," (IEA, 2013a, p. 645). That is, the IEA believes that its 450/Low Carbon case provides a 50 percent chance for the world to control climate change.

As we see in Table 1.3, as with the EIA's reference case, under the IEA's 2030 Reference case, global emissions are at 40,825 mmt CO_2 - again, more than twice as high as the 20,000 mmt target for controlling climate change. The situation is only modestly improved in the IEA's New Policies case, in which they project 2030 CO_2 emissions to total 36,493 mmt. Even under the 450/Low Carbon case, the IEA still projects emissions to be 24,663 mmt CO_2. Of course, this is a dramatic improvement relative to all the other cases. But it is still 23 percent higher than the 20,000 mmt 2030 target.

It is critical to underscore that the IEA describes the 450/Low Carbon case as offering only a 50 percent chance of the world succeeding in controlling climate change. This estimate underscores the urgency of advancing a realistic agenda that offers a significantly higher probability of achieving success in controlling climate change than the IEA's 450 program.

Component Parts of CO2 Emissions per Capita Ratio

To provide additional perspective on variations in per capita CO_2 emissions level by country, it will be useful to decompose the emissions per capita ratio into three component parts. This yields three ratios, each of which provides a simple measure of one major aspect of the global climate change challenge. That is, CO_2 emissions per capita can be expressed as follows:

Emissions/population = (GDP/population) x (Q-BTUs/GDP) x (emissions/Q-BTU).

These three ratios provide measures of the following in each country setting:

1. *Level of development*: Measured by GDP/capita;
2. *Energy intensity*: Measured by Q-BTUs/GDP;
3. *Emissions intensity:* Measured by emissions/Q-BTU.

Table 1.4 shows the results of the decomposition for the world, the U.S, China, as well as Brazil, Germany, Indonesia, South Africa, and the ROK. Considering first the U.S. and China, we see that emissions per capita are three times higher in the U.S, at 18.2 mt versus 6 for China. The three factors generating this overall result are as follows:

1. *Level of development:* Average GDP per capita in the U.S, at $50,000, is 8 times higher than that for China;
2. *Energy intensity:* The U.S. is twice as efficient as China, with its Q-BTU/GDP ratio at 6.2 versus 12.1 for China;
3. *Emissions intensity:* The mix of energy sources in the U.S. is 40 percent cleaner than that in China, at 57.5 emissions/Q-BTU versus 79.3 for China.

Table 1.4: Determinants of per capita CO2 emissions levels by country, 2010: Level of development, energy intensity and energy mix

CO_2 Emissions/population = (GDP/population) x (Q-BTUs/GDP trillions) x (Emissions/Q-BTU)

	CO_2 emissions/ population	GDP/ population *($2005 PPP)*	Energy intensity ratio: Q-BTUs/ trillion dollars GDP	Emissions intensity ratio: CO_2 emissions/ Q-BTU
World	4.6 mt	$10,300	7.1 Q-BTUs	65.9 mmt
China	6.0 mt	$6,200	12.1 Q-BTUs	79.3 mmt
U.S.	18.2 mt	$50,000	6.2 Q-BTUs	57.5 mmt
Brazil	2.3 mt	$11,600	5.1 Q-BTUs	39.9 mmt
Germany	9.7 mt	$41,500	4.1 Q-BTUs	57.1 mmt
Indonesia	1.7 mt	$3,600	6.8 Q-BTUs	69.1 mmt
South Africa	9.5 mt	$7,500	14.6 Q-BTUs	84.5 mmt
ROK	11.7 mt	$22,000	9.8 Q-BTUs	53.8 mmt

Source: Authors' calculations based on Tables 1.1 and 1.2.

Both the U.S. and China will need to sharply reduce their levels of emissions per capita, to bring the world to an average of 2.4 mt per capita within 20 years. Obviously, in absolute terms, the U.S. challenge is far greater, given its current per capita emissions level of 18.2 mt. But the U.S. is at least much further along in both operating at a higher level of efficiency and utilizing cleaner energy sources. Nevertheless, the U.S. still needs to intensify the efforts already underway to raise efficiency and increase reliance on low-carbon energy sources.

Table 1.4 also makes clear that there are sharp disparities between our five selected countries, not only in terms of income levels, but also in terms of energy efficiency and their existing mixes of energy sources.

Let's first again consider Brazil, which is performing quite well in terms of energy emissions, at 2.3 mt per capita. Brazil is accomplishing this while still operating at a fairly high per capita GDP level of $11,600. The reasons for Brazil's strong performance in per capita emissions is that it both operates at a high level of efficiency - utilizing only 5.1 Q-BTUs of energy per $1 trillion in GDP, and by utilizing clean renewable energy sources to a substantial degree. This allows Brazil to produce only about 40 mmt of emissions per Q-BTU of energy.

The cases of South Africa and Germany are again useful for comparative purposes. As we have seen, their levels of emissions per capita are nearly identical, at 9.7 and 9.5 mt respectively. But Germany is generating this level of emissions while its average capita GDP level is $41,500, while in South Africa, average GDP per capita is $7,500. Of course, the reason emissions per capita are nearly identical is because Germany is operating at a very high level of efficiency, 4.1 Q-BTUs per GDP. This is nearly four times more efficient than South Africa, where the energy intensity ratio is 14.6 Q-BTUs/GDP. The German energy mix is also nearly 50 percent cleaner than that for South Africa.

This comparison suggests a pathway for South Africa to dramatically lower its emissions level by both raising its efficiency standards as well as its reliance on clean energy sources. To do so will enable the South African economy to at least approach the 2.4 mt per capita CO_2 emissions standard within 20 years while still experiencing healthy economic growth. As for the German economy, the figures in Table 1.4 show that there is considerable room for improvement, particularly with its emissions intensity ratio. As we discuss in Chapter 9, investments on the order of 1 percent of GDP per year in clean renewables should enable Germany to cut its emissions ratio by about 15 percent in 20 years. Germany also plans to make still greater improvements in hits energy intensity ratio over this same time period.

There are similarly useful perspectives to extract for the Indonesian case, its much lower level of per capita GDP relative to both Germany and even South Africa notwithstanding. As we see in Table 1.4, Indonesia operates at roughly the world average in terms of both energy intensity emissions intensity. But this is with an economy in which per capita GDP is $3,600. For Indonesia to reach a substantially higher level of average income over the next 20 years while still maintaining an acceptable level of emissions per capita, they will need to raise their level of efficiency and reliance on clean energy. This is what will enable Indonesia to increase per capita GDP at a healthy rate while still maintaining their CO_2 emissions level at roughly the global target figure of 2.4 mt per capita. As mentioned above, and as we consider in more depth in subsequent chapters, building a clean energy economy in Indonesia does not need to be an obstacle to operating along a strong long-term growth trajectory. Rather, clean energy investments in Indonesia can be a major engine supporting Indonesia's favorable long-term growth performance.

The ROK is a high-income country, with per capita GDP at $22,000 per year. The economy operates at a higher per capita CO_2 emissions level than both Germany and South Africa, at 11.7 mt. It is also generating energy with relatively clean sources, with its emissions intensity ratio at 53.8. This is modestly better than both the U.S. and Germany. However, the ROK's energy intensity ratio, at 9.8 Q-BTUs/GDP, is nearly double that for Brazil, and 60 percent higher than the U.S. Of course, the ROK has a history of success with implementing industrial policies capable of integrating cutting-edge technologies into the economy. As we discuss in Chapter 12, its current share of research and development spending relative to GDP is already the highest in the world. This background enables us to conclude that there is indeed a strong prospect for the ROK to dramatically reduce its absolute emissions levels within 20 years; and to do so without having to sacrifice GDP growth in the process.

Options for Reducing Carbon Emissions

Notwithstanding the wide differences in levels of development among Brazil, Germany, Indonesia, South Africa and the ROK, and more broadly, across the globe, the fact remains that there are only a limited number of ways in which any country, regardless of its level of development, can control its carbon emissions while still consuming energy resources to an extent sufficient to support rising average living standards. These are (listed in no particular order of significance):

1. Raise the economy's level of energy efficiency;

2. Among fossil fuel energy sources, increase the proportion of natural gas consumption relative to coal, since carbon emissions from burning natural gas are about one-half those from coal;

3. Invest in the development and commercialization of some combination of the following technologies:

    a. Clean renewables, including solar, wind, hydro, geothermal and some types of bioenergy;

    b. Nuclear power;

    c. Carbon Capture and Sequestration (CCS) processes in generating coal, oil, and natural gas-powered energy.

The focus of this report is to examine the prospects for each of these options in our distinct country settings. That, indeed, is what will constitute the core of any country's clean energy investment agenda. As we will show, once we have identified the key components of a clean energy investment project for each country, we will then be in a position to estimate the impact of this project on creating employment opportunities. But here again, we emphasize that the job creation elements of the project will emerge as an outgrowth of each economy's investments in clean energy. We are not advancing a jobs policy that operates independently of each country's clean energy investment agenda.

We present two sets of estimates of the employment impacts of large-scale clean energy projects in Brazil, Germany, Indonesia, South Africa, and the ROK. The first is the aggregate level of new employment generated through investments in various types of renewable energy and energy efficiency activities in each of our five specific country settings. Overall, we find that, in all five selected countries, clean energy investments generate more jobs than spending the same amount of money within each country's fossil fuel sectors. There are of course differences in the relative levels of job creation by country, as well as the quality of the jobs generated by investments in clean energy versus fossil fuels. We obtain further perspective on these questions of job quality when we disaggregate these country-specific employment estimates according to four criteria: gender balance; the share of self-employment versus wage employment; the share of jobs created in micro-enterprises versus larger enterprises; and the educational attainment levels associated with each type of job linked to clean energy activities. These disaggregated employment statistics enable us to gain clarity as to which groups in society are likely to benefit from new employment opportunities generated by clean energy investments.

We have not been able to observe directly the possible ways in which a large-scale expansion of clean energy investments can contribute toward reducing poverty per se in either our five country settings or elsewhere. But our disaggregated employment figures can nevertheless provide relevant data for better understanding this critical aspect of the global clean energy investment project. In general, people who work in informal employment with low educational attainment levels also tend to receive low earnings. Creating new employment opportunities for people in these circumstances - including more formal employment jobs operating at higher productivity levels - should also provide opportunities for better pay and more job security. In addition, the expansion of employment generally will help reduce poverty resulting from mass unemployment.

Structure of Report

The remainder of this report is divided into three sections. Section 1 examines prospects for supplying energy over the next 20 years through alternative energy sources. Within Section 1, Chapter 2 covers non-renewable energy sources, including oil, coal, natural gas and nuclear power. We first review in Chapter 2 the basic facts on the extent of CO_2 emissions that are generated from consuming oil, coal and natural gas, as well as high-emissions bioenergy sources. This will enable us to see clearly the levels of fossil fuel consumption that can be sustained while still achieving the target of reducing global CO_2 emissions to no more than 20,000 mmt within 20 years. We will then consider the alternative ways to continue utilizing non-renewable energy sources while still reducing emissions from these energy sources. The possibilities here are to expand nuclear power and CCS technologies as well as fuel switching, with cleaner-burning natural gas substituting for emissions-intensive coal. But we conclude in this chapter that none of these alternatives with non-renewables can produce an adequate framework for controlling CO_2 emissions. Specifically, there is no scenario for achieving the IPCC's 20-year emissions reduction targets through consuming any combination of oil, coal and natural gas at close to their current levels. In addition, CCS technologies and nuclear power create major and unavoidable public safety concerns.

Chapter 3 covers renewable energy sources, including bioenergy, hydro, wind, solar, and geothermal power. We argue that in order for the world economy to meet its intermediate CO_2 emissions reduction targets within 20 years and, subsequently for 2050, it will be necessary to create a rapidly expanding and successful renewable energy sector. This means producing energy increasingly from wind, solar, geothermal, bioenergy, and hydropower sources. As we will review in this chapter, it is in fact realistic to allow that clean renewables could provide in the range of 30 percent of all global energy supplies within 20 years. The main driver here is that the trajectory for prices and costs for renewables is becoming increasingly favorable. In a wide range of conditions - though not under all circumstances - renewable energy from most sources will be at cost parity with non-renewables within the next 5-10 years. There are certainly areas of concern with renewables. The most significant is that, as mentioned above, some bioenergy sources, including corn ethanol and woodburning, offer little or no improvement on emissions relative to burning coal or oil. A rapidly expanding bioenergy sector could also create strains on global agricultural resources and, thereby global food prices. Also, large-scale hydro projects, under most circumstances, will generate serious environment problems. We examine these issues in Chapter 3. We conclude that, even while recognizing these various concerns, the prospects are quite favorable for the large-scale expansion of solar, wind, geothermal, small-scale hydro as well as clean bioenergy.

Chapter 4 addresses a range of issues concerning energy efficiency. The first basic conclusion of this chapter is that significantly raising energy efficiency levels for all countries, at all levels of development, is necessarily one of the two cornerstones of the global green growth project, along with clean renewable energy investments. One major area of support for this conclusion is the evidence we review from a range of studies as to the costs of large-scale gains through energy efficiency investments. These cost estimates vary widely. But as we will show, at even the highest cost estimates, of around $30 billion in investments per Q-BTU of energy savings, these investments are cost effective, in that they still generally pay for themselves within three years. The main challenge for enabling the global energy efficiency investment market to grow rapidly is to develop more effective systems of financing and risk-sharing. We do also consider the prospect that large-scale efficiency investments may not have their intended effect of reducing energy consumption at all. This would be due to the "rebound effect, " whereby better energy efficiency encourages consumers to expand their energy-using activities. However, we conclude that any rebound effect that may emerge as a byproduct of an economy-wide energy efficiency investment will not be large enough to counteract their significant environmental benefits. Still, the most effective way to limit rebound effects is to combine efficiency investments with complementary measures to greatly expand the supply of clean renewables and to raise the price or put firm limits on producing CO_2 emissions.

Section 2 of this report focuses on employment impacts of economic activity in the clean energy sectors - including here both renewables and efficiency investments - and the non-renewable energy sectors. We also address issues related to the employment question, in particular the extent to which any given country's clean energy investment project can operate through expanding domestic economic activity as opposed to relying increasingly on imports. Answering this question, in turn, entails considering the types of national industrial policies that will be needed for countries to successfully mount large-scale clean energy investment projects.

Our primary focus in Chapter 5 is to examine how much any country, and our five selected countries in particular, is likely to expand its investments in clean energy sectors on the basis of its own domestic resources. To the extent that a country runs up against domestic productive capacity constraints while expanding its investments in energy efficiency and clean renewable energy sources, it then faces two alternatives: either scale back the clean energy investment project or rely increasingly on imports to maintain the ambitious investment agenda. Our main consideration in raising these questions is employment effects. That is, to what extent will changes in the domestic content of the country's output in the relevant sectors affect the overall job-generating prospects of its clean energy investments? We focus on two considerations. The first is the role that can be played by a country's industrial policies to expand domestic productive capacity in the relevant sectors of the economy. We emphasize here both credit and labor market policies as central components within a broad industrial policy framework. We then also consider the extent to which countries currently rely on fossil fuels to both meet their energy consumption needs, and, potentially, to also generate export earnings. We address the effects of retrenchments in the fossil fuel sectors on the economy broadly, and, in particular, on the workers whose livelihoods depend on these sectors, as these sectors face retrenchment.

Chapter 6 considers our methodology for generating estimates of employment impacts of economic activity in both the clean energy and fossil fuel sectors of Brazil, Germany, Indonesia, South Africa and the ROK. Our estimates are figures generated directly from data from national surveys of public and private economic enterprises and organized systematically within each country's national I-O model. Here is one specific example of how our methodology works. If a business invests an additional $1 million on energy efficiency retrofits of an existing building (or its equivalent within each country's national currency), how much of the $1 million will they spend on hiring workers, how much will they spend on non-labor inputs, including materials, energy costs, and renting office space, and how much will be left over for business profits? Moreover, when businesses spend on non-labor inputs, what are the employment effects through giving orders to suppliers, such as lumber and glass producers or trucking companies? We also ask this same set of questions for investment projects in renewable energy as well as spending on operations within the non-renewable energy sectors. There are certainly limitations with our use of the I-O model, which we review. But we conclude that this is the most reliable methodology for our purposes. We also consider in Chapter 6 some broader methodological and measurement questions. For example, should we regard a high employment impact for a given clean energy investment strategy as necessarily being a favorable development, or are we simply observing the effects of a moving onto a lower level of labor productivity? We also address a series of more technical measurement issues in Chapter 6, and pursue these questions further in Appendices 3 and 4.

Chapter 7 presents these employment estimates by country, both the aggregated and disaggregated figures. With respect to aggregate figures, we focus on the levels of employment generated through spending $1 million within the various specific energy sectors. With the disaggregated employment figures, we show the percentage of jobs based on our four criteria - gender balance; the proportions in self-employment and working in micro-enterprises; and the educational attainment levels of people employed in the various energy-linked activities.

Overall, we find here that, per $1 million in spending in each country (converted at current exchange rates), clean energy investments generate, on average, about 37 jobs in Brazil, 10 jobs in Germany, 100 jobs in Indonesia, 70 jobs in South Africa, and 15 jobs in the ROK. Critically, as mentioned above, we also find that the clean energy investments create more jobs in all five countries than spending the same amount of funds within each country's fossil fuel sectors. In the cases of Brazil, Indonesia, and South Africa, the net employment gains for clean energy investments are substantial. They are more modest in Germany and especially the ROK. Still, in all cases, we find that investing in building a clean energy economy will also be a net positive source of job creation.

Not surprisingly, our disaggregated employment results vary by country. We observe, for example, a high proportion of employment in informal sectors in Brazil, Indonesia, and South Africa, and, to a somewhat lesser extent, the ROK, as indicated by our figures on both self-employment and micro-enterprise employment. This pattern is linked, first, to the large proportion of agricultural employment that will be generated by the growth of clean bioenergy production. It is also associated with the large increase in construction work that would result through the expansion of energy efficiency building retrofit projects. The major increase in investment funds flowing into construction and agriculture should also provide opportunities to raise the level of formalization for these sectors. This should entail increased mechanization and productivity growth.

In its current composition, employment in clean energy areas is heavily male dominated in all five countries. This is due to the significant role played by both manufacturing and construction in overall clean energy investments. Advancing major clean energy initiatives in all five countries (and elsewhere) could therefore be seen as an opportunity to open up decent job opportunities for women in these heretofore male employment strongholds.

The levels of educational attainment in the clean energy areas are generally not especially high. Indeed, if anything, they are somewhat lower than those for workers in the fossil fuel sectors. This suggests that, at least at the level of general educational levels, there should not be major challenges in finding qualified workers to cover the rising employment needs for expanding clean energy activities. At the same time, some of these new employment activities will entail new activities and skills. For example, installing solar panels on roofs and wiring these panels so they supply electricity are distinct tasks relative to the jobs that are traditionally performed by either roofers or electricians. Similarly, refining agricultural wastes into biofuels is different than refining corn into ethanol or, for that matter, refining petroleum into gasoline. Countries advancing clean energy investment projects will need to make provisions for these and similar areas that demand new types of training and skill acquisition. This is an issue we address separately in Chapter 5.

We do not present figures in Section 2 on actual numbers of jobs that are likely to be generated within each country through the various investment projects. Rather, this is one of the central topics we take up in Section 3, which consists of our five country-specific studies. The chapters proceed as follows: Chapter 8, Brazil; Chapter 9, Germany; Chapter 10, Indonesia; Chapter 11, South Africa; and Chapter 12, the ROK. In each of these country-specific chapters, we examine their broad energy indicators; some alternative projections for energy development over the course of a 20-year cycle; the country's likely economic growth trajectory over such 20-year cycles; and the range of costs each country is likely to face through undertaking large-scale investments in clean energy.[4]

In all five country settings, we deliberately work with relatively conservative assumptions on each country's economic growth trajectory and the costs that countries will face in implementing large-scale investment activities in renewable energy and energy efficiency. As we will see, the cost estimates for renewable energy and energy efficiency projects range widely, according to which countries and regions are being considered and, at a more technical level, what specific methodologies are being used to generate estimates. For the purposes of this report, it is less important to try to establish what are the most reliable GDP growth forecasts and cost estimates than to be able to evaluate the viability of large-scale clean energy investments when we assume that GDP growth will be moderate and investment costs will be relatively high. If the actual costs of renewable and efficiency investments are lower than what we have assumed, then this only strengthens our conclusion that a transformative clean energy investment agenda is a realistic prospect for all five of our selected countries.

For all of the countries except Brazil, we consider the impact on energy supply and CO_2 emissions levels of the country devoting 1.5 percent of annual GDP on investments in renewable energy and energy efficiency. For two reasons, we assume a lower rate of investment in these areas for Brazil. The first reason is that Brazil is already a very strong performer in both its reliance on renewable energy and its level of energy efficiency. The second reason is that, in Brazil, uniquely among our five selected countries, CO_2 emissions from energy-based sources accounts for less than 40 percent of the country's total GHG emissions. As such, for roughly the next decade, Brazil should devote a relatively large share of their resources to controlling methane and nitrous oxide emissions from non-energy sources.

Overall, our country-specific analyses demonstrate that each of our five selected countries can achieve major advances forward in reducing CO_2 emissions through the clean energy investment projects that we outline. The projects that we outline, in turn, build from the existing policy approaches and prospects being developed in each of the five countries. Through this approach, we are able to describe trajectories through which each of the countries can realistically reduce its ratio of per capita CO_2 emissions to an extent that the world as a whole can expect to achieve the overall 20-year CO_2 emissions target of 20,000 mmt.

Once we identify the broad levels of investment activity for each country - i.e. about 1.5 percent of annual GDP for all the countries other than Brazil, and with Brazil at about 0.9 percent of GDP - we can then estimate total amounts of employment creation through investments in renewable energy and energy efficiency. We show these employment figures both in absolute terms and as a share of each country's total labor market.

We also examine our estimates for the total numbers of jobs generated through clean energy investments in comparison with the same level of spending in each country on its existing fossil-fuel based energy infrastructure. Crucially, we find that in all countries, investing in building a clean energy economy is a net source of job creation relative to maintaining the

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[4] In developing these scenarios for 20-year clean energy investment projects, we have had to be specific as to what we mean by a "20-year project." In particular, many of the scenarios we consider provide projects for the year 2030, as if the year 2030 were 20 years from the present. But at present, of course, the year 2030 is now only 16 years away. At the same time, in some cases, the most recent data points are for the year 2010, while in other cases, data are available as recently as 2012 or even parts of 2013. Our approach to managing this issue is, in general, to present our analyses within a 20-year time frame, rather than specifically focusing on 2030 as our end-point. But we do also make considerable use of projections that are specifically focused on the year 2030. Most importantly, we have attempted to manage this issue in ways that do not distract focus on the basic issues at hand, regardless of whether our time frame ends in the year 2030 or, perhaps one, two or three years later.

economy's fossil fuel-based operations. We present these country-by-country employment creation estimates first in terms of employment levels in Year 1 of the overall 20-year clean energy investment cycle. We then also provide projections on employment creation in Year 20 of the 20-year cycle, building from a range of assumptions as to each country's relative rates of labor productivity growth as well as GDP growth. Overall, our results on employment creation throughout the 20-year clean energy investment cycle enable us to conclude that, in all five of our specific country settings, the project of building a clean energy economy is also a project for expanding employment opportunities.

SECTION 1

PROSPECTS FOR ALTERNATIVE ENERGY SOURCES

CHAPTER 2: PROSPECTS FOR NON-RENEWABLE ENERGY

As we noted at the end of Chapter 1, there are only a limited number of possible ways for economies to reduce their absolute levels of carbon emissions while still either increasing their per capita consumption of energy-based services or at least maintaining their current consumption levels. These are: raising energy efficiency; expanding the use of either clean renewable energy sources or nuclear power; capturing the CO_2 emissions from burning fossil fuels through CCS technology; or switching to cleaner-burning natural gas or oil and out of coal.

In this chapter, we will first review the basic facts on the extent of CO_2 emissions that are generated from consuming oil, coal and natural gas, as well as high-emissions bioenergy sources. This will enable us to see clearly the levels of fossil fuel consumption that can be sustained while still achieving the target of reducing global CO_2 emissions to no more than 20,000 mmt within 20 years. We will then consider the alternative ways to continue utilizing non-renewable energy sources while still reducing emissions from these energy sources - i.e. through expanding nuclear power and CCS technologies as well as through fuel switching from coal to natural gas and oil.

Emission Levels from Alternative Energy Sources

To estimate the impact on emissions of any given level of energy consumption supplied from oil, coal, natural gas and high-emissions renewable sources, we need to begin with the basic data on emissions that result from these alternative non-renewable sources.

Table 2.1 reproduces figures reported by the US Energy Information Administration (EIA) as to the CO_2 emissions levels from oil, coal, natural gas and bioenergy sources, with specific figures referring to the use of these energy sources for alternative purposes.[5] As we discuss further below, generating electricity from operating nuclear power plants does not produce GHG emissions.[6] The data in Table 2.1 are shown in terms of millions of metric tons of carbon dioxide equivalent per Q-BTU of energy. The basic results are as follows:

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[5] The IEA publication *CO_2 Emissions from Fossil Fuel Combustion* (IEA, 2013b) provides an extensive discussion on methodologies for estimating CO_2 emissions from oil, coal, and natural gas combustion. Among other useful features of this discussion is its explanation as to how differences can emerge in estimating emissions from a given level of combustion from a specific fossil fuel source. They also note that "in most cases, these differences will be small," (p. 1.5).

[6] We also review below the evidence regarding emissions generated through mining and refining uranium needed in generating nuclear energy, and in the process of constructing nuclear power plants.

Table 2.1: CO2 emissions levels from alternative fossil fuel energy sources

CO_2 emissions per Q-BTU of energy generated (mmt)

Petroleum	
Gasoline (net of ethanol)	71.3
Liquefied petroleum gas used as fuel	63
Liquefied petroleum bas used as feedstock k	12.3
Jet fuel	70.9
Distillate fuel (net of biodiesel)	73.2
Residual fuel	78.8
Asphalt and road oil	0
Lubricants	37.1
Petrochemical feedstocks	25.1
Kerosene	72.3
Petroleum coke	92.1
Petroleum still gas	64.2
Other industrial	74.5
Coal	
Residential and commercial	95.4
Metallurgical	93.7
Coke	114.1
Industrial other	94
Electrical utility	95.5
Natural gas	
Used as fuel	53.1
Used as feedstock	28
High-emissions bioenergy	
Biomass	88.5
Biogenic waste	90.7
Biofuels heats and coproducts	88.5
Ethanol	65.9
Biodiesel	73.9
Liquids from biomass	73.2

Source: U.S. Energy Information Administration (2012b), “Assumptions to the Annual Energy Outlook 2012”.

Petroleum. We see in Table 2.1 that emissions levels vary according to how petroleum is being utilized. This includes the extent to which the oil is being combusted with the various usages. Thus, when petroleum is used for gasoline, it emits 71.3 mmt of CO_2 per Q-BTU of energy. By contrast, as a petrochemical feedstock, the emissions level is 25.1 mmt of CO_2 per Q-BTU equivalent. There are no emissions when gasoline is used for producing asphalt and road oil, since these processes entail no petroleum combustion.

Coal. The range of emission levels is narrower with coal, between 94-95 mmt of CO_2 per Q-BTU, for all purposes other than combusting coke, in which case, the emissions are higher, at 114.1 mmt per Q-BTU.

Natural gas. Emissions are at 53 mmt of CO_2 per Q-BTU when natural gas is used as a fuel, i.e. about 45 percent lower than those for coal-based energy. Emissions from natural gas are then cut roughly in half when used as a feedstock, to 28 mmt of CO_2 per Q-BTU.

High-emissions bioenergy. The level of emissions varies according to the specific uses being put to bioenergy sources. Thus, biomass and biogenic waste are roughly equivalent to coal in their level of emissions per Q-BTU of energy, while ethanol and biodiesel are comparable to gasoline.

Weighted Averages for Emissions Levels

Given the range of emissions levels within each of the fossil fuel energy sources, it is useful to calculate weighted averages of emissions levels, based on the proportions of consumption within each energy source. We show these weighted average figures in Table 2.2, working from overall global energy consumption and emissions levels for oil, coal and natural gas in 2010.

Table 2.2: Weighted averages of global emission levels for oil, coal, and natural gas, 2010

	(1) **Energy consumption** *(Q-BTUs)*	(2) **CO_2 emissions** *(mmt)*	(3) **CO_2 emissions per Q-BTU** *(mmt)* *(= column 2/1)*
Petroleum and other liquid fuels[a]	163 Q-BTUs	11,200 mmt	68.7 mmt
Coal	138 Q-BTUs	13,800 mmt	100 mmt
Natural gas[b]	110.6 Q-BTUs	6,200 mmt	56.1 mmt

Source: Authors' calculations based on U.S. Energy Information Adminstration (2013), "International Energy Outlook 2013," Table 20 (for emissions); IEA, "Key World Energy Statistics 2012," p. 37 (for energy consumption).

Notes: a) The "petroleum and other liquid fuels" category includes, according to the EIA, petroleum- derived fuels and non-petroleum derived fuels, such as ethanol and biodiesel, and coal-based synthetic liquids. Petroleum coke, which is a solid, is included. Also included are natural gas plant liquids, crude oil consumed as a fuel, and liquid hydrogen. b) The average emissions per Q-BTU of natural gas are slightly lower in the U.S. (53.1 mmt/Q-BTU) than the world average (56.1 mmt/Q-BTU). The lower value of carbon content is used by the U.S. Energy Information in its "Annual Energy Outlook" and is presented in here in Table 2.1. The higher value is used by the International Energy Agency in its "World Energy Outlook" and is presented here in Table 2.2 The difference in these values is a result of product mix, differences in production processes, and the age and heat rate of natural gas plants, as documented in IEA (2013d), Deutsche Bank Climate Change Advisors (2011), and EIA (2012b).

As we see, these weighted average figures, rounded, are 69 mmt per Q-BTU of energy derived from petroleum or other liquid fuels; 100 mmt per Q-BTU of coal-derived energy; and 56 per Q-BTUs for natural-gas derived energy. We note that the figure for petroleum and other liquid fuels is inclusive of ethanol and other biofuel sources.[7]

Environmental and Safety Concerns

Nuclear Power

As of 2010, nuclear power provided 27 Q-BTUs of energy throughout the global economy, which represented about 5.2 percent of global energy supply.[8] Eighty-five percent of global nuclear power supply is generated within the OECD economies.[9] In terms of the world achieving GHG emission targets - both the 20-year intermediate target and the 2050 target - nuclear power provides the obvious important benefit that it does not generate GHG emissions or air pollution of any kind while operating.

At the same time, the processes for mining and refining uranium ore and making reactor fuel require large amounts of energy. Nuclear power plants have large amounts of metal and concrete, which also require large amounts of energy to manufacture. If fossil fuels are used to make the electricity and manufacture the power plant materials, then the emissions from burning those fuels could be associated with the electricity that nuclear power plants generate.[10]

It is difficult to reach firm conclusions as to the extensiveness of these secondary emissions effects from producing nuclear energy. In their survey of the relevant literature, Beerten et al. (2009) conclude that none of the relevant studies on this question "takes into account the different mining techniques in a proper manner". They also conclude that insufficient evidence is available as to the "energy and GHG emissions involved with the waste processing, storage and disposal on the one hand and the decommissioning of the plant on the other hand," (p. 5067).

However, even if we assume a best-case scenario in terms of full cycle emission from generating nuclear energy, we still of course need to recognize the longstanding environmental and public safety issues associated with nuclear energy. These concerns include:

- ***Radioactive wastes.*** These wastes include uranium mill tailings, spent reactor fuel, and other wastes, which according to the EIA "can remain radioactive and dangerous to human health for thousands of years" (EIA 2012c, p. 1).

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[7] The average emissions per Q-BTU of natural gas are slightly lower in the U.S. (53.1 mmt/Q-BTU) than the world average (56.1 mmt/Q-BTU). The lower value of carbon content is used by the U.S. Energy Information in its "Annual Energy Outlook" and is presented in here in Table 2.1. The higher value is used by the International Energy Agency in its "World Energy Outlook" and is presented here in Table 2.2. The difference in these values is a result of product mix, differences in production processes, and the age and heat rate of natural gas plants, as documented in IEA (2013d), DeutschBank (2011), and EIA (2012b). In addition, the "petroleum and other liquid fuels" category does not include emissions from biomass sources. In the EIA's 2012 Annual Energy Outlook, Table D-5, these emissions are included, at least in part, in the "other" category. We incorporate these emission figures into our coal category. We also note that these weighted averages of emissions per Q-BTU of energy, as derived from the 2010 actual levels of energy consumption in the U.S., are nearly identical to the estimated figures the EIA projects in their scenarios for U.S. energy consumption in 2030 and beyond, and thus we use these in our calculations of emissions generated through the alternative 2030 scenarios.

[8] EIA (2012d).

[9] ibid.

[10] This paragraph is paraphrased from the EIA, ("Nuclear Explained," 2014).

- ***Storage of spent reactor fuel and power plant decommissioning.*** Spent reactor fuel assemblies are highly radioactive and must be stored in specially designed pools or specially designed storage containers. When a nuclear power plant stops operating, the decommissioning process involves safely removing the plant from service and reducing radioactivity to a level that permits other uses of the property.

- ***Political security.*** Nuclear energy can obviously be used to produce deadly weapons as well as electricity. Thus, the proliferation of nuclear energy production capacity creates dangers of this capacity being acquired by organizations - governments or otherwise - who would use that energy as instruments of war or terror.

- ***Nuclear reactor meltdowns.*** An uncontrolled nuclear reaction at a nuclear plant can result in widespread contamination of air and water with radioactivity for hundreds of miles around a reactor.

Even while recognizing these problems with nuclear energy, it is still the case, as noted above, that nuclear power supplies over five percent of global energy supply. For decades, the prevalent view throughout the world was that these risks associated with nuclear power were relatively small and manageable, when balanced against its benefits. However, this view has been upended in the aftermath of the March, 2011 nuclear meltdown at the Fukushima Daiichi power plant in Japan, which resulted from the massive 9.0 Tohuku earthquake and tsunami.

The full effects of the Fukushima meltdown cannot possibly be known for some time. But an initial recent research paper by Ten Hoeve and Jacobson (2012) on the overall health effects of Fukushima finds that they are likely to be very large. Ten Hoeve and Jacobson conclude that the health effects from inhalation, external exposure, and ingestion of radionuclides will range between 15-1,100 cancer related deaths and between 24 and 1,800 morbidities, with most of the impact within Japan itself. Their estimates do not include the effects on the roughly 20,000 workers at the plant in the months following the accident. They also do not include the nearly 600 deaths that had been certified as "disaster related," through fatigue or aggravation of chronic illnesses due to the disaster.[11]

In its most recent 2013 *International Energy Outlook*, the EIA acknowledges that Fukushima has substantially intensified concerns worldwide about the viability of expanding, or even maintaining, nuclear energy as a major power source. The EIA writes:

> *The Fukushima Daiichi disaster could have long-term implications for the future of world nuclear power development in general. Even China - where large increase in nuclear capacity have been announced and are anticipated in the IEO 2013 Reference case - halted approval processes for all new reactors until the country's nuclear regulator completed its safety review. Germany and Switzerland announced plans to phase out or shut down their operating reactors by 2022 and 2034, respectively...The uncertainty associated with nuclear power projections for Japan and for the rest of the world has increased (EIA, 2013, p. 95).*

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[11] The edited volume by Schreurs and Yoshida (2013) addresses a broader set of political and economic considerations of the Fukishima disaster. As of August 2013, the Fukushima crisis escalated seriously as Japan's Nuclear Regulatory Authority (NRA) stating , as reported by Reuters, "that it feared more storage tanks were leaking contaminated water. According to Reuters, "Water in the latest leak is so contaminated that a person standing close to it for an hour would receive five times the annual recommended limit for nuclear workers," (Takenaka and Topham, 2013).

Overall then, it is clear that these safety considerations with nuclear energy must be accorded significant weight. As such, nuclear energy cannot be seen as serving as a reliable long-term source of non-carbon emitting energy supplies. This means that, to the extent possible, it is far preferable to rely on clean renewable energy sources and advances in energy efficiency as the preferred alternatives as we proceed with reducing our dependence on oil, coal, and natural gas.

Carbon Capture and Sequestration

CCS is a broad term that encompasses a number of specific technologies that are capable of capturing CO_2 from point sources, such as power plants and other industrial facilities. Through CCS technologies, the captured CO_2 is then transported, usually through pipelines, in some form to locations where it is then stored indefinitely in subsurface geological formations.

One specific approach entails converting the captured CO_2 into liquid form, then moving the liquid CO_2 through pipelines to oil reservoirs. If the oil has already been extracted from such reservoirs, then the dormant reservoir can serve as a permanent CO_2 storage facility. But if the reservoir does still contain oil, then the CO_2 injections can be used to push the remaining oil out of the repository more efficiently. As of 2009, *Science* reported on five CCS projects around the world of this type that were in operation and another seven that were in the process or being planned. Two of the operating projects were in the North Sea, and the other three were in Sastatchewan, Canada; Kaniow, Poland; and In Salah, Algeria (*Science*, September 2009, "Carbon Sequestration," pp. 1644-45.)

The broad case on behalf of CCS is straightforward: the development of effective CCS technologies will allow for the world's enormous fossil fuel energy resources to continue to be exploited without these energy sources continuing to release such high levels of CO_2 into the atmosphere. As former U.S. Energy Secretary Steven Chu wrote in 2009:

> *The world has abundant fossil fuel reserves, particularly coal. The United States possesses one-quarter of the known coal supply, and the United States, Russia, China and India account for two-thirds of the reserves. Coal accounts for 25 percent of the world's energy supply and 40 percent of the carbon emissions. It is highly unlikely that any of these countries will turn their back on coal any time soon, and for this reason, the capture and storage of CO_2 emissions from fossil fuel power plants must be aggressively pursued (Chu, 2009, p. 1599).*

At the same time, as surveyed forcefully by Joseph Romm (2008) of the U.S. Center for American Progress there are four major problems associated with CCS technologies, which in combination, render the approach unsuitable for serving as a major clean-energy strategy either in the in the relatively short- or the longer term. These four problems entail issues of 1) costs; 2) timing; 3) scale; and 4) permanence and transparency. It is worth quoting at length from Romm's overview:

1. ***Cost:*** *Coal plants with CCS are very expensive today. A 2012 study by the U.S. Congressional Budget Office found that plants equipped with CCS technology have capital costs averaging 76 percent higher than non-CCS plants.*[12] *The modeling work*

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[12] CBO (2012), p. 7.

> *done for the California Public Utility Commission (CPUC) on how to comply with the AB32 law (California's Global Warming Solutions Act), puts the cost of coal gasification with carbon capture and storage at a staggering 16.9 cents per kWh.*
>
> 2. ***Timing:*** *The world does not even have a single large-scale (300+ MW) coal plant with CCS anywhere in the world…. Most governments and most U.S. utilities have scaled back, delayed, or cancel their planned CCS projects (see below). As Howard Herzog of MIT's Laboratory for Energy and the Environment said in February 2008, "How can we expect to build hundreds of these plants when we're having so much trouble building the first one?"*[13]
>
> 3. ***Scale:*** *We need to put in place a dozen or so clean energy "stabilization wedges" by mid-century to avoid catastrophic climate outcomes….For CCS to be even one of those would require a flow of CO2 into the ground equal to the current flow of oil out of the ground. That would require, by itself, re-creating the equivalent of the planet's entire oil delivery infrastructure, no mean feat.*
>
> 4. ***Permanence and transparency:*** *We need to set up some sort of international regime for certifying, monitoring, verifying, and inspecting geologic repositories of carbon - like the U.N. weapons inspections systems. The problem is, this country [the U.S.] hasn't been able to certify a single storage facility for a high-level radioactive waste after two decades of trying and nobody knows how to monitor and verify underground CO_2 storage. It could take a decade just to set up this system (Romm, 2008).*

In addition to the issues highlighted by Romm's survey, there are also broader environmental issues at stake. The possibility of leakages from the underground CO_2 repositories is one such danger. Any such leakages could produce contamination of ground water, and thereby, drinking water. Leakages could also mean new releases of the very CO_2 emissions that the technology is designed to mitigate. Still another issue is the environmental damage from continuing to extract coal through mountaintop removal and strip mining.

Considering all of these factors, the IEA's 2013 *World Energy Outlook* presents a highly pessimistic assessment of the prospects for CCS:

> *Progress in developing CCS has been disappointingly slow. Only a handful of large-scale CCS projects, mainly in natural gas processing, are operating, together with some low-cost schemes in industrial applications. While projects are more economically viable if the captured CO2 can be used for enhanced oil recovery, there is, to date, no commercial CCS application in the power sector or in energy-intensive industries. Beyond technological and economic challenges, there could be legal challenges related to the potential for CO_2 gas escape from underground storage. Although some progress has been made in developing regulatory frameworks, deployment support is lacking and the absence of a substantial price signal has so far impeded necessary technological development and more widespread update (IEA, 2013a, p. 53).*

In short, following from this most recent assessment by the IEA, we conclude that the prospects for deploying CCS technologies on a large scale globally are not favorable. Thus, as we noted

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[13] Quoted in Biello, 2008.

above with respect to nuclear power, to the extent possible, it is far preferable to rely on clean renewable energy sources and advances in energy efficiency rather than unproven CCS technologies as the preferred alternatives as we proceed with reducing our dependence on oil, coal, and natural gas. It is of course possible that major technological breakthroughs will create a much more favorable outlook for CCS than those presented in summary assessments by Romm (2008) and the IEA (2013). But the evidence for any such major breakthroughs does not presently exist. As such, as we will explore in depth in Chapters 3 and 4, the more prudent approach for building clean energy economies is to encourage the rapid advances that are already underway with clean renewables and energy efficiency.

Hydraulic Fracturing

The EIA (2012b) forecasts that total levelized costs for generating electricity from natural gas-powered processes will be substantially lower than those from any other conventional or renewable energy source. We discuss this in detail in Chapter 3, in comparing the costs generating electricity from renewable sources relative to those from coal, natural gas and nuclear power. But these figures are also critical for our current discussion, so we present the main findings in Table 2.3 below, as they relate specifically to the issue of assessing hydraulic fracturing technology.

Table 2.3: Total levelized costs for electricity generation from alternative energy sources

U.S. EIA projections for 2017

	Total 2017 estimated costs per megawatt hour (dollars)	**Total 2017 estimated costs relative to natural gas (percent)**
Conventional natural gas (no CCS)	$66.1	-
Hydro	$88.9	+ 34.5%
Wind	$96.0	+ 45.2%
Conventional coal (no CCS)	$97.7	+ 47.8%
Nuclear	$114.7	+ 73.5%
Biomass	$115.9	+ 75.3%
Solar PV	$152.7	+ 131.0%

Source: Authors' calculations based on U.S. Energy Information Administration (2012b), "Assumptions to the Annual Energy Outlook 2012."

As we see in Table 2.3, the EIA projects that, as of 2017, the total costs of electricity generation from natural gas without CCS technology will be $66.1 per megawatt hour. This figure is 26 percent lower than for hydro, the next lowest source for electricity generation, at $88.9 per megawatt hour. According to the EIA's 2017 projections, the costs of natural-gas-fired electricity (without CCS) are lower than all other sources of electricity generation, both non-renewable and renewable, ranging from wind and coal (45 and 48 percent more expensive than natural gas, respectively) to solar PV (131 percent more).

The factor that is producing such low-cost electricity projections from natural gas is the EIA's assumption of a rapidly expanding use of hydraulic fracturing technology to extract natural gas from shale rock. But the issue with fracking technology is that some, though not all, credible research finds that fracking consistently produces serious environmental costs along with an inexpensive energy supply. In particular, fracking has been demonstrated to contaminate drinking water with methane gas in aquifers overlying the major shale formations of northeastern Pennsylvania and upstate New York. Yet other recent research has found that methane emissions can be significantly reduced when producers take active measures to control methane emissions.

It will be useful here to review these alternative perspectives. To begin with, we draw from an important 2011 overview paper by Jackson, Pearson, Osborn, Warner and Vengosh of Duke University. Jackson et al. begin by describing the basics of fracking technology and explain why this technology is capable of extracting natural gas at significantly lower costs than conventional extraction methods:

> *The extraction of natural gas from shale formations is one of the fastest growing trends in American on-shore domestic oil and gas production….Large-scale production of shale gas has become economically viable in the last decade attributable to advances in horizontal drilling and hydraulic fracturing (also called "hydrofracturing" or "fracking"). Such advances have significantly improved the production of natural gas in numerous basins across the United States, including the Barnett, Haynesville, Fayetteville, Woodford, Utica, and Marcellus shale formations. In 2010, shale gas production doubled to 137.8 billion cubic meters, and the EIA projects that by 2035 shale gas production will increase to 340 billion cubic meters per year, amounting to 47% of the projected gas production in the United States.*
>
> *Hydraulic fracturing typically involves millions of gallons of fluid that are pumped into an oil or gas well at high pressure to create fractures in the rock formation that allow oil or gas to flow from the fractures to the wellbore. Fracturing fluid is roughly 99% water but also contains numerous chemical additives as well as propping agents, such as sands, that are used to keep fractures open once they are produced under pressure. The chemicals added to fracturing fluid include friction reducers, surfactants, gelling agents, scale inhibitors, acids, corrosion inhibitors, antibacterial agents, and clay stabilizers. The Interstate Oil and Gas Compact Commission (IOGCC) estimates that hydraulic fracturing is used to stimulate production in 90% of domestic oil and gas wells, though shale and other unconventional gas recovery utilizes high-volume hydraulic fracturing to a much greater extent than conventional gas development does. Horizontal wells, which may extend two miles from the well pad, are estimated to be 2-3 times more productive than conventional vertical wells, and see an even greater increase in production from hydraulic fracturing. The alternative to hydraulic fracturing is to drill more wells in an area, a solution that is often economically or geographically prohibitive (Jackson et al., 2011, pp. 1-2).*

What is the environmental impact of fracking? One perspective is the environmental/safety issues with shale extraction are manageable. This position is most strongly supported by the findings reached in a major 2013 research study directed by David T. Allen of the University of Texas-Austin, which was funded by the natural gas industry (Allen et al., 2013). Allen et al. found that methane emissions could be cut by as much as 98 percent - from 81 to 1.7 megatons per well - when controls were utilized to capture these emissions.

The 2011 study by Jackson et al. presents a sharply different view, especially around the issue of groundwater contamination. They conclude as follows:

> *A recent study by Osborn and colleagues in the Proceedings of the National Academy of Sciences, USA provides to our knowledge the first systematic evidence of methane contamination of private drinking-water in areas where shale gas extraction is occurring. The research was performed at sites above the Marcellus and Utica formations in Pennsylvania and New York. Based on groundwater analyses of 60 private water wells in the region, methane concentrations were found to be 17-times higher on average in areas with active drilling and extraction than in non-active areas, with some drinking-water wells having concentrations of methane well above the "immediate action" hazard level (2011, pp. 3-4).*

In a more recent 2013 study, "Increased Stray Gas Abundance in a Subset of Drinking Water Wells Near Marcellus Shale Gas Extraction," Jackson et al., reached basically the same conclusion as their 2011 paper regarding the impact of fracking technology on drinking water. For example, in their 2013 paper, they conclude that "Methane was detected in 82 percent of drinking water samples, with average concentrations six times higher for homes less than one kilometer from natural gas wells," and that "Ethane was 23 times higher in homes less than one kilometer from gas wells," (2013, p. 1).

Certainly, neither the University of Texas nor the Duke University studies can be considered to have produced definitive findings. Yet taken together, they bring greater clarity regarding a key question at hand: whether adequate controls can be put in place for greatly reducing the methane emissions that are occurring in the absence of such controls. Establishing such controls would no doubt be costly, and, as such, the industry would prefer to avoid paying these costs.[14] From this perspective, the safety concerns regarding fracking are comparable to those connected with nuclear energy.

As a result of the negative findings regarding contamination of drinking water, in May, 2012, Vermont became the first state in the U.S. to pass legislation banning fracking. As of this writing, New York also operates with a moratorium on fracking. Other states and municipalities have either imposed temporary moratoria or are in the process of debating such measures.

In Europe, as of October 2013, countries that have banned fracking include France and Bulgaria, which have the largest deposits of exploitable shale rock resources in on the Continent. The Czech Republic, Northern Ireland, and the regions of Canatabria in Spain, and Friebourg in Switzerland have also established bans, while Romania, Germany and Luxembourg have declared moratoria. [15]

It is also the case that the recent political crisis in the Ukraine has created pressure for European countries to reduce their dependence on natural gas supplies imported from Russia.[16] Regardless of how these geopolitical issues are resolved, it remains the case, as we will discuss below, that allowing current, or even increasing levels of natural gas consumption levels is not compatible with achieving the 20-year global emission reduction target.

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[14] Koch 2103 presents a range of reactions to the findings by Allen et al. quoted in Koch, (2013).

[15] This listing of countries comes from Petro Global News (2013).

[16] EurActiv (2014).

Fuel Switching from Coal to Natural Gas

In addition to the safety issues raised through hydraulic fracturing technology, it is also the case that relying heavily on coal to natural gas fuel switching will not provide anywhere close to an adequate level of emissions reductions necessary to meet the global 2030 emission reduction target. We can see this clearly by considering the EIA's reference case for total global energy consumption in 2030. As we have discussed, with this 2030 reference case, total global energy consumption is at 729 Q-BTUs in 2030. Total emissions are at 41,000 mmt, i.e. roughly twice as high as the target level of 20,000 mmt for meeting the climate change control target.

Within the framework of this reference case, let us consider two alternative global fuel-switching scenarios: that both 50 percent and 100 percent of global coal consumption is replaced through natural gas, but that otherwise, the EIA's reference case remains as they have projected it. Of course, even the 50 percent coal-to-natural gas fuel-switching scenario is implausibly large. We have included the 100 percent fuel switch to establish the outer boundary of a fuel-switching scenario on a global scale. We show the results of these illustrative exercises in Table 2.4.

Table 2.4: Impact on CO2 emissions of coal-to-natural gas fuel switching within U.S. EIA's 2030 Reference case Global Energy Consumption Scenario

	2030 Reference case	2030 with 50 percent coal-to-natural gas fuel switching	2030 with 100 percent coal-to-natural gas fuel switching
Coal consumption (Q-BTUs)	200 Q-BTUs	100 Q-BTUs	0 Q-BTUs
CO_2 emissions from coal (mmt)	19,500 mmt	9,800 mmt	0 mmt
Natural gas consumption (Q-BTUs)	126 Q-BTUs	226 Q-BTUs	326 Q-BTUs
CO_2 emissions from natural gas (mmt)	8,600 mmt	15,400 mmt	22,300 mmt
Coal + natural gas CO_2 emissions (mmt)	28,100 mmt	25,200 mmt	22,300 mmt
Oil and other liquid fuel CO_2 emissions (mmt)	13,300 mmt	13,300 mmt	13,300 mmt
Total CO_2 emissions (mmt)	41,400 mmt	38,500 mmt	35,600 mmt
		(7% reduction)	(14% reduction)

Source: Authors' calculations based on U.S. Energy Information Administration (2013), "International Energy Outlook 2013.

As Table 2.4 shows, on its own, the overall impact of even these highly aggressive coal-to-natural gas fuel-switching scenarios is quite modest. Within the context of the EIA's 2030 Reference case global energy consumption scenario, the 50 percent coal-to-natural gas fuel switch reduces overall CO_2 emissions by 7 percent, from 41,400 mmt to 38,500 mmt globally. Even the 100 percent coal-to-natural gas fuel switch produces an emissions reduction of only 14 percent, to 35,600 mmt globally. Of course, these emissions reduction levels need to be evaluated against the need to reduce global emissions down to about 20,000 mmt by 2030 or thereabouts.

What these illustrative exercises illustrate clearly is the importance of exploring the prospects for investments in energy efficiency and clean renewable energy sources as the central elements of a global green growth strategy.

CHAPTER 3: PROSPECTS FOR RENEWABLE ENERGY SOURCES

In order for the world economy to meet its intermediate CO_2 emissions reduction targets within 20 years and, subsequently for 2050, it will be necessary to create a rapidly expanding and successful renewable energy sector. This means producing energy increasingly from wind, solar, geothermal, bioenergy, and hydropower sources. Even if, with strong energy efficiency measures accompanying ongoing economic growth, the absolute level of global energy consumption were to fall by 10-20 percent over the next 20 years, it would still be necessary that clean renewable energy sources would provide about one-third of global energy supply. At present, total renewable sources account for about 13 percent of global energy supply.

As we will review in this chapter, it is in fact realistic to allow that clean renewables could provide in the range of one-third of all global energy supplies within 20 years. It is already the case that, in terms of *additions* to capacity, renewable power generation technologies account for about half of all new power generation worldwide.[17] The main driver here is that the trajectory for prices and costs for renewables is becoming increasingly favorable. In particular, clean renewables are already close to closing the cost gap with non-renewable energy sources. In a wide range of conditions - though of course not under all circumstances - renewable energy from most sources will be at cost parity with non-renewables within the next 5-10 years.

The current dynamic of the global renewable energy sector is well summarized in the 2013 report by the International Renewable Energy Agency (IRENA):

> *In the past, deployment of renewables was hampered by a number of barriers, including their high up-front costs. Today's renewable power generation technologies are increasingly cost-competitive and are now the most economic option for off-grid electrification in most areas, and, in areas with good resources, they are the best option for centralized grid supply and extension….The rapid deployment of these renewable technologies has a significant impact on costs, because of the high learning rates for renewables, particularly for wind and solar. For instance, for every doubling of the installed capacity of solar photovoltaic (PV), module costs will decrease by as much as 22 percent (IRENA, 2013, p. 12).*

In considering the prospects for renewable energy supplies to achieve an ambitious growth target, the first point to emphasize is that these energy sources vary widely, in terms of their basic feedstocks, the means by which they generate energy, their costs, and their environmental impacts and related externalities.[18]

Bioenergy provides the most critical case in point here. This is first of all because bioenergy sources account for 75 percent of global renewable energy supply, which amounts to about 10 percent of total energy supply (IEA, 2014). Considering the short- to medium term - i.e. within

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[17] IRENA, 2012.

[18] The massive IPCC study *Renewable Energy Sources and Climate Change Mitigation* (2013) provides a comprehensive reference guide on these issues.

the 20-year time frame on which we are focused in this report - bioenergy will continue to be the largest source of renewable energy throughout the globe. For this reason alone, prospects for the bioenergy sector merit our careful attention.

But expanding the bioenergy sector also presents major challenges. To begin with, depending on the production processes utilized, bioenergy may not be - and, in most cases, in fact, is not - a low-emissions energy source. For example, corn ethanol is the most heavily consumed bioenergy source in the U.S. at present. Under currently prevailing refining methods used, the CO_2 emissions produced by corn ethanol can be comparable to burning oil. This is also true for biomass energy when - as is mostly the case at present throughout the globe - the energy sources and production practices are not carefully managed to minimize carbon emissions.

An equally serious concern with producing bioenergy is that it can entail significant increases in the demands on the world's agricultural resources. This in turn could lead to rising agricultural prices. This problem is especially serious with respect to food prices. We have seen over the past decade how sharp increases in global food prices have produced massive increases in food insecurity and malnutrition worldwide.

Biomass/biofuels can also be a carbon-neutral source of energy, if the raw materials are wastes and non-food crops and if these raw materials are refined through the use of renewable sources. The impact of bioenergy production on agricultural resources and food prices can also be minimized when the underlying feedstocks are wastes and non-food crops. But, to date, these other techniques for producing bioenergy are utilized only to a small extent worldwide. In considering the expansion of renewable energy sources, our focus therefore needs to be on low- to zero-emissions sources, which we term "clean renewables. We return to this point below.

The other renewable sources - hydro, wind, solar, and geothermal power - produce no CO_2 emissions. Yet at present, among these, only hydro is producing energy on a significant scale globally - i.e. 2.3 percent of all global energy supply, or 17.5 percent of all renewable supply (IEA, 2013e). For the most part, it is not desirable that large-scale hydro projects expand significantly past their current capacity level. This is because there are likely to be serious environmental issues connected with additional large-scale dam construction in terms of disrupting existing communities and eco systems. At the same time, prospects are much more favorable for expanding electricity-generating capacity from small scale hydro projects. This would be in addition to expanding capacity from other emissions-free renewable energy sources - that is, wind, solar, geothermal and clean bioenergy.

Renewable Energy Costs

Renewable energy costs vary widely depending on technologies, feedstocks, available resources and the specific conditions at any given power-generating site. The prospects for achieving cost reductions for renewables will also vary, depending on how these same factors play out, in particular as investors learn to improve renewable energy technologies then to incorporate these technical innovations into production processes. The 2013 IRENA report provides a useful overview here:

> *Depending on local resources, biomass, geothermal, and hydropower can all produce electricity at very competitive costs. Onshore wind is typically the next most expensive, while solar PV and CSP are more costly. However, this cost order typically follows an inverse relationship to resource availability. The availability of low-cost resources for hydropower, geothermal and biomass are all constrained to a greater or lesser extent, while long lead times for the first two mean that capacity additions cannot be ramped up or down rapidly….Conversely, wind and solar resources are much larger and are distributed, albeit unevenly, around the world. This, together with targeted policy support, has seen the level of wind and solar PV capacity grow much more rapidly than hydropower, biomass and geothermal (IRENA, 2013, p. 24).*

Figure 3.1 below, reproduced from the 2013 IRENA study, provides a clear picture on cost ranges for renewables both in 2012 and projected for 2020. The 2020 figures, of course, incorporate estimates as to the rates at which more efficient technologies are being adapted between 2012 and 2020. These projected cost reductions thus reflect the estimated "learning curves" for renewable energy technologies. The cost figures being reported in the figure are the total levelized costs of producing electricity (LCOE) through renewable sources. Total levelized costs include five components:

- **Capital costs.** The IRENA study assumes an average cost of capital at 10 percent. But it also discusses in detail the variables, which can lead to large differences in costs of capital.[19]

- **Fixed operations and maintenance.** These include standard costs that do not vary with output levels, including land and maintenance of buildings and machines.

- **Variable operations and maintenance.** This includes fuel costs for operating renewable energy projects, which will be most significant in the case of bioenergy.

- **Transmission.** This includes the operations of the electrical grid system. In the case of direct distributed energy, transmissions costs are eliminated.

- **Capacity utilization rate.** The projected utilization rate for equipment, which varies with market demand and resource availability.

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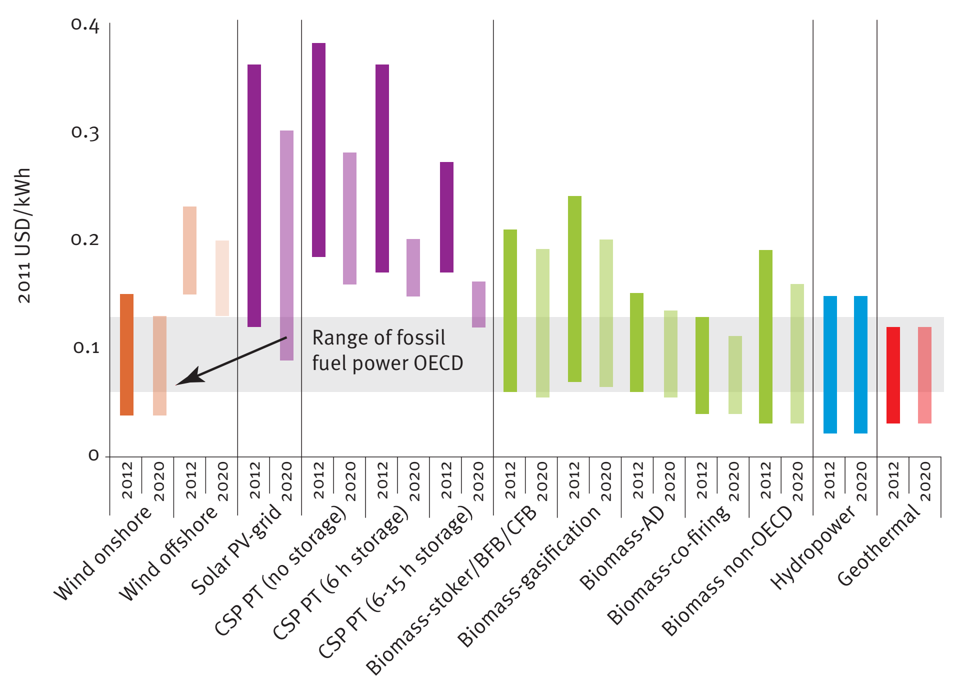
[19] Further details on sources of variation in capital costs are provided in Limaye and Zhu (2012).

Figure 3.1: Typical levelized cost ranges for renewable power generation technologies, 2012 and 2020



PT = parabolic through, ST = solar tower, BFB/CFB = bubbling fluidized bed/circulating fluidized bed, AD = anaerobic digestion.
Source: IRENA (2013), "Renewable Power Generation Costs in 2012: An Overview," Figure ES-2.

The basic findings that emerge from Figure 3.1 are as follows:

1. The largest range of costs is with solar power, both in 2012 and with their projections for 2020. In 2012, generating electricity from solar PV technologies ranges between about 14 and 35 cents per kilowatt hour (kWh). IRENA projects that solar PV costs will decline in 2020. But their projected range, between about 8 and 30 cents, will still be wide.

2. The lowest costs are through hydro electricity generation, at about 3 cents per kWh. But these costs do also rise as high as about 15 cents.

3. The costs of generating electricity through onshore wind, biomass, hydro and geothermal are all at rough parity with fossil fuel electrical generation prices within the OECD economies. Solar power, with both PV and CSP technologies, as well as offshore wind, are the only two renewable sources in which total levelized costs are consistently higher than the range for fossil fuels.

4. The cost range for fossil fuel electricity generation is narrower than for most renewables. But the differences in range are relatively small for wind, most biomass, hydro and geothermal. It is only with solar power that the cost range is significantly wider than that for fossil fuel energy.

5. The lower average costs and narrower cost range for fossil fuels reflects the fact that these sectors are operating with mature technologies that have been developed over decades, and have been supported on a massive global scale over this full period by both private investors and public subsidies.[20]

6. Rates of decline in costs between 2012 and 2020 - reflecting the technological 'learning rates' over these eight years -vary significantly by renewable energy source. For example, IRENA projects large cost reductions for both solar PV and Concentrated Solar Power (CSP) over these years. With grid-based solar PV systems, IRENA estimates that the levelized cost range per kWh will decline from between about 18-37 cents in 2012 to between about 9-30 cents as of 2020. As the figure shows, at 9 cents per kWh as of 2020, solar PV will become cost competitive with fossil fuel generated electricity under average circumstances. By contrast, IRENA is projecting much more modest learning rates and cost reductions between 2012-2020 for onshore wind, most bioenergy sources, and no cost improvements for either hydro or geothermal power. At the same time, as noted above, IRENA shows onshore wind, most bioenergy sources, hydro and geothermal power as already operating basically at levelized cost parity with fossil fuel-generated electricity as of 2012.[21]

Differences in Renewable Electricity Costs by Region

Beyond the broad renewable energy cost estimates shown in Figure 3.1, it is important for the purposes of this report to also examine costs at a more detailed scale. The 2013 IRENA study does also provide cost estimates on a regional basis. We report on their main findings in Tables 3.1-3.5 below, which show cost figures for each of the renewable energy sources. Each of the tables shows average costs by region as well as the range of costs among the individual projects for which IRENA has collected data.

Wind. Table 3.1 shows cost figures for onshore wind projects. As we see, average costs per kWh of generating electricity from onshore wind range between 8 cents in China and India to 12 cents in Other Asia. We do also see a wide range of costs within each region. For example, the average cost in Latin America is 9 cents, but the range is between 4 and 16 cents. In Africa, the average cost is also 9 cents, while the range is between 5 and 17 cents

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[20] The development of the global fossil fuel industry has been well-documented, for example, by Yergin (1992 and 2011).

[21] These learning rate patterns between 2012 and 2020 projected by IRENA for various renewable sources are broadly consistent with those estimated by the EIA. The EIA measures learning rates as the capital cost reductions that will be associated with a doubling of capacity for any given technology. In EIA (2013c, p. 104), learning rates for biomass, hydro, and wind at 1 percent; geothermal as ranging between 1-8 percent, solar PV and biofuels at between 1-10 percent; and solar CSP as between 1-20 percent. In short, the EIA estimates that the greatest upside potential for cost reductions are with solar. But this is in large part because costs presently are very high and existing productive capacity is very modest.

Table 3.1: Onshore wind: Estimated levelized costs of electricity (LCOE) generation in non-OECD countries/regions, 2011

Estimates are in 2011 dollars; figures are cents per kilowatt hour (kWh)

	Average	Range
Africa	9	5-17
China	8	5-11
Eastern Europe and Central America	11	7-17
Other Asia	12	8-16
India	8	3-12
Latin America	9	4-16

Source: International Renewable Energy Agency (2013), "Renewable Power Generation Costs in 2012: An Overview," Figure 4.8 and underlying IRENA cost database.

Hydro. Table 3.2 shows figures for large-scale hydro projects. Here average costs for generating electricity range between 3 cents per kWh in China to 12 cents in Other Asia. In addition, the cost range within regions is also wide. In Africa, the average cost is 6 cents per kWh, but the range is between 1 and 17 cents.

Table 3.2: Large-scale hydro projects: Estimated levelized costs of electricity (LCOE) generation in non-OECD countries/regions, 2011

Estimates are in 2011 dollars; figures are cents per kilowatt hour (kWh)

	Average	Range
Africa	6	1-17
China	3	1-8
Eastern Europe and Central America	10	3-14
Other Asia	12	8-16
India	8	3-12
Latin America	9	4-16

Source: International Renewable Energy Agency (2013), "Renewable Power Generation Costs in 2012: An Overview," Figure 5.8 and underlying IRENA cost database.

As we discussed above, these figures for large-scale hydro projects are less relevant in terms of expanding capacity into the future than the projects for small-scale hydro. We show the IRENA figures on small-scale hydro projects in Table 3.3. As we see there, average costs for small-scale hydro projects are generally lower than those for large-scale projects and the range of costs within regions is also somewhat narrower. For example, in Other Asia, the average cost for small-scale hydro projects is 4 cents per kWh, while large-scale hydro costs average 12 cents. In India, small-scale hydro projects average 5 cents per kWh while large-scale projects average 8 cents. In Latin America, small-scale projects average 5 cents while large-scale average 9 cents. These figures for small-scale hydro suggest that there are major opportunities for expanding hydropower through smaller projects. Most significantly, in all regional settings, the average costs for small-scale hydro are either at rough parity with or lower than those for fossil fuel sources of electricity generation.

Table 3.3: Small-scale hydro projects: Estimated levelized costs of electricity (LCOE) generation in non-OECD countries/regions, 2011

Estimates are in 2011 dollars; figures are cents per kilowatt hour (kWh)

	Average	Range
Africa	6	2-10
China	3	1-6
Eastern Europe and Central America	4	2-6
Other Asia	4	2-13
India	5	2-13
Latin America	5	2-9

Source: International Renewable Energy Agency (2013), "Renewable Power Generation Costs in 2012: An Overview," Figure 5.8 and underlying IRENA cost database.

Solar. Table 3.4 shows cost figures for solar PV. As we saw with the average global figures for solar PV, as well as solar CSP, by regions, the cost figures for solar are still quite high relative to both fossil fuels and other renewable sources, even while costs have been falling significantly in recent years. Thus, by region, the average costs for solar PV range between 15 cents per kWh in Latin America to 30 cents in Other Asia. Costs also vary widely between regions. In China, average costs are 19 cents per kWh, while the range is between 11-53 cents. In India, average costs are 23 cents per kWh, while the range is between 8-37 cents. The average costs per region and the cost range are even higher for solar CSP technologies.

Table 3.4: Solar photovoltaic: Estimated levelized costs of electricity (LCOE) generation in non-OECD countries/regions, 2011

Estimates are in 2011 dollars; figures are cents per kilowatt hour (kWh)

	Average	Range
Africa	21	18-54
China	19	11-53
Middle East	28	21-32
Other Asia	30	14-70
India	23	8-37
Latin America	15	12-31

Source: International Renewable Energy Agency (2013), "Renewable Power Generation Costs in 2012: An Overview," Figure 6.9 and underlying IRENA cost database.

As the IRENA study emphasizes, solar energy carries the best long-term promise as a clean renewable energy resource into the future. The underlying feedstock - sunshine - is generally abundant in all regions of the world relative to other renewable sources. The technologies can operate effectively at a variety of scales, including individual rooftops. With rooftop solar and its close equivalents - such as community-level power-generating projects - electricity can be distributed without having to rely on an electrical grid system. Over time, these advantages will be tremendously beneficial to advancing solar energy. Nevertheless, solar remains the high-cost technology, even among renewables, and is likely to continue as such for at least the next decade.

Bioenergy. Table 3.5 shows cost figures on electricity generation through biomass sources. In this case, average costs are low, at between 5-6 cents per kWh of electricity, in all non-OECD regions. But the cost ranges are also very large within each region – 1-20 cents in India; 2-20 cents in Africa; 3-18 cents in Latin America and 2-17 cents in Other Asia. The Chinese biomass projects report the smallest range, at 2-10 cents, but this range as well is large in absolute terms, if not relative to other regions. Given this wide range of costs, in pursuing opportunities to expand bioenergy-fired electricity production, the specific conditions will clearly be decisive. These figures also do not distinguish according to feedstocks and refining methods. That is, we do not know from these figures whether the electricity production is generating reductions in CO_2 emissions relative to burning fossil fuels. This fact underscores further the need to examine the specific conditions involved in each bioenergy electricity project.

Table 3.5: Biomass: Estimated levelized costs of electricity (LCOE) generation in non-OECD countries/regions, 2011

Estimates are in 2011 dollars; figures are cents per kilowatt hour (kWh)

	Average	Range
Africa	5	2-20
China	6	2-10
Other Asia	6	2-17
India	5	1-20
Latin America	5	3-18

Source: International Renewable Energy Agency (2013), “Renewable Power Generation Costs in 2012: An Overview,” Figure 8.5 and underlying IRENA cost database.

Geothermal. Unlike with the other renewable electricity sources, IRENA does not report on geothermal-powered electricity costs on a region-by-region basis. They also do not provide a range of estimated costs. They do give figures on average costs for projects in four countries - Chile, Indonesia, Kenya and the Philippines. They show figures for projects ranging in size between about 30 megawatts up to 240 megawatts. These cost figures range between a low of about 3 cents per kWh for projects at about 60 and 125 megawatts to a high of 6.5 cents for projects of about 240 megawatts. This clearly is a very limited sample. But it does show that, under favorable conditions, geothermal-powered electricity can be produced at low costs in non-OECD countries.

Renewable Electricity Costs in the United States

As a comparison with the IRENA renewable electricity cost data for non-OECD countries, it will be useful to examine comparable figures for the U.S. economy. We present such figures in Table 3.6 for biomass/biofuels, onshore wind, large-scale hydro, solar PV, and geothermal energy. The first column of this table shows the reference case levelized electricity costs estimated by the EIA for projects coming online as of 2017, including both the average costs and the estimated cost range, with the range of estimates in parenthesis. Column 2 of Table 3.6 shows the EIA's "Low Renewable Technology Cost case" for 2035. In this case, the EIA assumes that costs fall by 40 percent for all renewable sources other than hydro. The EIA assumes hydro costs remain fixed at their reference case, even while other renewable costs are falling by 40 percent. For purposes of direct comparison, in column 3, we show the midpoint of the average levelized cost figures for the various non-OECD regions for all five renewable energy sources.

Table 3.6: U.S. renewable energy costs: Estimated levelized costs of electricity (LCOE) generation, 2011

Figures are current cents per kilowatt hour (kWh); figures in parenthesis are cost range

	Average reference case for 2017	Low Renewable Technology Cost case for 2035	Midpoint 2011 costs for non-OECD regions
Biomass/biofuels	11.6 (9.8-13.7)	6.9	5.5
Onshore wind	9.6 (7.7-11.2)	5.8	9
Large-scale hydro	8.9 (5.8-14.7)	8.9	8.5
Solar PV	15.3 (11.9-23.9)	9.2	22
Geothermal	9.8 (8.4-11.2)	5.9	4.5

Sources: Authors' calculations based on U.S. Energy Information Administration (2012c), "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2012", Tables 1 and 2; U.S. Energy Information Administration (2012b) "Assumptions to the Annual Energy Outlook 2012."

The key finding here is that that the cost figures for the non-OECD countries are comparable to, if not generally somewhat lower than those for the U.S. This is despite the fact that the non-OECD figures are for 2011 while the U.S. figures are for 2017 in the reference case and 2035 in the low renewable technology cost case. Thus, with bioenergy, the non-OECD midpoint average, at 5.5 cents, is lower than the low-point reference case figure for the U.S, at 9.8 cents. The non-OECD figure is also lower than the 2035 low-cost U.S. figure, at 6.9 cents. With geothermal energy as well, the non-OECD mid-point figure, at 4.5 cents is below even the low-cost case for 2035 for the U.S. By contrast, the figures for wind and hydro are roughly comparable between the U.S. reference case and the non-OECD midpoint average. Solar PV is the only case where the non-OECD midpoint average cost figure, at 22 cents is high relative to the U.S. In this case, the non-OECD figure is at parity with the high-end figure for the U.S. 2017 reference case.

Broadly speaking, these figures show that the costs of generating electricity from renewable sources in the non-OECD countries are within close range of the U.S. cost figures. As regards the U.S. cost estimates, it is also crucial to note that, even with the reference case figures for 2017, these costs are at rough parity with those for most non-renewable energy sources. We can see this in Table 3.7, which reports the EIA's 2017 reference case figures for electricity generated by coal, natural gas and nuclear power, and compares those cost figures with those for hydro, wind, and biomass. The EIA's figures for coal and natural gas are presented in two ways - through conventional production methods and through using CCS technologies to reduce the CO_2 emissions generated by burning coal or natural gas.

Table 3.7: U.S. energy costs: Estimated average levelized costs of renewables vs. fossil fuels and nuclear for plants entering service, 2017

	Average total system levelized costs (2010 dollars/mWh)	**Average costs relative to hydro (percent)**	**Average costs relative to wind (percent)**	**Average costs relative to biomass (percent)**
Conventional coal	$97.7	+11.0%	+1.8%	-15.7%
Advanced coal with CCS	$138.8	+57.7%	+44.6%	+19.8%
Natural gas - conventional combined cycle	$66.1	-24.9%	-45.2%	-43.0%
Natural gas - advanced combined cycle with CCS	$90.1	+2.4%	-6.2%	-22.3%
Advanced nuclear	$111.4	+26.3%	+15.8%	-4.1%

Source: Authors' calculations based on U.S. Energy Information Administration (2012c), "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2012."

As the table shows, the EIA estimates that, in terms of average costs, hydro, wind, and biomass are all competitive with four of the five nonrenewable energy sources shown - conventional coal, coal with CCS, natural gas with CCS, and nuclear. As of 2010, conventional coal was the most significant source of electricity in the U.S., generating about 48 percent of total U.S. supply. Nuclear power generated another 21 percent of total supply as of 2010. In combination then, conventional coal and nuclear power were responsible for generating nearly 70 percent of all U.S. electricity in 2010.[22] It is therefore notable that the EIA is projecting that, in terms of average costs, hydro, wind and biomass will all be fully competitive with coal plants operating in 2017. In addition, the EIA is projecting that the average costs for hydro and onshore wind will both be significantly lower than those for average nuclear power plants operating in 2017. The EIA projects that the average costs for biomass will be only four percent more expensive that the average for nuclear power.

According to the EIA's estimates, conventionally produced natural gas is the only nonrenewable energy source included that is consistently less expensive to produce than renewables. But these low cost figures for conventional natural gas result from an assumption of growing reliance on hydraulic fracturing technology for extracting natural gas from shale rock deposits. Beyond the matter of CO_2 emissions from burning natural gas, we have discussed the serious environmental problems around hydraulic fracturing technology in Chapter 2. We also discussed

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[22] Authors' calculations based on statistics from EIA (2013d), Table 1.2.

in Chapter 2 the equally serious problems in developing CCS technologies on a large scale.

Overall then, the EIA's own official estimates on levelized electricity costs suggest that the renewable electricity sector in the U.S. is likely to become fully competitive with non-renewable electricity in a matter of a few years. This finding is consistent with the results for the non-OECD countries as reported by IRENA.

At the same time, these figures do not mean that all renewable sources will be equally cost competitive within all regions of the world. We have rather seen that costs vary widely among renewable sources by region. We have also seen that in the case of solar energy, the most promising long-term renewable energy source, costs are still unlikely to be competitive in the near future under most conditions. Nevertheless, overall, what these figures show is that in most regions there will be some combination of renewable energy sources that can generate electricity at competitive costs.

Comparative Costs after Incorporating Environmental Impacts

CCS Costs and Carbon Pricing

In addition to the comparative cost results summarized above, it is also the case that renewables would become still more competitive with non-renewables if the market prices of non-renewables incorporated some reasonable measure of the environmental costs generated through producing energy from these sources.

One way in which we can obtain a range of estimates as to the effects of incorporating these environmental costs into fossil fuel prices is to consider the cost effects of utilizing CCS technologies in fossil fuel prices. As we saw in Table 3.7, the EIA estimates that total levelized costs rise by 42 percent when CCS technology is applied to coal-fired electricity generation (from $97.7 to $138.8 per megawatt hour), and by 37 percent when CCS is used with natural gas electricity generation (from $66.1 to $90.1 per megawatt hour). It would be reasonable to assume that utilizing CCS technology in oil production would generate a roughly equivalent level of cost increases - i.e. between 35 and 40 percent.

We can get a second perspective by considering estimates as to the impact on fossil fuel prices of either a carbon cap or carbon tax policy approach to putting a price on carbon emissions. In their 2011 edition of the *Annual Energy* Outlook, the EIA developed scenarios for both 2025 and 2035 which they term their "GHG Price" case. Under these scenarios, the price of carbon emissions begins at $25 per metric ton in 2013 and rises to $75 per ton of CO_2 as of 2035. However, the EIA estimates that this policy will not raise the price of crude oil *at all* relative to their Reference case, either in 2025 or 2035. Indeed, the EIA reports that oil prices decline modestly in both 2025 and 2035 in their GHG Price scenarios. The EIA does not provide an explanation for this counterintuitive result.[23]

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[23] The relevant figures are in the first two rows of Table D.18, p. 200 in EIA (2011).

An alternative scenario for carbon prices as of 2035 is presented in the IEA's 450/Low Carbon case that we described in Chapter 1. Under this 450/Low Carbon case, the IEA assumes that the price on carbon "reaches $125 per ton of carbon in most OECD countries in 2035." This IEA scenario also allows that "several non-OECD countries are assumed to put in place cap-and-trade schemes to limit CO_2 emissions," (IEA, 2013b, p. 42). However, at least in their published documents, the IEA does not provide an estimate as to what the impact of this scenario would be on global fossil fuel prices.

It will be useful to provide some additional perspective as to the impact of carbon pricing on overall fossil fuel prices. This is especially the case, given that the IEA provides no estimates for price effects within their 450/Low Carbon case, and that the EIA reports the highly unlikely result that carbon prices of $25 per ton as of 2013 and $75 per ton as of 2035 will generate lower crude oil prices in both 2025 and 2035. One simple alternative approach is to assume a straightforward mark-up framework, at least as a first approximation. This would assume that the cost and price increases on fossil fuels from the carbon price policy would follow proportionally from both the stipulated level of the given carbon price policy - such as $75 per ton under the EIA's 2035 scenario and $125 per ton under the IEA's 450/Low Carbon scenario - and the amount of CO_2 emissions generated by oil, coal or natural gas.

For example, within the framework of a $75 per ton carbon price, as with the EIA's 2035 model, we would simply calculate the number of tons of carbon that are emitted by burning a given amount of oil, coal, or natural gas. Once we know that figure, we then assume that the $75 per ton in carbon pricing would be fully passed through and incorporated in the market prices of oil, coal, or natural gas.

We have performed this simple set of calculations within the framework of the EIA's 2035 Reference Case. That is, we use the EIA's Reference Case estimates for the average market prices of crude oil, coal, and natural gas in 2035. We then use figures on the amounts of CO_2 that are emitted through burning oil, coal and natural gas. For this, we draw on the figures we reported in Table 2.2, showing that CO_2 emissions per Q-BTU were about 69 mmt for oil, 100 mmt for coal, and 56 mmt for natural gas.

In Table 3.8, we present our estimates of this carbon price policy using this approach.[24] As Table 3.8 shows, the impact of the $75 per ton carbon price will range widely between the market prices of oil, coal, and natural gas. As we see, the approximate average crude oil price will rise by about 21 percent, from $140 to $170 per barrel. This is a significant percentage increase, but it is far below those for coal and natural gas. The coal price would rise by 250 percent, by $7.50 to $10.50 per 1 M-BTUs. The natural gas price would rise by about 64 percent, by $7 to $11.50 per 1 M-BTUs.

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[24] We present the details of these calculations in Appendix 1.

Table 3.8: Estimating fossil fuel price increases through carbon pricing

Estimates based on:

- *Carbon emissions per Q-BTU reported in Table 2.2*
- *EIA's 2035 carbon price of $75 per ton*
- *EIA's 2035 Reference Case prices for oil, coal, and natural gas*
- *Simple mark-ups of carbon-price cost increases on fossil fuel prices*

	Approximate CO_2 emissions levels	**Approximate average EIA 2035 reference case fossil fuel prices**	**Fossil fuel cost mark-up with 75 dollars per ton carbon price**	**Average fossil fuel prices after 75 dollars per ton carbon price mark-up**	**Percentage fossil fuel price changes after carbon price mark-up**
Oil	69 mmt per Q-BTU	$140 per barrel	$30 per barrel	$170 per barrel	21.4%
		(= $48 per 1 M-BTUs)	*(= $10 per 1 M-BTUs)*	*(= $58 per 1 M-BTUs)*	
Coal	100 mmt per Q-BTU	$3 per 1 M-BTUs	$7.50 per 1 M-BTUs	$10.50 per 1 M-BTUs	250.0%
Natural gas	56 mmt per Q-BTU	$7 per 1 M-BTUs	$4.50 per 1 M-BTUs	$11.50 per 1 M-BTUs	64.3%

Sources: See Table 2.2 and Appendix 1.

Two factors influence these percentage changes. The first, of course, is the level of CO_2 emissions generated by the respective fossil fuel energy sources. But the second is the initial pricing levels for the respective energy sources. Thus, per 1 M-BTUs, the EIA's 2035 Reference Case coal price is about 40 percent lower than that for natural gas, at $3 versus $7 respectively per 1 M-BTUs. As such, when we impose the carbon price on coal, the percentage impact is greater because the initial price is lower. Note further that, even with coal prices rising much more than natural gas percentage-wise, the price level for coal, at $10.50 per 1 M-BTUs, remains lower than the $11.50 per 1 M-BTUs price for natural gas. As for comparative oil prices, Table 3.8 first reports oil prices per barrels of oil rather than per 1 M-BTUs, but we also then convert these figures onto a per 1 M-BTUs basis. As Table 3.8 shows, as converted, the 2035 oil price with a $75 per ton carbon price is $58 per 1 M-BTUs. Therefore, on a per 1 M-BTUs of energy basis, the price of coal in 2035 would still be only 18 percent that for oil while operating in the framework of a $75 per ton carbon price.

Renewables vs. Fossil Fuel Costs with CCS or Carbon Pricing

As we have already reviewed earlier in this chapter, the average costs for generating electricity through onshore wind, biomass, hydro and geothermal power are already either at, or at least rapidly approaching, cost parity with fossil fuels and nuclear power, even prior to taking account of the environmental costs tied to non-renewables. Solar power is consistently more expensive, but its costs are also coming down most rapidly. Once we then also take account of the environmental costs of burning fossil fuels through either a carbon price in the range of $75 per ton (the EIA 2035 price) or $125 per ton (the IEA's 2035 price), or requiring the use of CCS technologies, most renewable costs will become significantly less expensive than fossil fuels and nuclear power under average conditions.

We have also seen that the cost ranges by region for renewables are wider than those for fossil fuels. However, as we have estimated, even with the lower EIA $75 per ton carbon price as of 2035 (as opposed to the EIA's $125 per ton price), the market prices for fossil fuels could increase by amounts up to about 20 percent for oil, 60 percent for natural gas, and 250 percent for coal. Under such circumstances, most renewable prices would become cheaper than fossil fuel energy even in regions where renewable prices are at the higher ends of their range.

Even if we assume that solar energy prices will decline only incrementally over the next 20 years, solar would also still reach approximate cost parity with fossil fuels under average conditions within a policy framework that includes a $75 per ton carbon price. Of course, the relative gains from solar would become sharper still if the carbon price is at $125 per ton.

For reasons that we discuss in Chapter 2, it is neither likely nor desirable that CCS technologies be relied upon as the means of controlling the environmental costs of burning fossil fuels. Still, as we have seen, the EIA estimates that operating with CCS technologies would raise levelized fossil fuel production costs by about 35-40 percent in the production of electricity. This would also push most fossil fuel costs above those for renewables.

Overall though, the most effective approach for incorporating the environmental costs into fossil fuel prices will be to establish carbon pricing. With the global economy operating under a carbon pricing framework, the result will be to substantially accelerate the process whereby, in all regions of the world, the full range of clean renewable energy sources become cost competitive, if not less expensive, than fossil fuels and nuclear power.

Capital Expenditures for U.S. Renewable Energy Investments

Given the similar range in total costs of producing electricity from renewable energy sources between the non-OECD countries and the U.S., the U.S. figures from the EIA on capital expenditures provide a useful benchmark for assessing the capital costs in other countries as well. We present these data in Table 3.9. These EIA figures are especially useful for this report, since we do not have consistent capital expenditure figures broken out for Brazil, Germany, Indonesia, South Africa, and the ROK. We can however use the U.S. capital expenditure figures for providing a reasonable cost range in our five selected countries. We emphasize that we are not suggesting that these U.S.-based cost figures will necessarily be accurate for specific settings within each of the five selected countries. For example, these figures are, if anything, probably too high for Indonesia, Brazil, and South Africa, where labor costs will be much lower than the U.S. Nevertheless, our approach is precisely to err, if anything, on overestimating the renewable energy investment costs in any given country setting, rather than underestimating these costs. As such, we will work from these figures in our country-by-country discussions as to how much new capacity could be produced if these countries devote roughly 1 percent of GDP per year to investments in clean renewables.

Table 3.9: U.S. capital expenditure costs for building renewable electricity capacity

Figures are present values of total capital costs; $1 per mWh = ($1 billion/3.42 Q-BTUs).

	2017 Reference Case			**2035 Low Cost Technology Case** *Assumes 40 percent cost reduction except for hydro*		
	1) Costs per mWh	**2) Costs per Q- BTU**	**3) Average costs over 20-year cycle per Q-BTU**	**4) Costs per mWh**	**5) Costs per Q- BTU**	**6) Average costs over 20-year cycle per Q- BTU**
	(dollars)	*(Billion dollars)*		*(dollars)*	*(Billion dollars)*	
Bioenergy	$709	$207 billion	$10.4 billion	$425	$124 billion	$6.2 billion
Hydro	$974	$284 billion	$14.2 billion	Same as reference case		
Onshore Wind	$1,035	$306 billion	$15.3 billion	$621	$183 billion	$9.1 billion
Solar PV	$1,782	$521 billion	$26.1 billion	$1,069	$312 billion	$15.6 billion
Geothermal	$974	$285 billion	$14.2 billion	$584	$167 billion	$8.3 billion

Source: Authors' calculations based on U.S. Energy Information Administration (2012b), "Assumptions to the Annual Energy Outlook 2012."

Working first with the EIA reference case estimates for 2017, column 1 of Table 3.9 shows the present value of total lump-sum capital expenditures to produce one megawatt hour of additional electricity-generating capacity from alternative renewable energy sources. In column 2, we convert the units of the present value figures from megawatt hours into a lump sum of billions of dollars per Q-BTU of new electricity-generating capacity. Column 3 presents these same reference case figures as an annual average level of investment per year over 20 years, as expressed in Q-BTUs of capacity. In columns 4-6, we present the same set of figures, except that we now operate under the EIA's low technology cost assumptions for 2035. As noted above, the EIA's Low Renewable Technology Cost case assumes that the levelized costs for hydropower do not decline at all relative to its Reference case.

These figures show that, in the EIA's Reference case, the present value of capital expenditures for renewable investments range between $207 billon per Q-BTU with bioenergy to $521 with solar PV. Spanning over a 20-year investment period, this amounts to between $10.4 and $26.1 billion per year. Moving to the Low Renewable Technology Cost case, the range is between $124 and $312 billion per Q-BTU, which amounts to between $6.2 and $27.7 billion per year for 20 years.

When we move into examining the cases of Brazil, Germany, Indonesia, South Africa and the ROK, we will use these capital expenditure figures to consider both how much renewable energy capacity can be produced through an investment strategy in the range of 1 percent of GDP per year. We will then estimate how many jobs will be generated through this investment strategy.

These capital expenditure figures are especially important for our efforts at estimating the employment-generating impacts in each of our five countries of expanding their renewable energy sectors. As we have discussed at the outset, we are organizing our discussions on employment impacts on the assumption that each of our selected countries will pursue an investment project in expanding their renewable energy capacity at around 1 percent of the country's GDP per year.

Bioenergy, CO2 Emissions and Food Prices

Emissions Control

The term "biomass," as described by the U.S. Environmental Protection Agency (EPA) describes "many different fuel types from such sources as trees, construction, wood, and agricultural wastes; fuel crops; sewage sludge; and manure. Agricultural wastes include materials such as corn husks, rice hulls, peanut shells, grass clippings, and leaves."[25] Biomass can be converted into energy in either solid, liquid or gas form. A biomass energy source converted into liquid form is a biofuel.

Based on the feedstock used and the refining technology, biomass/biofuels energy sources vary greatly in their emission levels. We see this in Table 3.10 with respect to biofuels. The table reports on the level of GHG emissions for five types of ethanol as well as one biodiesel energy source relative to emissions from gasoline or diesel fuel used in 2005[26]

Table 3.10: Percentage emissions levels reductions over 30-year cycle relative to gasoline or diesel fuel over 30-year cycle

Corn ethanol	+34%
Refined through coal-fired processing	
Corn ethanol	-26%
Refined through biomass-fired processing with combined heat and power	
Sugercane ethanol	-26%
Waste grease biodiesel	-80%
Corn stover ethanol	-116%
Switchgrass ethanol	-124%

Source: U.S. Environmental Protection Agency. 2009, May. "EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels."

Starting with corn ethanol refined through coal-firing, we see that, over a 30-year cycle, the overall level of GHG emissions - incorporating all stages in production, from growing crops, refining, and burning the fuel to generate energy - actually generates 34 percent higher emissions levels relative to burning gasoline. But corn ethanol can also produce lower emission levels than gasoline if it is refined through a biomass-fired refining process. However, even in this case, the emissions reductions compared with gasoline are relatively modest, at about 26 percent over a 30-year cycle. The emissions reductions are also about 26% lower than gasoline when burning sugarcane-based ethanol.

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[25] "Non-Hydroelectric Renewable Energy," EIA (2013e).

[26] EPA (2009) includes a fuller listing than those shown in Table 3.5 and also includes emission figures over a 100-year cycle in addition to the 30-year cycle shown in the table here.

As is clear from Table 3.10, the way to achieve major emission reductions is through burning waste grease biodiesel fuel, or even more so, corn stover or switchgrass-based ethanol. This is because with either waste grease or corn stover, there are no production costs, including energy consumption, required to supply the bioenergy raw material. With switchgrass as the raw material, the production costs - including energy consumption requirements - are minimal. Even when including the refining and energy-generating processes, the EPA study finds that, netting out everything, these fuel sources achieve reduced emission levels.

More generally, according to the Union of Concerned Scientists (2010) bioenergy sources can be considered part of the terrestrial carbon cycle - the balanced cycling of carbon from the atmosphere into plants and then into soils and the atmosphere during plant decay. When bioenergy is developed properly, emissions of biomass carbon are taken up or recycled by subsequent plant growth with a relatively short time, resulting in low net carbon emissions. As such, the Union of Concerned Scientists includes the following as clean, or what they term "beneficial" biomass resources:

1. Energy crops that do not compete with food crops for land;

2. Portions of crop residues such as wheat straw or corn stover;

3. Sustainably-harvested wood and forest residues; and

4. Clean municipal and industrial wastes.

The Union of Concerned Scientists contrasts these with "harmful biomass resources and practices." These harmful resources and practices include clearing forests, savannas or grasslands to grow energy crops, and displacing food production for bioenergy production that ultimately leads to the clearing of carbon-rich ecosystems elsewhere to grow food. They write that "harmful biomass adds net carbon to the atmosphere by either directly or indirectly decreasing the overall amount of carbon stored in plants and soils."

At present, as mentioned above, the proportion of bioenergy generated through clean processes is negligible outside of Brazil. But the potential is high for a major expansion in these energy sources. Thus, a 2009 study by the U.S. National Academy of Sciences (NAS) estimated that by 2020, 550 tons of biomass could be sustainably harvested to produce cellulosic and other advanced biofuels - that is bioenergy exclusive of that derived from corn ethanol or other heavy carbon-emitting sources. This study further estimates that this supply of biomass could produce 45 billion gallons of ethanol in the U.S. This translates into 6.4 Q-BTUs of energy from "clean" biofuels. The prospects for a major expansion in clean bioenergy should be comparable in other countries as well.

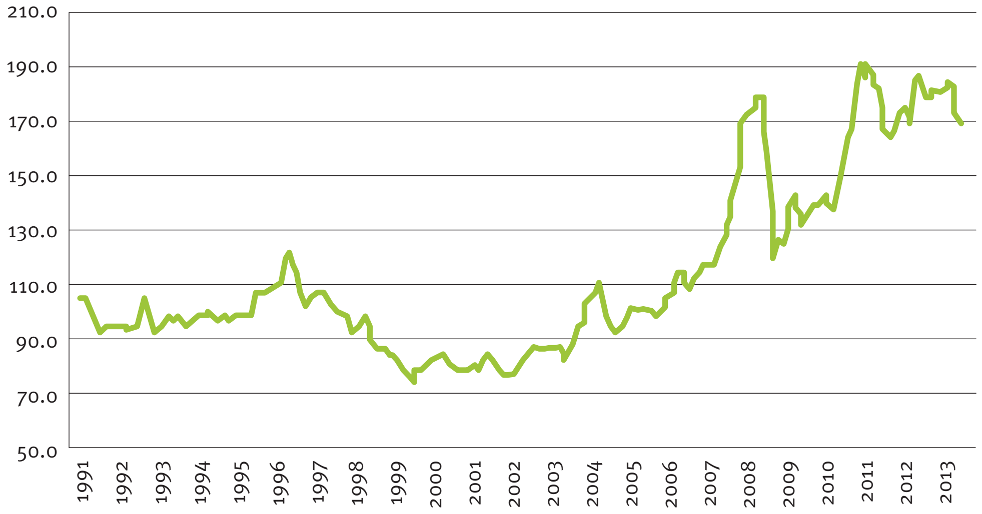
Will Expanding Bioenergy Production Raise Food Prices?

One major concern raised about a rapid expansion of bioenergy production is that it will raise food prices with an adverse impact on low-income and poor families. The manufacture of bioenergy uses agricultural products as basic inputs and large increases in the production of bioenergy will increase the demand for agricultural output and divert production away from food and towards non-food bioenergy production. The potential problem is that this rapid growth in bioenergy demand will translate into higher prices for food (Sexton et al., 2008).

The possibility that bioenergy production could be responsible for rising food prices became a growing concern with the increase in global agricultural commodity prices, which began around 2004. Figure 3.2 below documents the movement of global food prices from 1991-September 2013. As the figure shows, the most intense period of the global economic crisis - from the second half of 2008 through 2009 - interrupted the upward trend in food commodity prices, but, by 2011, the prices of many food commodities had rebounded to around their pre-crisis peaks (Abbott, Hurt and Tyner, 2011). This was also a period in which production of bioenergy surged. In particular, world biofuel production, as a liquid energy source, grew five-fold between 2001 and 2011, with the most rapid increases occurring in 2007/8 - the peak of the food price hikes (HLPE, 2013). The fact that the growth in biofuels production corresponded with the increase in agricultural commodity prices raised questions of whether biofuels were responsible for high food prices.

Figure 3.2: Food commodity price index, January 1991-September 2013

Food commodity price index, International Monetary Fund, Jan. 1991 to Sept. 2013 (2005 = 100).



Source: Authors' presentaiton based on the IMF Food Price Index downloaded from http://www.imf.org/external/np/res/commod/External_Data.xl.

Note: 2005=100.

Those who argue that bioenergy production is the primary reason behind rising food prices see rising demand for agricultural goods as the primary force behind increasing prices. Specifically, they point out that production of bioenergy accounts for a large share of the *increase* in overall agricultural production and present this as evidence that demand for food grains outstrips supply (Wilkinson et al., 2013). However, the precise nature of the link between biofuel production and food prices remains unsettled. Many factors contributed to the increase in food prices over this period. The growing production of and the growing supply of bioenergy was not likely to have been a major contributor (Sexton et al., 2008; Trostle et al., 2011). Other considerations include the large-scale entry of financial investors into commodity futures markets, changes in the U.S. dollar exchange rate, and shocks to agricultural production from droughts and other extreme weather events (Baffes and Haniotis, 2010; Trostle et al., 2011; Wilkinson et al., 2013).

During the period in which food prices soared, other commodity prices experienced similar increases. This includes commodities having little connection to bioenergy, such as metals. This suggests that a common factor that operates across diverse markets drove up prices - e.g. speculative investment in a range of commodity futures (Gilbert, 2010). Biofuels production does not fit this description. A study of commodity price increases over this period by World Bank researchers concludes that the expansion of bioenergy played a modest role in raising food prices, but other factors were more important (Baffes and Haniotis, 2010). This same report notes that “biofuels account for only about 1.5 percent of the agricultural area under grains/oilseeds cultivation” (p. 12). Other studies find little evidence of a connection between biofuel production and the increases in food prices over this period (Gilbert, 2010). The fact that food prices fell after the 2008 global financial crisis while biofuels production continued to increase further suggests that biofuels are not the dominant drivers of food prices (Trostle et al., 2011). To the extent that there is an emerging consensus, it appears to be that the expansion of biofuels had some impact on food prices, but that other factors were likely more important in explaining the kind of price increases experienced from 2004 to 2008.

Studies of the impact on future food commodity prices of policies to promote the production of biofuels reach similar conclusions. A 2012 report from the Institute for European Environmental Policy reviewed research that modeled the impact of biofuel mandates, both within the European Union and globally, on commodity prices (Kretschmer, Bowyer and Buckwell, 2012). With regard to global and multi-regional mandates, the report found that the prediction of price increases varied widely and depended on the modeling approach used, with food commodity prices increasing between 1 and 35 percent. Even considering the higher predicted food price increases, the review concludes “the price changes projected into the future found in the studies reviewed here are all positive, but not massive, especially in comparison to the recently experienced global commodity price spikes,” (p. 49). The promotion of bioenergy production in the future will likely have a positive impact on food prices. But again, this impact will likely be modest.

It is also important to recognize that, up to this point in time, the growth of biofuels as a liquid energy source has largely been a response to high prices of gasoline, not to issues of sustainability and climate change (HLPE 2013). Increased biofuels production reduced the cost of gasoline (Sexton et al., 2008). Ironically, the growth in biofuels likely reinforced the use of fossil fuels by keeping gasoline prices low and thereby reducing incentives to develop cleaner alternatives. Higher gasoline prices make biofuels production more profitable, encouraging its expansion. Some point to rising fuel prices as an important factor in the surge in food prices. This is because high fossil fuel prices encourage the production of biofuels, which, in turn, may impact food prices (Wilkinson et al., 2013).

New bioenergy technologies have the potential of both reducing the threat of climate change and addressing concerns over food security. For instance, clean bioenergy sources, as we have discussed above, would help improve food security through making a major contribution toward the reduction of CO_2 emissions (Sexton et al., 2008). At the same time, as has been shown in this report, the development of viable clean biofuels will make a substantial contribution to reducing GHG emissions. What is needed is a new approach to bioenergy policy that jointly emphasizes environmental sustainability and food security. The more comprehensive approach would include land use policy, support for developing new technologies, research to raise agricultural yields, and strategies for confronting the primary threats to food security. By designing policies to encourage technological innovations, raising agricultural productivity, and promoting biofuels that have a smaller impact on food crops, the effects on food prices will be minimized. We discuss these policy issues further in Chapters 8 and 9, when we take up these issues specifically with respect to Brazil and Germany. Especially in Germany, major initiatives are already underway for developing an effective clean bioenergy sector.

Furthermore, increases in commodity prices do not translate into a one-to-one increase in the food prices that consumers pay. Overall food prices depend on the food processing and distribution system in place. In high-income countries, such as the U.S., commodity prices only account for about 15 percent of the overall price of food. Therefore, a doubling of commodity prices may result in a much smaller increase in food prices. For developing countries, the relationship between commodity prices and food prices can be much more direct. The difference in price effects should be taken into account when thinking about global approaches to jointly addressing climate change, poverty, and hunger. Income support policies (e.g. cash transfer schemes and related strategies) can be important complementary policies to off-set the impact of higher food prices on the poor.

It is also essential to note that food price increases have been associated with extreme weather events and climate change has the potential to emerge as a significant contributor to food insecurity and rising food prices in the future (Carty, 2012; Commission on Sustainable Agriculture and Climate Change, 2012; Nelson and Olofinbiyi, 2012). Therefore, strategies, which aim to stabilize food prices and improve food security, must focus on reducing GHG emissions and directly address climate change. Switching to clean biofuel technologies is a central part of an overall strategy to reduce emissions and, because of this, a well-designed biofuels policy will enhance, not undermine, food security in the long run.

Overall, we can conclude from the full range of evidence presented in this chapter that, in all regions of the world, there will almost certainly be some combination of clean renewable sources that can produce significant energy supplies at cost parity relative to non-renewables, either at present or within the next five years. Of course, this conclusion will be greatly supported if effective carbon pricing policies are in all regions of the world. Moreover, the process of lowering costs for clean renewables will only accelerate as the utilization of these technologies expands. As we noted at the outset of this chapter, the high technological learning rates, especially for solar energy, will generate major cost reductions. With solar PV modules, costs have been declining by as much as 22 percent for every doubling of installed capacity.

Despite these general trends, it is still also true that, to know which particular combination of clean renewable sources can be utilized efficiently in any given specific setting can be determined only within the context of that specific setting. Equally, establishing at what point clean renewables can effectively substitute *at scale* for non-renewables also requires an understanding of the specific resources available and broader economic circumstances within each region. As such, the on-the-ground decision makers within each region and country, such as the managers of grid systems, will have to examine all the relevant considerations as they move to expand renewable capacity and correspondingly reduce dependence on fossil fuels and nuclear power.

The global investment patterns for clean renewables have been generally positive in recent years. Thus, the 2014 edition of *Global Trends in Renewable Energy Investments* (Frankfurt School-UNEP Collaborating Center, 2014) reports, among its other findings, that:

- Renewable energy excluding large hydro made up 43.6 percent of the new power capacity added in all technologies in 2013 (the same figure as 2012), and raised its share of total generation worldwide to 8.5 percent from 7.8 percent.

- Although investment in renewable energy capacity in 2013, including all hydro, was below gross investment in fossil-fuel power, at $227 billion compared to $270 billion, it was roughly double the net figure for investment in fossil-fuel power excluding replacement plant.

As we explore further in later chapters, annual global clean renewable investments will need to rise well beyond $227 billion, which is equal to about 0.3 percent of 2013 global GDP. Rather, overall clean renewable investments will need to reach about 1 percent of global GDP, which would equal $870 billion for 2013 (with annual global energy efficiency investments rising to about 0.5 percent of global GDP). Still, investment levels within this range are rapidly becoming a realistic goal in virtually all country settings, in that clean renewable energy can be supplied at competitive costs and, as we will discuss below, the investments to build and operate the capacity will generally be a significant net new source of job opportunities.

CHAPTER 4: PROSPECTS FOR ENERGY EFFICIENCY

Significantly raising energy efficiency levels for all countries, at all levels of development, is necessarily one of the two cornerstones of the global green growth project, along with clean renewable energy investments.

It is important to clarify the distinction between *energy conservation* and *energy efficiency*. Energy conservation entails reducing the amount of economic activity that requires the consumption of energy. Some examples of energy conservation are using machine-powered heating and cooling systems less in buildings, traveling fewer miles, and relying less on energy-powered machinery in industrial processes.

By contrast, energy efficiency entails using less energy to achieve the same, or even higher, levels of energy services from the adoption of improved technologies and practices. The IEA's 2013 *Energy Efficiency Market Report* describes the market for energy efficiency as follows:

> *The cost-effective supply of energy efficiency can be defined as the investment opportunities for which the sum of the benefits, stemming from avoided energy consumption, outweighs the investment costs….The energy that is not consumed as a result of energy efficiency measures, whether it is a barrel of oil, cubic metre of gas, tonne of coal or terawatt hour of electricity, is described in terms of the physical energy quantities avoided. This important notion of how energy efficiency can directly substitute, and be equated with, supply-side commodities is central to conceptualizing the supply of energy efficiency….Energy efficiency is a domestically produced energy resource, for which the market is often local. Like other energy markets, its equipment and infrastructure may be imported, but avoiding ongoing fuel requirements can provide greater control over domestic energy supply (IEA, 2013c, p. 29).*

Energy conservation does have a role to play in reducing global CO_2 emissions and fighting climate change, given that, in particular, businesses, public institutions and upper-income households in advanced economies could readily reduce their energy-consuming activities without significantly affecting their mode of operations or living standards. But for the vast majority of the world's population, one of the central drivers of rising living standards will be to significantly enhance access to low-cost energy-based services, such as well-functioning modern buildings, convenient modes of transportation, and workplaces in which the use of energy-driven machinery raises productivity. This is why energy efficiency has to play a much more important role than energy conservation in the unified global project of controlling climate change while raising mass living standards.

What Are the Opportunities?

This central role for energy efficiency is widely understood. The World Bank researchers Ashok Sarkar and Jas Singh offer this overview:

> *Energy efficiency is rapidly becoming a critical policy tool around the world to help meet this substantial growth in energy demand. Evidence from the past 3-4 decades of experience around the world indicate that EE [energy efficiency] programs generally entail positive and multiple benefits for the government, energy consumers, and the environment. Such programs can: conserve natural resources; reduce the environmental pollution and carbon footprint of the energy sector; reduce a country's dependence on fossil fuels, thus enhancing its energy security; ease infrastructure bottlenecks and impacts of temporary power shortfalls; and improve industrial and commercial competiveness through reducing operating costs. In terms of project economics, EE options are seen as "no regrets" policies, since their net financial cost can be negative, i.e. the measures are justified purely based on high financial returns….Amongst the menu of feasible technical options currently available to help reduce the rate of growth of greenhouse gas emissions produced by the energy sector, EE technologies stand apart as the most cost-effective ones, as shown in numerous analyzes by various stakeholders, ranging from the Intergovernmental Panel on Climate Change (IPCC) to private sector practitioners such as the analyses done by McKinsey (Sarkar and Singh, 2010, p.5561).*

This perspective is also advanced in numerous other World Bank studies on climate change and building green economies in developing countries. For example, a 2008 analysis focusing on Brazil, China, and India by Taylor et al. argues as follows:

> *As a domestic measure that reduces reliance on imported energy, energy efficiency programs are typically a key part of national efforts to improve the security of future energy supply. Energy efficiency is favored in environmental improvement strategies because it reduces the need for energy development, transportation and distribution, onsite use, and all the associated environmental impacts. But perhaps the greatest attraction of many energy efficiency measures is their cost effectiveness. Cost vary among technologies and countries where energy efficiency measures are implemented, but often are only one-quarter to one-half the comparable costs of acquiring additional energy supply (Taylor et al., 2008, p. 28).*

The 2011 Industrial Development Report by UNIDO, *Industrial Energy Efficiency for Sustainable Wealth Creation*, focuses specifically and in detail on prospects for efficiency investments in the industrial sectors of developing countries. UNIDO summarizes the perspective of this study as follows:

> *Industrial development…must become sustainable. Continued high resource consumption and carbon-intensive and polluting technologies will sap the potential for growth and development. Innovative solutions, national and global, are vital to making industrial activity more sustainable - to attuning it to environmental and social needs. The "green industry" approach can provide the blueprint for sustained industrial development. Increasing industrial energy efficiency is a key foundation for green industry worldwide. By building on past successes, countries can develop their*

> *industries while tempering the impacts on resource depletion and climate change (UNIDO, 2011, p. 23).*

Among its research findings, this UNIDO study presents results of a survey of 357 industrial firms in developing countries, whose purpose was to better understand the decisions of these firms on investing in energy efficiency projects. The total level of efficiency investments for the surveyed firms was $614 million, with individual projects ranging from as low as $100 up to $73 million. The types of investments included direct equipment replacements; waste reuse; residual temperature reuse; pipes and insulation improvements; better use of infrastructure; and fuel optimization.

The UNIDO researchers were able to assess the financial viability of these projects through their survey findings. They found that, in line with practice in developed countries, more than 90 percent of surveyed firms in the sample used simple payback rules to assess the financial viability of their investments. The surveyed firms approved projects only if they had a simple payback of no more than 2-3 years. The actual mean payback period for 119 projects with data was 23 months. The UNIDO researchers were able to generate more systematic internal rate of return (IRR) estimates as well for these projects. They found that the estimated mean IRR was 25 percent for projects with a three-year lifespan and no resale value. They also found that the mean IRR rose with each additional year of life, to 37 percent for four years, 43 percent for five years and 50 percent for 10 years. UNIDO concluded from these results that “these higher rates compare favorably with average returns in capital markets, which are typically lower over comparable timeframes,” (UNIDO, 2011, p. 78).[27]

Focusing now on the advanced economies, the overall prospects for these countries is that large-scale efficiency investments can produce significant reductions in their *absolute levels* of energy consumption. As with the developing countries, such gains in efficiency for advanced economies can be achieved without having to experience reduced GDP growth. This conclusion is expressed strongly, for example, in the major 2010 study by the U.S. National Academy of Sciences (NAS), *Real Prospects for Energy Efficiency in the United States.* Their overarching findings include the following observations:

> *Energy efficient technologies for residences and commercial buildings, transportation and industry exist today, are expected to be developed in the normal course of business, that could potentially save 30 percent of the energy used in the U.S. economy while also saving money. If energy prices are high enough to motivate investment in energy efficiency, or if public policies are put in place that have the same effect, U.S. energy use could be lower than business-as-usual projections by…17-20 percent in 2020 and 25-31 percent in 2030….The full deployment of cost-effective energy-efficient technologies in buildings alone could eliminate the need to add to U.S. electricity generation capacity (NAS, 2010, p. 4-5).*

To provide some details on the extent of energy savings available in the U.S. from specific investment areas, we show in Table 4.1 below the estimates of the National Academy of Sciences the NAS on the savings opportunities available just with electricity consumption in commercial U.S. buildings. As the table shows, the potential energy savings estimated by the NAS includes 25 percent for lighting systems, 48 percent for space cooling, 45 percent for ventilation, 39

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[27] More details on this survey are found in Alcorta et al. (2012).

percent for space heating and between 25-60 percent for office equipment usage. Overall, the NAS finds that savings as of 2030 could reach nearly 2 Q-BTUs just with electricity use in the commercial building sector. This would represent a 35 percent savings relative to the U.S. Energy Department's EIA's 2030 Business-as-Usual (BAU) assumptions - and, on its own, a fully 2 percent *absolute reduction* in overall U.S. energy consumption relative to current levels. Moreover, on average, the NAS estimates that the costs of achieving this level of savings would be 2.8 cents per kilowatt hour. As of 2013, average electricity costs for commercial buildings were 11 cents per kilowatt hour.

Table 4.1: Main sources of energy efficiency investments in U.S. commercial building electricity use

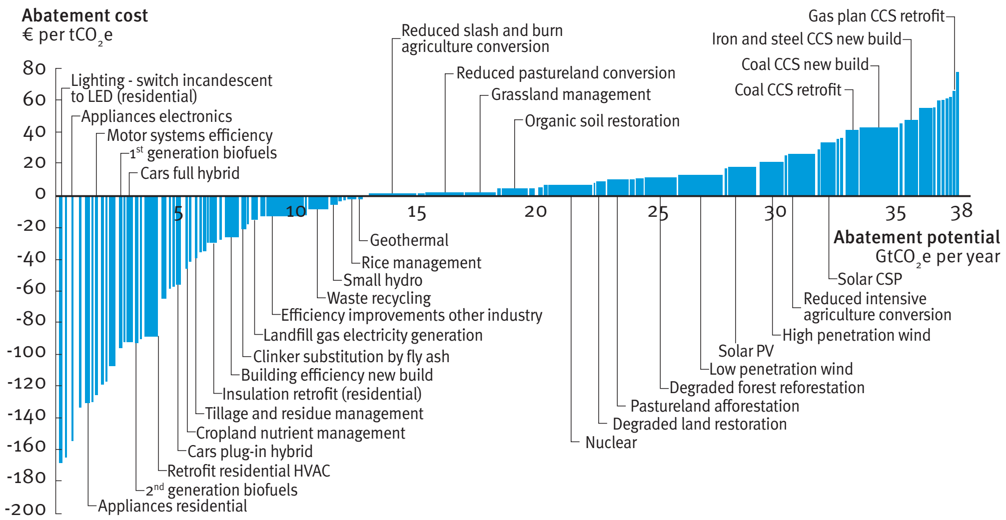
End use-electricity	Savings in Q-BTUs, 2030[a]	Savings relative to EIA reference case (percent)	Cost of conserved energy (cents per kWh in 2010 dollars)[b]
Lighting	0.47	25%	5.4
Space cooling	0.39	48%	2.9
Office equipment - PCs	0.24	60%	4.1
Office equipment - non PCs	0.23	25%	3.3
Ventilation	0.2	45%	0.5
Refrigeration	0.12	38%	1.4
Space heating	0.1	39%	0.5
Other uses and thermal shell	0.65	35%	1.5
Other	0.02	14%	4
Total	2.4 Q-BTUs	35%	2.8 cents per kilowatt hour

Source: Adapted by authors from Table 2.10 in NAS (2010) "Real Prospects for Energy Efficiency in the United States".

Notes: a) Calculated using AEO 2012 Reference case Table A4; b) Costs from Brown et al. (2008) were inflated using the GDP implicit price deflator (BEA 2012).

As noted by Sarkar and Singh above, the work by the business consulting firm McKinsey and Company are useful here. McKinsey estimates that, on a global scale, energy efficiency investments are the most cost-effective approach to reducing GHG emissions. McKinsey shows this most dramatically through their Global Greenhouse Gas Abatement Cost Curve, which we reproduce as Figure 4.1 below. As McKinsey's figure shows, there are large numbers of specific investment activities that can reduce GHG at negative costs. Virtually all of these are various sorts of efficiency investments. They include investments in lighting, consumer appliances and electronics, heating and air-conditioning systems, building insulation, electrical motors, hybrid automobiles, and waste recycling.

Figure 4.1: McKinsey Global Greenhouse Gas Abatement Cost Curve beyond BAU, 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Exhibit from "Impact of the Financial Crisis on Carbon Economics: Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve", 2010b, McKinsey & Company, www.mckinsey.com/. Reprinted by permission.

In a 2010 study, McKinsey researchers further argue that while the benefits of efficiency investments can be captured in all regions of the world and all countries, the largest benefits per dollar of expenditure are available in developing countries. Specifically, McKinsey estimates that, using existing technologies only, developing countries could realistically slow the growth of energy demand through 2020 by more than half - from 3.4 to 1.4 percent per year - without having to reduce GDP growth at the same time. McKinsey estimates that gains in energy efficiency would generate about $600 billion per year in savings on energy costs throughout the developing world by 2020 (McKinsey and Company, 2010a).

Of course, as we saw in Table 1.3 of Chapter 1, countries vary widely in their existing level of efficiency. Reviewing those figures from Table 1.3, the energy intensity ratio for the world as a whole is 7.1 Q-BTUs per $1 trillion GDP. Among the countries shown in the table, the intensity ratios range widely, from 4.1 for Germany to 14.6 per $1 trillion for South Africa - that is, the German economy is operating at a level of energy efficiency more than three times higher than that of South Africa. Brazil is the next most efficient in energy use, with an efficiency ratio at 5.1 per $1 trillion, while China is the second least efficient, with its ratio at 12.1 per $1 trillion.

The Indonesian ratio, at 6.8 is close to the global average of 7.1. But this is with the Indonesian economy operating at a GDP per capita level of $3,600. Indonesia is aiming to raise per capita GDP at rapid rates over the next 20 years. The challenge will be for the Indonesian economy to maintain healthy GDP growth while also significantly incorporating energy efficiency investments into their growth process. That would enable the economy to consume energy within a system that, for example, more closely resembles that of Brazil than South Africa.

At the same time, it is important to note that even in the case of Germany, the most energy-efficient large advanced economy in the world, there is a clear recognition that significant advances in efficiency are necessary and attainable at reasonable costs. Thus, the German federal government's official 2010 *Energy Concept* document sets as a goal a 20 percent decline in absolute energy consumption by 2020 and a 50 percent reduction by 2050 (BMUB, 2010). The *Concept* document places special emphasis on opportunities for energy savings in the economy's stock of buildings. As with most advanced economies, the operations of buildings are responsible for about 40 percent of all energy consumption. The BMUB's *Energy Concept* sets as the country's goal to be able to operate its entire building stock at virtually zero net emissions by 2050. This will entail significant up front investments in energy-efficiency technologies for buildings, including the thermal shell, as well as heating and cooling and lighting systems. But these investments are more than self-financing within a reasonable time frame, given the energy savings achieved through the up-front investments.

Estimating Costs of Efficiency Gains

Estimates as to the investment costs for achieving energy efficiency gains vary widely. In Table 4.2, we show summary estimates from three sets of studies. As we see, the 2008 World Bank study by Taylor et al. puts average costs at $1.9 billion per Q-BTU of energy savings, based on a study of 455 projects in both industrial and developing economies. The McKinsey study that we cited above estimates costs for a wide range of non-OECD economies at $11 billion per Q-BTU of energy savings. Focusing just on the U.S. economy, the U.S. National Academy of Sciences NAS estimated average costs for energy efficiency savings in the buildings and industrial sectors at about $29 billion per Q-BTU.

Table 4.2: Estimates of investment costs for energy efficiency gains

	Regions/countries estimated	**Estimated costs** *(dollars per ton of oil equivalent savings)*	**Estimated costs** *(billion dollars per Q-BTU of savings)*
World Bank (Taylor et al., 2008, p. 29)	455 projects in 11 industrial and developing countries	$76 per ton of oil equivalent (TOE)	$1.9 billion per Q-BTU *(conversion):* *1 Q-BTU =~25.2 million TOE*
McKinsey and Co. (2010, p. 27)	Africa, India, Middle East, South East Asia, Eastern Europe, China	-	$11 billion per Q-BTU
NAS (2010; as summarized in Pollin et al. 2014)	U.S.	-	~ $29 billion per Q-BTU for buildings, industry

It is not surprising that average costs to raise energy efficiency standards would be significantly higher in industrialized economies. As we will discuss further below, a high proportion of overall energy efficiency investments are labor costs, especially projects to retrofit buildings and industrial equipment. However, these wide differences in cost estimates are not simply resulting from variations in labor and other input costs by regions and levels of development. Thus, the World Bank estimate of $1.9 billion per Q-BTU includes both industrialized and developing countries, while the McKinsey $11 billion per Q-BTU estimate - nearly 6 times greater than the World Bank figure - is primarily coming from developing country projects.

These alternative studies do not provide sufficiently detailed methodological discussions that would enable us to identify the main factors generating these major differences in cost estimates. But it is at least reasonable to conclude from these figures that, with on the ground real-world projects, there are likely to be large variations in costs down to the project-by-project level. Thus, parallel to the situation with specific renewable energy projects that we discussed in Chapter 3, the costs for energy efficiency investments that will apply in any given situation will necessarily be specific to that situation, and must be always be analyzed on a case-by-case basis.[28]

At the same time, for the purposes of this report, we will need to proceed with some general rules-of-thumb for estimating the level of savings that are attainable through a typical set of efficiency projects in our five selected countries, as well as in other settings. A conservative approach will be to allow that, relative to the World Bank and U.S. National Academy of Sciences figures, the midrange cost estimate provided by McKinsey at $11 billion per Q-BTU of savings, is appropriate for low-and middle-income economies, including Brazil, Indonesia and South Africa. We will also assume that the cost figure for Germany will be equivalent to the National Academy of Sciences the estimate for the U.S., at around $30 billion per Q-BTU of savings. We then will also assume that the cost figure for the ROK is at an approximate midpoint between those two other figures, at around $20 billion per Q-BTU.[29]

In working with these cost figures, we should also emphasize again that, in all cases, the payback period for such energy efficiency investments are generally estimated to be relatively short - in most cases, less than three years for full payback.

Why Aren't Energy Consumers Picking Up Free Money?

The question that is often posed in evaluating opportunities for successful energy efficiency investments is straightforward: if such large opportunities for cost savings exist - independent of environmental benefits - then why are governments, businesses, and households failing to embrace them? This issue is addressed frequently in the literature.[30]

The first answer is that, to a considerable extent, efficiency investments have indeed been embraced over the past few decades. As a measure of this, Table 4.3 shows the change in aggregate energy efficiency from 1990-2011 for the world as a whole, for countries at different income levels, as well as for the U.S, China, and our five selected countries. As we see, for the world as a whole, energy efficiency improved by 31 percent between 1990 and 2011, an average annual rate of efficiency gains of 1.3 percent. The averages for low/middle- and high-income countries are both slightly higher than the world average. Among individual countries, China has achieved the largest efficiency gains, improving by 164.3 percent between 1990 and 2011. Among our selected countries, Germany has achieved the largest efficiency gains, improving by 54.2 percent between 1990 and 2011. Brazil and the ROK are the least successful performers here, showing little to no improvements in energy efficiency over this period. But in the case of

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[28] The survey research by Alcorta et al. (2012) on individual industrial efficiency projects in developing country does provide useful details on cost variations on a project-by-project basis.

[29] In our individual country analyses below, we will also provide more detailed evidence from individual country studies. In addition, a valuable resource for energy efficiency investment activity at the country-specific level is the IEA's 2013 *Energy Efficiency Market Report*, on which we will also draw in later sectors.

[30] These references include McKinsey & Company 2010a; Sakar and Singh (2010); World Bank (2006); World Energy Council (2013).

Brazil, we do need to remember that, as of 2011, it is nevertheless operating at a high *level* of efficiency, requiring only 5.1 Q-BTUs of energy to produce $1 trillion of GDP.[31]

Table 4.3: Change in energy efficiency levels, 1990–2011

Measured as GDP per dollar of energy consumption

	Change in efficiency over full period	Average annual change in efficiency
World	31.0%	1.3%
Low and middle income countries	39.4%	1.6%
High income countries	33.3%	1.4%
U.S.	42.9%	1.7%
China	164.3%	4.7%
Brazil	-2.6%	-0.1%
Germany	54.2%	2.1%
Indonesia	23.7%	1.0%
South Africa	12.9%	0.6%
ROK	1.9%	0.1%

Source: Authors' calculations based on World Bank (2014), "World Bank Indicators," Table 3.8: Energy dependency, efficiency, and carbon dioxide emissions.

Despite these steady and widespread gains in energy efficiency worldwide, it is nevertheless still the case, as we have reviewed above, that widespread opportunities for further large efficiency are still available. Why, then, are these equivalents of $50 bills lying on the sidewalk not being picked up?

The basic problem, as widely recognized in the literature, is that the estimates of large benefits that are attainable through efficiency investments are based on engineering evidence, such as the figures we have referred to above in this chapter. However, typically, such engineering-based evidence neglects other considerations that are significant, and can be decisive, in moving forward with energy efficiency investments. These other considerations include the following interrelated factors:

- ***Necessity to obtain investment financing.*** Even though energy efficiency investments have the potential to yield high returns and rapid paybacks, they still entail significant up-front financing commitments. If adequate financing structures are not available, the projects will not proceed.

- ***Perceptions of high risk.*** The general engineering evidence on gains from efficiency investments applies to a large range of investment projects, but does not necessarily apply to any single project. For any given project to proceed, the decision-makers need to be convinced that they specifically will receive the benefits that are available generally. This entails investors assuming risks. The perceptions of risk are higher when experiences with efficiency investments are not widely known or understood.

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[31] See Zhang et al. (2011) for a discussion of total factor energy efficiency.

- ***High transaction costs.*** Precisely because financing structures for efficiency investments are not generally well-developed and perceptions of risk are higher than actual risk levels in most cases, the transaction costs involved in bringing an efficiency investment to fruition are relatively high.

- ***Split incentives.*** This occurs when one entity would be responsible for making the energy efficiency investments but another entity pays the costs of consuming energy. This is most prevalent in non-owner occupied buildings, in which building owners are responsible for maintaining the buildings while tenants are responsible for paying for their own energy consumption.

- ***Difficulties in structuring contracts***. The other four factors - weak financing institutions; perceptions of high risks; high transaction costs; and split incentives - in turn create difficulties in establishing contractual terms that adequately reflect these concerns, but at the same time, provide adequate recognition of the large benefits that are attainable, as identified through engineering evidence.

These issues are highlighted, for example, in the 2008 World Bank study (Taylor et al., 2008) that focused on the cases of Brazil, China, India and other middle-income developing countries. This study notes that "the key impediments to effective energy efficiency investment through the market are the intertwined problems of current high transaction costs; perceived high risks driving up the implicit discount rates associated with projects; and difficulties in structuring workable contracts for preparing, financing, and implementing energy efficiency investments," (p. 50-51).

With respect to industrial efficiency specifically, these issues are examined in a chapter-length analysis "Barriers to Industrial Energy Efficiency," in the 2011 UNIDO Industrial Development Report. The UNIDO researchers conclude that:

> *Aversion to investment seems to stem from a combination of failures in the markets for energy-efficient goods and services and departures from the rational behavior of orthodox economic theory. These forces overlap to create barriers to improving energy efficiency including: lack of awareness of efficiency opportunities; difficulty borrowing money for energy-efficiency investments; inadequate technical know-how; and disconnection between those responsible for investing and those operating the equipment (UNIDO, 2011, p. 86).*

The implication that follows from these observations is not that the engineering information regarding gains from efficiency investments is wrong, or irrelevant to assessing the viability of real-world projects. To the contrary, the point is rather that both public policy and private initiatives are needed to overcome these barriers to capturing the large-scale benefits from efficiency investments that the engineering research has identified.

There is already a large literature that attempts to address these obstacles to the successful expansion of efficiency investments in different country settings.[32] We briefly review these issues in Chapter 6, in the context of examining industrial policies to advance the global clean energy investment project.

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[32] UNIDO (2011) provides a chapter-length analysis (pp. 100 – 124) on these policy matters as they apply to industrial energy efficiency. See also Spratt, Griffith-Jones and Ocampo (2013) for a good overview, including interviews with industry participants, along with the other works cited above.

Potential Rebound Effects

In advancing an ambitious agenda for energy efficiency in Brazil, Germany, Indonesia, South Africa, and the ROK, and more generally throughout the globe, it is critical to also examine what is termed the "rebound effect" and the related phenomenon of a "backfire" effect. The issue posed with the rebound effect is: if economic activities that entail the consumption of energy can be accomplished at lower costs due to the gains in energy efficiency, wouldn't this fall in energy costs encourage, in turn, more energy-consuming activities? And to the extent that more energy-consuming economic activity powered specifically by fossil fuels does take place because of these efficiency gains, wouldn't this reduce the benefits of efficiency investments for lowering CO_2 emissions? It is even possible that, in some circumstances, the initial gains in energy efficiency would end up being lower than the subsequent increase in energy consumption. This outcome is what we mean by the "backfire effect." When the backfire effect occurs specifically with respect to fossil fuels, the net result is that improvements in energy efficiency, anomalously, end up generating increases in emissions.

The possibility that rebound and backfire effects could occur was first proposed in the economics literature by William Stanley Jevons in his 1865 book, *The Coal Question*. Jevons wrote that the invention of a more efficient steam engine would ultimately lead to increased coal consumption by way of making the use of coal economically desirable for many uses. He claimed that overall coal consumption would increase even as the coal used for particular applications may decrease. Jevons wrote that "It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth."[33]

Since Jevons's era, further research on the rebound effect only became highly active in the 1980s and 1990s, including the influential contributions by Khazzoom (1980), focused on the U.S. case, and Brookes (1990), focused on the UK. A large professional literature has subsequently emerged, which we briefly review below. But beyond even the findings of most of the recent literature, the prospects for rebound effects needs to be examined within a broader context of a given economy's level of development and policy priorities. We also consider this factor below.

Direct and Indirect Rebound Effects

It is important initially to distinguish two broad categories of rebound effects, direct and indirect effects.

Direct effects refer to a given activity, such as driving a car or heating a home. The rebound effect here measures how much more consumers engage in such activities due to rising energy efficiency in these activities, which in turn yields falling per unit energy costs. For example, how many more miles might people drive as a result of operating more energy-efficient automobiles, or how much more they may heat or cool buildings after efficiency investments bring the costs down.

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[33] This paragraph is paraphrased from Gavankar and Geyer (2010).

Indirect effects take different forms. These include the following:

- When the costs of energy fall, consumers can then spend more on everything else besides directly energy-consuming activities such as driving a car or heating a building. But the remaining goods and services - everything from education, health care, or consumer goods - also make use of energy. When demand for these products rises, that in turn will produce increased demand for energy.

- Businesses experiencing falling energy costs may increase their use of energy-intensive equipment in their production processes.

- Investments in energy efficiency involve expenditures on capital goods which themselves require products that require energy inputs (e.g. supplies for building weatherization projects).

- To the extent that energy efficiency investments encourage faster economic growth, this accelerated overall economic growth rate would mean a higher overall level of energy demand.

There is no doubt that both direct and indirect rebound effects occur. But the first critical question is not whether they occur, but rather how large they are. A second, related, question is, to what extent do rebound effects vary, depending on the specific conditions in any given economy, as well as the economy's relevant policy environment.

Measuring Rebound Effects

Major professional reviews of this literature include those by Greening, Greene and Difiglio (2000), Sorrell (2007), Sorrell, Dimitropoulos and Sommerville et al. (2009) and Gavankar and Geyer (2010).[34] We draw on the main findings from these literature reviews in what follows.

Direct Rebound Effects. Most research into the size of the direct rebound effect has been focused on the household sector in the U.S., that is, residential energy use and household transportation (Sorrell, Dimitropoulos and Sommerville et al., 2009). The effect is based on how consumers may change their behavior in response to changing prices. But there are several methodological issues and potential sources of bias in trying to measure the direct rebound effect for households.

To begin with, since direct rebound effects are tied to the idea of demand for energy services, the size and nature of the effect will depend on how "energy services" are defined. But such definitions are subject to substantial variation. For example, with the transportation sector, energy services are frequently defined in terms of number of miles traveled. However, this measure does not take into account choices about the types of vehicles driven. Would consumers want bigger cars if such vehicles became more efficient? A consistent measure of "energy services" would have to control for this factor, but does not always do so.

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[34] Nadel (2012) is a less formal but still quite useful recent discussion of the topic. Gillingham et al. (2013) provides a brief updated assessment of what they term "a vast academic literature" on this issue. The main conclusion reached by Gillingham is fully consistent with the more lengthy survey studies.

Another concern is that many studies assume that changes in demand in response to increases in energy efficiency are equivalent to changes in demand associated with comparable changes in prices. But this may not be the case. This is because changes in energy efficiency may not translate directly into reductions in prices if the efficiency improvements require new investments with additional capital costs. If the demand effect is calculated without taking account of such capital costs, the rebound effect is likely to be overstated.

A third important concern is being able to accurately identify causality. Most studies on the rebound effect assume that when energy efficiency increases, this efficiency increase is the driving factor causing a subsequent rise in energy demand. However, higher demand for energy emerging from independent factors could also cause consumers to respond by investing in energy efficiency - that is, the causality between an increase in energy demand and energy efficiency would be the reverse of the relationship that the rebound effect presupposes.

Table 4.4 shows estimates of the direct rebound effects by category of energy services, as drawn from the literature reviews by Greening, Greene and Difiglio (2000) and Sorrell, Dimitropoulos, and Sommerville (2009). The evidence reported in these surveys is primarily drawn from U.S. economy-based studies, but includes evidence from other OECD economies as well.[35] As the table shows, these estimates range widely in both studies. Nevertheless, though these two surveys were published nine years apart from one another, they summarize similar sets of conclusions as to the likely range of household rebound effects. Thus, these articles find that for automobiles, heating and cooling systems, the rebound effect is likely to lie in the range of 10-30 percent relative to the total amount of energy saved. For home appliances and lighting, the rebound effect is lower, and may be close to zero. A zero rebound effect reflects the level of consumer saturation - for example, utilizing more energy-efficient clothes or dishwashing machines will likely have little to no impact on the demand for people to wash their clothes or dishes more frequently. For such activities, when demand for energy services is near its saturation point, efficiency gains will translate proportionally into reduced energy consumption.

Table 4.4: Estimates of direct rebound effects from two recent survey papers

	Estimated range from Greening, Green and Difiglio survey (2000)	**Estimated *likely range* from Sorrell, Dimitropoulos and Sommerville survey (2009)**
Personal vehicles	10–30%	10-30%
Space heating	10-30%	10-30%
Space cooling	0–50%	1–26%
Home appliances	0%	‹ 20%
Lighting	5–12%	‹ 20%

Sources: Adapted from Table 3 in Greening, Green and Difiglio (2000) and Table 1 in Sorrell, Dimitropoulos, and Sommerville (2009).

Note: The Sorrell et al. survey includes a category "other energy services." The estimates for this category are used for home appliances and lighting in this table. The term "likely range" in describing the Sorrell et al. figures is the assessment of these authors probable range for the direct rebound effects, based on their literature review.

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[35] The precise definition of the rebound effect is the elasticity of demand for energy services with respect to energy efficiency.

Indirect Rebound Effects. Research on the magnitude of indirect, or economy-wide, rebound effects are even more limited than those for direct effects. Various methodologies have been utilized in the literature, including consumer expenditure surveys, macro-econometric models, and theoretical general equilibrium models. They have produced a wide range of estimates of the indirect effect, but the results are highly sensitive to the methodology used and the underlying assumptions within the method used. Sorrell concludes regarding these studies that “while a number of methodological approaches are available to estimate these effects, the limited number of studies to date provides an insufficient basis to draw any general conclusions,” (2007, p. 57).

Broader Context for Considering Rebound Effects

As these survey papers all recognize, the size of any rebound effects will depend on the level of development of an economy, the purposes for which energy is being consumed in the economy, and the economic policies being pursued at a given time.

For example, in the historical period in Britain described by Jevons, the use of steam engines was growing rapidly as a crucial component of the 19th century industrial revolution. The very purpose of producing more efficient steam engines at that time was to facilitate an accelerated rate of industrialization, powered by coal-powered machinery. The Jevons case has relevant parallels with developing countries today, including especially Indonesia and South Africa among our five selected countries. These are expanding economies in which per capita energy consumption is rising. In these cases, we would expect that increased energy efficiency, that produces lower costs for consuming a unit of energy, will encourage, for example, more intensive use of automobile travel or household appliances. Conditions will be different with economies that are already at high GDP levels, such as the U.S. or Germany. In these cases, the per-capita consumption of energy-intensive activities is far closer to a saturation point than is true in Indonesia or South Africa.

But the more critical issue here is the historical and policy environment in which efficiency investments are occurring. If we consider the case of Britain in the Jevons era, the purpose of improving energy efficiency was precisely to support the greater use of coal-fired power. But in all regions of the global economy in the current era, the overarching purpose of raising energy efficiency is quite distinct. The proximate purpose is to maintain or enhance the benefits of energy-driven machines, while lowering the need for energy inputs to power these machines. The fundamental purpose is, quite simply, to play a major role in fighting climate change.

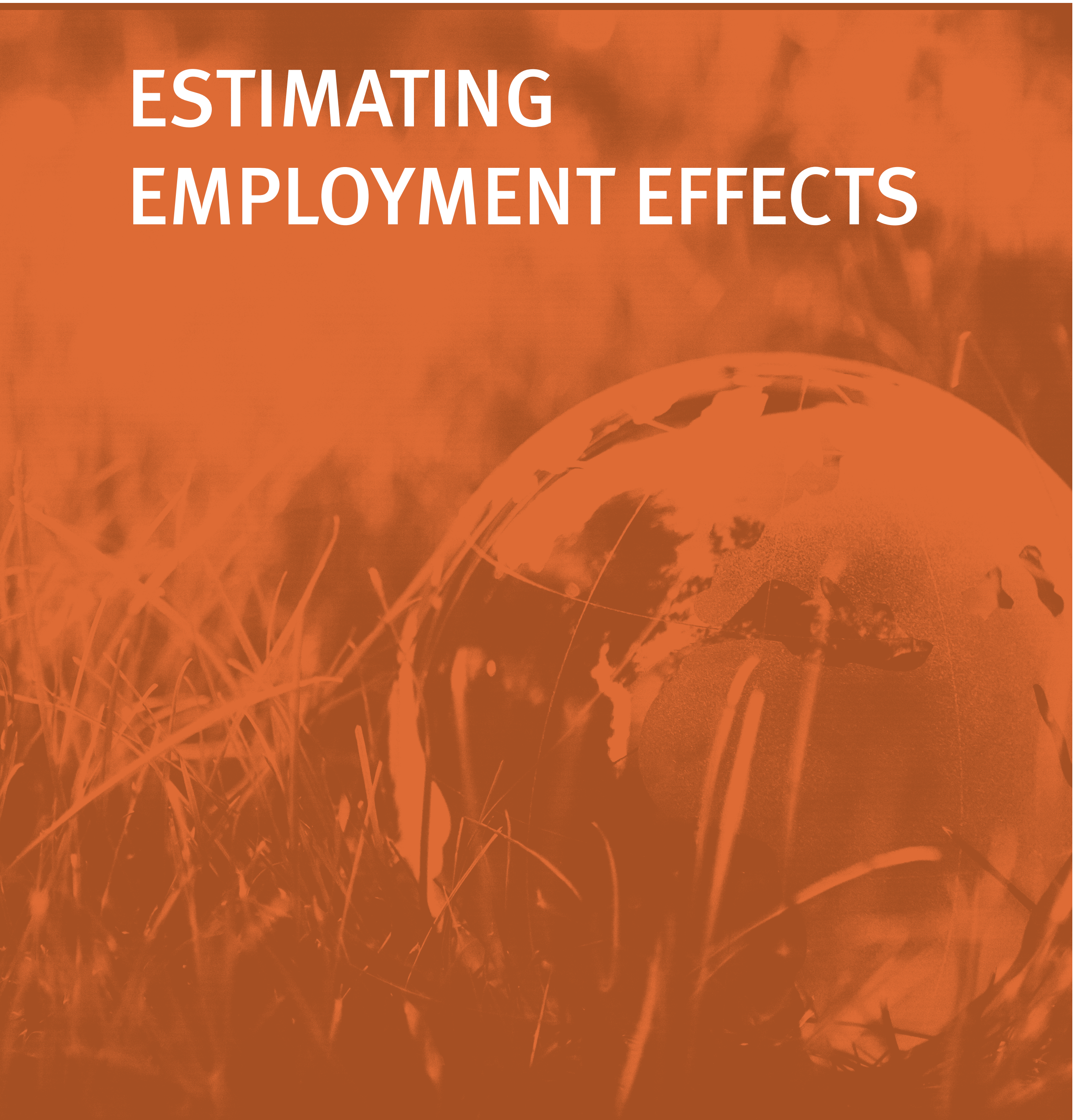
Thus, for all countries at all levels of development, it is critical that the effort to increase energy efficiency would be accompanied by complementary policies that, in combination, can succeed in dramatically reducing CO_2 emissions. As one major obvious set of complementary measures, policies to promote affordable clean renewable energy investments would allow for higher levels of energy consumption - including through some limited rebound effects - without leading to increases in CO_2 emissions. Another major complementary policy to promoting energy efficiency investments would be to set a price on carbon emissions through either a carbon cap or carbon tax. As such, a policy environment that complements energy efficiency investments with strong support for renewable energy and putting a price on carbon emissions will purposefully create a much smaller rebound effect than a situation - such as that in Jevons’

England - when the drive for energy efficiency was undergirding early industrialization, free of environmental constraints.

The evidence we presented in Table 1.3 on energy intensity levels for different countries is also pertinent here. As we saw there, Germany presently operates at an efficiency level roughly 50 percent higher than the U.S., with the respective intensity ratios at 4.1 versus 6.2 Q-BTUs per $1 trillion in GDP. Brazil is at more than twice the efficiency level of the ROK, and nearly three times that of South Africa (5.1 versus 9.8 and 14.6 Q-BTUs per $1 trillion in GDP respectively). There is no evidence that large rebound effects have been emerging as a result of the high efficiency standards achieved by Germany and Brazil relative to those of the U.S., the ROK or South Africa. Equivalently, there should be no presumption that rebound effects would be necessarily stronger in the U.S., the ROK, or South Africa once they began to significantly improve their efficiency performances. The basic variable here will be the overall policy environment.

SECTION 2

ESTIMATING EMPLOYMENT EFFECTS



CHAPTER 5: DOMESTIC PRODUCTIVE CAPACITY, IMPORTS, AND INDUSTRIAL POLICY FOR EMPLOYMENT GENERATION

The project of building a global clean energy economy will require highly ambitious policy initiatives in all regions, including advanced, middle-income, and developing economies. For the global economy to reduce CO_2 emissions from 33,600 to 20,000 mmt within 20 years - i.e. an *absolute decline* in emissions of 40 percent relative to 2010 levels, even while global GDP expands at a reasonable rate - will require countries to invest heavily in both clean renewable energy sources and energy efficiency. As we have discussed briefly at the outset and will examine further below, the necessary level of investment will need to be about 1.5 percent of GDP in most countries, including Brazil, Germany, Indonesia, South Africa and the ROK. How exactly each of these major economies allocates this level of investment expenditures will depend on the specific resources and capacities they have available, including the particulars of their climate; their existing energy resources and supply systems; and their capacity to mobilize physical and financial resources. We discuss some of these specific country-by-country considerations later in this report.

Our primary focus here is to examine how much any country, and our five selected countries in particular, is likely to expand its investments in clean energy sectors on the basis of its own domestic resources. To the extent that a country runs up against domestic productive capacity constraints while expanding its investments in energy efficiency and clean renewable energy sources, it then faces two alternatives: either scale back the clean energy investment project or rely increasingly on imports to maintain the ambitious investment agenda. We assume for purposes of this discussion that countries will want to follow through in advancing the ambitious clean energy investment project. We therefore need to consider the extent to which the impact of these clean energy investment projects will vary, depending on whether a country can rely on its domestic resources at least in its existing proportions of productive inputs, or whether it will need to rely on imports to supply an increasing share of inputs in building a clean energy economy.

Of course, whether a country needs to increase its reliance on imports as it expands its investments in clean energy will in turn affect the country's trade and current account balances. We discuss this issue of trade balances below, but do not provide a formal empirical analysis on this question. Our main focus, rather, is on employment affects. That is, within the context of a clean energy investment project at the level of about 1.5 percent of a country's GDP, what is the extent to which changes in the domestic content of the country's output in the relevant sectors will affect the overall job-generating prospects of its clean energy investments? This includes the sectors directly engaged in energy production as well as suppliers to those energy-producing sectors.

Specifically, we consider two alternative scenarios. In the first scenario, we allow that a country is able to maintain its existing level of domestic production in the clean energy sectors as it expands its clean energy activities by 1.5 percent of GDP. In the second scenario, we assume that the economy cannot expand production fast enough to maintain the current level of domestic content in its clean energy activities, but rather needs to raise its import share in the relevant sectors. As we discuss further below, we assume import content will need to rise in sectors in which imports already constitute more than 10 percent of total inputs. For those activities, we assume that import content rises by 20 percent over existing levels. The estimates we generate here will enable us to assess in Chapter 6 the extent to which overall employment creation from a clean energy investment project is likely to be affected by whether a country can expand its domestic productive capacities in proportion to its rising level of clean energy investments.

In addition to developing and reporting on the effects of these two scenarios regarding domestic content, we consider here two factors that will significantly influence the extent to which a country will be capable of expanding its supply of domestic inputs. These two factors are: 1) the role that can be played by a country's industrial policies to expand domestic productive capacity in the relevant sectors of the economy; and 2) the extent to which countries currently rely on fossil fuels to meet their energy consumption needs. We begin with our review on industrial policies, then present our quantitative analysis on domestic content ratios. We conclude by assessing the role of fossil fuel production for exports and consumption in our selected countries.

Industrial Policies for Clean Energy Transformations

Whether or not countries are able to advance a major clean energy investment agenda without significantly altering the economy's demand for imports will depend on the extent to which they can implement industrial policies capable of expanding their productive capacity in the economy's relevant sectors. It will be useful here to briefly examine some of the main issues and country-level experiences on this question.

What is Industrial Policy?

The term "industrial policy" is commonly used to refer to two distinct types of government interventions. In one usage, industrial policy refers to the regulation of competition, e.g. policies on monopolies, mergers and market restrictive practices. In the other usage, industrial policy has a broader meaning, associated closely with the concept of a "developmental state" - that is, a state that plays an active role in building effective institutions and frameworks that can successfully guide the development trajectory of a country's economy.[36]

In this discussion, we are focused on the second meaning of industrial policy - with industrial policies as one important element of a developmental state. But with industrial policy as a tool of a developmental state, a range of institutions, policy instruments and targets are put into play, which also need to be explicitly recognized. These could include R&D subsidies for government, university or private business research centers. It could also include preferential tax treatment,

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[36] Pitelis (2001) provides a succinct survey these alternative meanings to the term "industrial policy." See also Pollin (2012) for an overview of industrial policies, especially as applied in the U.S. and with respect to clean energy investments.

credit opportunities, or direct subsidies for specific sectors of the economy, including of course, renewable energy and energy efficiency investments. Some types of business regulations could also be seen as industrial policy interventions. Raising automobile efficiency standards is an example of a regulation that will be crucial for building a clean energy economy, especially in countries, such as the U.S., where public transportation systems are weak.

Rodrik captures well the meaning of the term "industrial policy" in this broader sense when he writes, "I will use the term to denote policies that stimulate specific economic activities and promote structural change. As such, industrial policy is not about *industry* per se. Policies targeted at non-traditional agriculture or services qualify as much as incentives on manufacturing," (2009, p. 3). Rodrik further notes that a main purpose of industrial policies is not the application of any specific policy measures but rather about building institutions that foster effective interrelationships between the public and private sectors to achieve important policy goals. He writes:

> *The task of industrial policy is as much about eliciting information from the private sector on significant externalities and their remedies as it is about implementing appropriate policies. The right model for industrial policy is not that of an autonomous government applying Pigovian taxes or subsidies, but of strategic collaboration between the private sector and the government with the aim of uncovering where the most significant obstacles to restructuring lie and what type of interventions are most likely to remove them. Correspondingly, the analysis needs to focus not on the policy outcomes - which are inherently unknowable ex ante - but on getting the policy process right (Rodrik, 2004, p. 3).*

Advancing Effective Industrial Policies

From a free market perspective, there are virtually no viable arguments on behalf of industrial policies. The central point is straightforward: governments should not be in the business of subsidizing one technology, industry, or location, much less one business firm over others. This amounts to governments "picking winners," which they are incapable of accomplishing effectively. On top of this, industrial policies of this sort force taxpayers to finance government policymakers' inept efforts at picking winners. In fact, the job of picking winners in the economy is more effective when private businesses compete in a free market to satisfy the demands of consumers. Some of the businesses' decisions will be good, and others will be bad. The point is that this will be sorted out through competitive markets, at no expense to taxpayers. More generally, free market proponents hold that economic outcomes established through market competition, in the absence of government interference, will always produce the most efficient allocation of an economy's productive resources and the highest level of overall economic welfare.

However, these free market perspectives do not accord with the actual trajectories of virtually all countries, in all historical epochs, that have experienced successful industrial development. As one critical case in point, we can see this clearly in the specific case of technological development in the U.S. As Ruttan (e.g. 2006) has made clear, nearly all major technical innovations within the U.S. economy have entailed huge expenses over long gestation periods. Individual business firms are unable to sustain expenses at this level on their own. This is especially the case because there is never a guarantee that those investors who assumed the initial burden of long time horizon, high-risk ventures will end up as the prime beneficiaries from such endeavors. Ruttan summarized the matter as follows:

> *Can the private sector be relied on as a source of major new general purpose technologies? The quick response is that it cannot. When new technologies are radically different from existing technologies and the gains from advances in technology are so diffuse that they are difficult to capture by the firm conducting the research, private firms have only weak incentives to invest in scientific research or technology development (Ruttan, 2006, p. 177; emphasis in original).*

Of course, we do not expect that all countries will need or want to attempt to advance the frontier in the development of clean energy technologies. But a second consideration as regards industrial policies is more broadly relevant for all countries pursuing a clean energy investment agenda. This is the project of *adapting* new technologies within a country's production processes and industrial systems, or what Mazzucato (2014) terms "innovation-led growth." Mazzucato explains how innovation-led growth is always the result of effective interactions between the private sector and what she terms "the entrepreneurial state." She writes:

> *In seeking to promote innovation-led growth, it is fundamental to understand the important roles that both the public and private sector can play. This requires not only understanding the importance of the innovation 'ecosystem' but especially what it is that each actor brings to that system. The assumption that the public sector can at best incentivize private sector-led innovation (through subsidies, tax reductions, carbon pricing, technical standards and so on)…fails to account for the many examples in which the leading entrepreneurial force came from the State rather than from the private sector….To understand the fundamental role of the State in taking on the risks present in modern capitalism, it is important to recognize the 'collective' character of innovation. Different types of firms (large and small), different types of finance and different types of State policies, institutions and departments interact sometimes in unpredictable ways - but surely in ways that can help shape to meet the desired ends (*Mazzucato, *2013, p. 193).*

In developing her concepts of the entrepreneurial state and innovation-led growth, Mazzucato concentrates in detail on how such policies can be advanced most effectively in promoting the "green industrial revolution." She argues that:

> *Getting to the much-needed green revolution presents a serious problem: given the risk aversion of businesses, governments need to sustain funding for the search for radical ideas that push a green industrial revolution along. Governments have a leading role to play in supporting the development of clean technologies past their prototypical states through to their commercial viability. Reaching technological 'maturing' requires more support directed to prepare, organize, and stabilize a healthy 'market,' where investment is reasonably low risk and profits can be made (Mazzucato, 2013, p. 136).*

Of course, the specific details of industrial policies need to designed, targeted, and implemented well. There are many cases when industrial policies have been executed successfully. As has been carefully documented, among others, in the classic works by Johnson (1982), Amsden (1989, 2001), Wade (1990), and Chang (1994), the dramatic rise of Japan, then the ROK, and the other "Asian Tiger" economies - Taiwan Province of China, Thailand, Singapore, and Malaysia - were built on a foundation of successful industrial policies, especially the ability to build successful export industries through adapting existing technologies in manufacturing production. The Chinese experience follows roughly in this same framework, while also incorporating uniquely Chinese features.[37] At the same time, we do need to recognize that even within the East Asian model, there have also been serious failures. For example, in the 1950s, the Japanese government famously instructed Honda to stick to manufacturing motorcycles, refusing to support Honda's plan to begin producing automobiles. The Japanese also tried and failed to build a commercial airline in the 1970s.

Considering more recent and directly relevant examples, Mazzucato (2013) documents both successes and failures with green industrial policies - in which she observes successes to date having mainly occurred in Western Europe and China, while, in her view, the U.S. and the United Kingdom have been less successful. The primary distinction between more or less successful experiences has been the willingness of governments to commit major resources over the long-term, as opposed to the more sporadic levels of commitments coming from the U.S. and the United Kingdom.

While Mazzucato's research on green industrial polices focuses primarily on countries operating at or near the technological frontier, UNIDO's 2013 Industrial Development Report considers green manufacturing industrial policies for all regions in the globe. The UNIDO study thus provides perspectives that are especially useful for less developed economies aiming to successfully advance a clean energy transition. The UNIDO study summarizes its analysis as follows:

> *The paradigm of continually increasing demand of finite resources must be shifted as the past abundance of relatively inexpensive natural resources, such as energy… is coming to an end. Approaches toward this "green structural change" will include adapting industries more technologically advanced and with higher labour and capital productivity. The key thus lies in decoupling natural resources use and environmental impacts from economic activity (UNIDO, 2013, p. 81).*

In all cases, one critical feature of a successful industrial policy is the establishment of viable development banks and, more broadly, of credit allocation systems that can support the investments in new areas. This point becomes clear in Amsden's illuminating discussion of development banking in *The Rise of "The Rest"* (2001). Amsden begins her discussion of this topic with the observation that:

> *The state's agent for financing investment was the development bank. From the viewpoint of long-term capital supply for public and private investment, development banks throughout "the rest" were of overwhelming importance (Amsden, 2010, p. 127, emphasis in original).*

Amsden goes on to document this in the cases of Mexico, Chile, as well as in three of our five selected countries - i.e. the ROK, Brazil and Indonesia. But she also points out that "the government's role in long-term credit allocation was substantial in parts of 'the rest' where development banks were of relatively minor importance," (p. 129). These cases include Malaysia, Thailand, Taiwan Province of China and Turkey. She writes of these cases, "where

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[37] The classic works on industrial policies and development in Japan, the ROK and the other Asian tigers includes Johnson (1982), Amsden (1989, 2001), Wade (1989) and Chang (2002), On China, an excellent relatively recent study is Li (2002). Valuable recent studies include Natsuda and Thoburn (2013) on the development of the auto industry in Thailand and Ado (2013) on adoption of local content rules as applied to resource-rich developing countries. UNIDO (2013) examines the issue of industrial policies specifically in the area of green manufacturing sectors in all regions of the globe.

necessary, the whole banking sector in these countries was mobilized to steer long-term credit to targeted industries, acting as a surrogate development bank."

The central importance of financial policies to support clean energy investments in developing countries has been explored in detail in several recent studies. One important example is the 2008 World Bank book *Financing Energy Efficiency: Lessons from Brazil, China, India and Beyond* (Taylor et al., 2008). This book includes 10 case studies of alternative energy efficiency financing structures. These include:

- A loan guarantee program for private energy efficiency financing in China, which began in 2003;
- The evolution of the Indian Renewable Energy Development Agency (IREDA) to provide subsidized loans for both renewable and energy efficiency investments; and
- Brazil's public benefit "wire-charge" mechanism, through which 1 percent of annual utility net revenues are utilized for public-benefit investments. Initially, renewables received 75 percent of these funds, but as of 2010, the funds were divided evenly between renewables and efficiency investments.

A more recent study by Spratt, Griffith-Jones and Ocampo (2013), *Mobilizing Investment for Inclusive Green Growth in Low-Income Countries*, examines the conditions under which the necessary large-scale investments in renewable energy and energy efficiency can be successfully advanced in low-income countries. The authors are particularly concerned that such investments be "inclusive," in the sense that the benefits of these investments be shared at least equally by the society's least advantaged groups. This would include expanding access to electricity, and providing clean energy, for electricity and other needs, at affordable prices. Two of the major findings of this study are as follows:

1. The importance of looking at "how best to structure investment vehicles that combine the detailed local knowledge required to overcome information asymmetries, with the scale required to minimize transaction costs and achieve diversification benefits;" and
2. The need to reduce the expectations of high returns on these investments from institutional investors. The authors write: "Achieving growth that is both green and inclusive is inherently difficult. Doing so using private investment, which requires very high returns may be impossible. Unless investors can be persuaded to adopt more reasonable expectations, alternative sources of finance may been needed if the goal of generating inclusive green growth in low-income countries is to be achieved" (p. 6).

It is also important to consider here the case of Germany, the most successful large advanced economy in the world in terms achieving high energy efficiency standards. It is clear that government development financing policies have been critical to Germany's success to date in implementing high efficiency standards. The overview of the IEA's 2013 *Energy Efficiency Market Report* focuses precisely on this point, as follows:

> *Germany is a world leader in energy efficiency. Germanys' state-owned development bank, KfW, plays a crucial role by providing loans and subsidies for investment in energy*

> *efficiency measures in buildings and industry, which have leveraged significant private funds (IEA, 2013c, p. 149).*

In Chapter 9, we discuss in more detail Germany's overall policy approach to advancing both energy efficiency and renewable energy investments.

Labor Market Issues within Industrial Policies

As we review in depth in Chapter 7, the demand for labor that will be generated through expanding clean energy investments will be widely disbursed in each of our five selected countries. It is important to recognize that the majority of jobs created by clean energy investments will be in the same areas of employment in which people already work. For example, constructing wind farms creates jobs for sheet metal workers, machinists and truck drivers, among others. Increasing the energy efficiency of buildings through retrofitting relies, among others, on roofers, insulators, and building inspectors. Expanding public transportation systems employs civil engineers, electricians, and dispatchers. Increasing demand for bioenergy will mean a significant increase in employment in standard agricultural activities. With respect to these types of employment opportunities within a national clean energy investment project, it will not be necessary for governments to introduce a distinct new set of job training programs that differ significantly from those that most countries already practice.

As we will also review in Chapter 7, the general level of educational attainment for workers in the clean energy sectors is not, for the most part, significantly different than those for workers presently employed in the oil, coal and natural gas sectors. Thus, as these fossil fuel activities contract, this will create an increased supply of workers available to operate within the clean energy sectors with appropriate levels of general educational credentials.

At the same time, some of these new employment activities will entail new activities and skills. For example, installing solar panels on roofs and wiring these panels so they supply electricity are distinct tasks relative to the jobs that are traditionally performed by either roofers or electricians. Similarly, refining agricultural wastes into biofuels is different than refining corn into ethanol or, for that matter, refining petroleum into gasoline. Countries advancing clean energy investment projects will need to make provisions for these and similar areas that demand new types of training and skill acquisition. The major 2008 global survey study *Green Jobs* commissioned by the United Nations Environmental Program and others (Renner, Sweeney and Kubit, 2008) addresses this issue of skills gaps and the needs for expanded training programs in various areas as follows:

> *A transition to a green economy will create demand for workers, many of them in skilled trades or professions, and filling these positions will require adequate training programs. At the cutting edge of technological development for wind turbine or solar PV design, for instance, specialization has progressed to the point where universities need to consider offering entirely new study fields and majors. Several countries have reported that a "skills gap" already exists between available workers and the needs of green industries. A 2007 survey of Germany's renewable industry concludes that companies in this field are suffering from a shortage of qualified employees, and especially those needed in knowledge-intensive positions. The Confederation of British Industry has*

> *expressed concern that sectors going green are struggling to find technical specialists, designers, engineers, and electricians. In the United States, the National Renewable Energy Laboratory has identified a shortage of skills and training as a leading barrier to renewable energy and energy-efficiency growth. In addition, Australia, Brazil, and China also report shortages of skilled workers. To remedy such shortages requires not only adaptations in training new workers, but also retraining efforts for those workers who transition from older, polluting industries to new ones. Along with the skills gap can be placed the "management challenge," which will consist in the development of new perspectives, awareness and managerial capacities. Managers must be willing and able to learn new skills, and to make use of the skills their subordinates have obtained (Renner, Sweeney and Kubit, 2008, pp. 25-26).*

Another major and more detailed study on skill requirements per se generated by clean energy investments is a 2011 publication by the International Labour Office, *Skills for Green Jobs: A Global View* (Strietska-Ilina et al., 2011).[38] The study also examines the skills issues tied to other green economy activities, such as afforestation, reforestation, waste management, and water management. This study surveys skill requirements tied to specific green economy occupations in 21 countries, including all five of our selected countries.[39] This study is especially useful in that it both identifies specific skills gaps as well as describes a range of formal training and other skill-acquisition measures for closing these gaps. Critically, authors of the study are clear in their assessment that most clean energy and other green-economy occupations will require updating skills as opposed to training workers for entirely new occupations. For example, the authors observe that:

> *The number of existing occupations that will change and update their skills content by far exceeds the number of new occupations that will emerge and will affect more jobs than the latter. This finding corresponds to the results of other studies. The greening of established occupations implies incremental changes in qualifications. New skills are needed because specific competencies are currently lacking, some existing skills relating to job tasks that become obsolete cease to be used, some tasks require global or interdisciplinary approaches, and sustainable development constraints are increasingly taken into account. This may lead to the diversification of existing occupations (for example, in management, with increased environmental management responsibilities) or to increased specialization of occupations (Strietska-Ilina et al., 2011, p. 100).*

Given the magnitude of the clean energy investment project that needs to be undertaken in most countries, including Brazil, Germany, Indonesia, South Africa, and the ROK, it is inevitable that skill bottlenecks will emerge at various points in the transition path. Still, these bottlenecks will be less severe than they might be otherwise, given that, as we have discussed: 1) most jobs and skill requirements in the clean energy economy are not significantly different than those already required of most people currently working in other sectors; and 2) the general educational attainment levels for most jobs within the clean energy sectors will be roughly comparable to those within the fossil fuel sectors that will be facing retrenchments. This then produces an increase in the labor supply that can move into the clean energy sectors. In addition, as we will discuss in detail later in this chapter, countries facing skill bottlenecks in

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[38] A companion study from the ILO is the 2013 report *Sustainable Development, Decent Work and Green Jobs*.

[39] The other 16 countries in the ILO survey are Australia, Bangladesh, China, Costa Rica, Denmark, Egypt, Estonia, France, India, Mali, Philippines, Spain, Thailand, Uganda, the United Kingdom and the U.S. Two studies that focus on the details of clean energy employment issues for the U.S. case are Pollin and Wicks-Lim (2008) and Pollin, Garrett-Peltier and Wicks-Lim (2009).

transitioning to a clean energy economy can increase their demand for imports in specific areas to at least partly cover gaps within their domestic workforce resources.

At the same time, skill gaps and bottlenecks will continue to emerge in building clean energy economies. This conclusion emerges clearly from both the 2008 UNEP and the 2011 ILO studies. We do anticipate such obstacles in projecting the 20-year clean energy investment project for Brazil, Germany, Indonesia, South Africa and the ROK that we describe in Chapters 8-12. Thus, in the country-specific modeling exercises we present in Chapters 8-12, the time frame we develop is a 20-year clean-energy investment period. However, we assume no progress in the first three years of the 20-year period in expanding capacity in energy efficiency and renewable energy capacity. We assume a significant feature of the initial three years of startup activity will entail policymakers and businesses recognizing where skill shortages exist and making adjustments in business operations and training programs to address these skill shortages.

In addition to these issues of skill shortages, there is the equally critical workforce issue of providing adequate transitional support for communities and workers that are presently dependent on the fossil fuel industries as their source of livelihoods. These workers and communities obviously face retrenchments over time as clean energy sources increasingly substitute for fossil fuels. The 2008 UNEP issue addresses this matter, presenting the concept of a “Fair and Just Transition,” which they describe as follows:

> *The shift to a low carbon and sustainable society must be as equitable as possible. A “Just Transition” framework is being assembled as a result of the work of the work of the trade unions, the ILO, national and local governments, and sustainability-conscious business and community-based organizations. The framework is built around the idea that the coming transition will have a huge effect on workers and communities. Many will benefit but others may face hardships as certain industries and occupations decline. From the point of view of social solidarity, and in order to mobilize the political and workplace-based support for the changes that are needed, it is imperative that policies be put in place to ensure that those who are likely to be negatively affected are protected through income support, retraining opportunities, relocation assistance and the like (Renner, Sweeney and Kubit, 2008, p. 27).*

The UNEP study acknowledges that the Just Transition approach is not yet adequately developed in any country.[40] Pollin et al. (2014) sketch an approach for the U.S. clean energy transition, building from the concept developed by the late U.S. labor and environmental leader Tony Mazzocchi of a “superfund for workers” who will face hardships due to necessary environmental transitions.[41] They estimate that a decent level of support for the affected fossil fuel workers within the U.S. context would be in the range of $40,000 per year for two years to cover wage subsidies, health insurance, counseling and retraining, relocation and job search costs.

This “superfund for workers” approach is consistent with the broader concept of “flexicurity” for workers described by UNEP, which entails a shift from the notion of *job* security to one of

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[40] Renner, Sweeney and Kubit et al., (2008) et al observe, for example that “examples of Just Transition are still few and far between,” (2008, p. 27).

[41] Mazzocchi explained his idea as early as 1993 as follows, “Paying people to make the transition from one kind of economy - from one kind of job - to another is not welfare. Those who work with toxic materials on a daily basis…in order to provide the world with the energy and the materials it needs deserve a helping hand to make a new start in life. …There is a Superfund for dirt. There ought to be one for workers,” (Mazzocchi ,1993, p.41). Indeed, as described by Leopold (2007) the concept of “just transition” itself came from Mazzocchi, as a revised version of the “superfund for workers” theme (Leopold, 2007, p. 417).

employment security. As described in the UNEP *Green Jobs* study, the core elements of the flexicurity model are:

- Flexible and secure contractual arrangements and work organizations;
- Active Labor Market Policies (ALMP) which effectively helps people to cope with rapid change, unemployment spells, reintegration and transition to new jobs;
- Reliable and responsive lifelong learning systems, to ensure the continuous adaptability and employability of all workers, and to enable firms to keep up productivity levels; and
- Modern Social Security systems, which provide adequate income support and facility labor market mobility. (Renner, Sweeney and Kubit, 2008, p. 291).

Again, the UNEP authors recognize that flexicurity-based labor market policies are functioning to date in only a few advanced European economies. What is nevertheless clear is the need to develop something resembling this policy framework in order for clean energy transitions to advance successfully - i.e. with the least possible level of opposition - in all countries and regions of the globe.

The Role for Alternative Ownership Forms

This last issue raised by Spratt, Griffith-Jones and Ocampo (2013) as to the difficulties of meeting the high profit requirements of private-sector clean energy investors raises the question: to what degree might alternative ownership forms play a constructive role in advancing the clean energy investment agenda?

In fact, the energy sector, on a worldwide scale, has long operated under a variety of ownership structures, including public/municipal ownership, and various forms of private cooperative ownership in addition to private corporate entities. The alternative ownership forms operate in all areas of the energy industry, including with both the conventional fossil fuel energy sources and within the renewable sectors. The European industry, in particular, operates with a high proportion of cooperative ownership forms, and the relative performance of these non-corporate business enterprises has generally been quite favorable relative to the traditional corporate firms. Two areas where we can observe this clearly are with research and development across the electricity sector and in the emergence of various sorts of community-based wind farms.

Research and Development in Electricity. Of course, the project of building a clean energy economy will entail large-scale commitments for R&D, and innovative approaches to commercialization of new technologies. With this in mind, the 2010 study by Sterlacchini is significant for examining the relationship between spending on R&D in the advanced industrialized economies the field of energy/electricity between from 1990 to 2004 and changes in the predominant ownership structures in the industry. In particular, Sterlacchini finds that

> *Within the most developed areas of the world, R&D investment in the field of energy/electricity has declined dramatically over the last decades. Although even public research has been reduced, the key area of concern rests on the behavior of the electricity supply*

> *industry. Investment in energy R&D by US utilities fell by 72 percent between 1990 and 2004. Over the same period, the electric companies of the EU reduced R&D expenditures by 62 percent (Sterlacchini, 2010, p. 2).*

Further, Sterlacchini concludes that this drastic decline in R&D spending resulted primarily from the widespread movement to privatize the electricity market, beginning in the 1990s. According to Sterlacchini, privatization in electricity has "increased competitive pressures to cut costs and those concerned with R&D have been particularly vulnerable. In particular, electric utilities have abandoned the long-term research projects concerned with fundamental and general-purpose technologies," (p. 2).

Community-owned wind farms. Bolinger (2001, 2005) has conducted comparative studies of "community ownership forms" in the wind energy industry specifically, in both Europe and the U.S. Bolinger defines "community wind" as "locally owned, utility-scale wind development that is interconnected to the grid on either the customer or utility side of the meter."[42] Bolinger reports that, at the end of the year 2000, roughly 80 percent of all wind power capacity in four northern European countries - Germany, Denmark, Sweden and the United Kingdom - could be considered community-owned. Moreover, because these four countries accounted for roughly half of the world's installed wind power capacity at that time, this means that community-owned projects accounted for roughly 40 percent of world wind power development at the end of 2000.[43]

Bolinger describes four important advantages to community ownership structures in the wind industry relative to traditional corporate ownership forms. These include:

1. *Lower costs of capital*. Community-based wind projects in Europe have been able to rely on a wide array of relatively smaller-scale local investors. In the U.S., community wind projects could have access to the capital market for "socially responsible" investing, which Bolinger estimates as being in the range of $2 trillion overall. Moreover, a study by Wiser and Pickle (1997) estimated that the costs of wind power could fall by 22 percent if the investors' required rate of return could fall from, say, 18 to 12 percent.

2. *Increased public support*. Direct community ownership of wind projects has raised public awareness in Europe and increased the number of local people who have direct financial stakes in such projects. Among other things, this has reduced community resistance to projects at the planning and permitting stages.[44]

3. *Potential for distributed generation benefits*. The relatively smaller size of community-owned projects creates the potential to site projects closer to where the turbines are sited and the energy is generated. This creates the possibility for significant reductions in the costs of transmitting energy over the grid. In Europe, clusters of wind turbines are

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[42] He further defines "locally owned" to mean that one or more members of the local community have a direct financial stake in the project, and that "utility scale" refers to new projects consisting of one or more turbines of 600 kW or greater in nameplate capacity, or older projects in excess of 50 kW.

[43] The level of government support for community-owned wind and solar farms has, in fact, risen more recently in the United Kingdom. In January 2014, the Energy and Climate Change Secretary Ed Davey announced the government's aim to require large onshore renewable energy developers to offer "a meaningful share" of the ownership in the projects in their communities (Shankleman, 2014). In the U.S. by contrast, the development of community ownership in the wind industry has been negligible to date. Virtually all wind-energy projects have been large-scale corporate owned wind farms. At the same time, there is some evidence that community wind projects are advancing, especially in Minnesota, Wisconsin, Iowa and Massachusetts, where both the physical and legal environments are relatively supportive (see also Finzel and Kildegaard, 2009).

[44] This is not to suggest that community-owned projects are free of controversy. One important issue that is frequently raised in Denmark, for example, concerns the noise levels created by some wind turbine systems the noise created by wind turbines (see, e.g. Johansson, 2013). These complaints have, in turn, generated efforts to control these noise levels through various methods (e.g. Cummings, 2102).

often connected into the grid without requiring any additional grid reinforcements. Such benefits are more likely to be available when community wind projects are established in more densely populated areas. For example, in Copenhagen as of 2005, two community-owned wind projects were operating within the city limits.

4. *Electricity price stability*. Community-owned wind projects operate at arms-length from the two forces that are most responsible for creating instability in energy prices generally and electricity prices specifically - that is, the global market for oil and the speculative commodities futures market for energy, including electricity. Because, by their basic ownership structure, community-based wind projects will continue to operate independent of the global price of oil as well as the commodities futures markets, this should create long-term conditions supportive of electricity price stability.

Against these built-in advantages of community-based wind projects, Bolinger notes disadvantages as well. The most significant is the greater difficulty with such projects in capturing economies of scale. Community-owned projects will tend to be smaller in scale than corporate-owned wind farms, though they do not necessarily have to operate on a small scale. This is precisely because they are tied to specific communities and local financing sources. Large-scale corporate wind farms are thus better equipped to spread the fixed costs of any given project, including permitting and legal costs and the full range of construction and transmission costs.

As Bolinger emphasizes, there will be conditions under which the benefits of economies of scale outweigh those of community-owned projects. But the reverse will also certainly be the case in many instances. The experiences in Germany, Denmark, Sweden, and the United Kingdom make clear that community-based ownership structures can succeed in the wind industry. It is also true that the incentive structure and regulatory environment in Europe are more supportive of a community-based model. The most important factor here is the prevalence of "feed-in" laws in Europe. The feed-in laws guarantee access to the grid for small-scale producers and also establish a guaranteed price at which utilities must purchase electricity from wind and other renewable energy producers.

100 Percent Community-Owned Renewable Supply in Rural Germany

In addition to the broad perspective on community-owned wind farms provided by Bolinger (2001 and 2005), a 2013 article by Li et al. describes an important case study of Freimant, a rural community of 4,200 residents in Germany's Black Forest region. As of 2008, Freimant had achieved 100 percent electric power supply through community-owned renewable sources. Wind energy is Freimant's main power source, but they also generate smaller amounts of energy from solar PV, biogas, and small-scale hydro plants.

On the basis of having surveyed the residents of Freimant, Li et al. emphasize that the project would not have advanced successfully on the basis of the residents environmental goals alone, even while such environmental concerns were foremost for policy-making bodies outside the community who supported the project. Li et al. summarize the sources of the success of the project as follows:

> *The residents' motivations for undertaking the project were strongly connected to community-interest as opposed to awareness of climate change, which is generally far more distantly connected with their daily life. The residents and local government were more concerned about their own benefit from the project and its influences on their local surroundings. Residents expect a financial benefit from community energy projects; a self-ownership of renewable energy plants increases motivation and local acceptance….Community energy projects contributing to climate protection by reducing the community's CO_2 emissions. They [also] create new income streams, have positive effects on the community's image and are a way to strengthen rural areas by establishing a regional value added chain…Especially for rural areas, energy projects are a chance to foster regional development, to secure agricultural holdings and to conserve cultural landscapes that have been shaped by agriculture over centuries. This case study has shown that there are people willing to act and that it is possible to achieve a 100% power supply from renewable sources (Li et al., 2013, p. 227).*

Overall, what emerges from this brief survey on industrial policies is that such policies, in some combination of appropriate specific initiatives, will be necessary in all cases for advancing a successful large-scale clean energy investment project - i.e. a project on the order of 1.5 percent of each country's GDP. It is well beyond the scope of this report to attempt to argue what will be the most effective specific combination of industrial policies in any given country setting. We do note that, as of this writing, we find no evidence of significant community-based clean energy projects operating in any of our five selected countries other than Germany. However, the fact that such projects have been successful in Germany and elsewhere in Western Europe — including communities such as Freimant that are not especially well endowed with either financial resources or the appropriate natural resources - suggests that such projects can, with time, be made successful elsewhere as well, including in Brazil, Indonesia, South Africa and the ROK .[45]

For our specific purposes of estimating the employment effects of a clean energy investment project, we will proceed under the simple assumptions that:

1. Countries that are able to mount successful industrial policies will be able to advance a large-scale clean energy investment project while still maintaining their current proportion of domestically-produced inputs in the economy's relevant sectors; and

2. Countries that do not mount successful industrial policies in behalf of the clean-energy investment project will see the import content in their economy's relevant sectors rise by 20 percent relative to current import proportions. We explain below how we derive this 20 percent adjustment figure.

Estimating Domestic Productive Resource for Clean Energy Investments

In Tables 5.1-5.5, we show for all five selected countries the percentage of overall activity in each of the energy-producing sectors that is produced with domestic resources. For example, in the

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[45] A useful resource for considering the practicalities for developing community-based renewable energy projects, focused on North America, is by the Commission for Environmental Cooperation (2010).

case of Brazil, we estimate that, as of the data provided in its most recent 2005 I-O table, domestic content was as follows for these energy sectors: 97 percent for bioenergy; 91 percent for wind; 96 percent for hydro, and so forth. For South Africa, the domestic content percentages are: 94 percent for bioenergy; 90 percent for hydro; 75 percent for wind, 83 percent for solar; 93 percent for coal, and 62 percent for oil and gas, among others. In Appendix 2, we describe the full calculations within each country's I-O tables through which we generated the results in Tables 5.1-5.5.

Within the framework of these existing domestic content ratios, we then pose the question: how much are these ratios likely to change as our selected countries undertake major new investment projects in renewable energy and energy efficiency and sustain these investment projects over a 20-year timespan? Of course, we cannot know the answer to this question in advance in our five distinct country settings, especially given that each country will also incorporate other transitional forces along its long-run growth trajectory. Therefore, as described briefly above, we focus here on considering two simple alternative scenarios in addressing this question. In the first scenario, we assume that the countries undertake effective industrial policies to support their clean energy investment projects. As a result of these effective policies, we then assume that the domestic content ratio within all energy-linked activities remains at their current levels.

In the second scenario, we assume that the countries' industrial policies are not as effective. As a result, domestic content in all tradable activities linked to each energy sector declines by 20 percent relative to their current levels. We consider two main issues in addressing this approach as our second scenario. The first is, how are we defining "tradable" activities within each country's I-O tables? The second is, why do we assume that the fall in domestic content should be 20 percent, as opposed to some other percentage?

Our definition of a "tradable" activity follows from the literature on this question. The most recent brief survey of which we are aware is Lombardo and Ravenna (2012). They define a "tradable" activity as one in which less than 90 percent of this activity's inputs come from domestic sources.[46] They write:

> *We define as tradable all goods from sectors where the tradability measure is above a fixed number. To provide comparability with results in the literature, we adopt a 10 percent threshold, as in De Gregorio et al. (1994) and Betts and Kehoe (2001). (Lombardo and Ravenna, 2012, p. 559).*

For activities, which are defined as tradable by this measure, why do we assume that domestic content will fall by 20 percent in our second scenario, i.e. when industrial policies to support clean energy investments are less successful? Here we work from the results presented in Bems (2008) on "Aggregate Investment Expenditures on Tradable and Nontradable Goods." For our purposes, the key findings in Bems are as follows:

1. Aggregate investment expenditure shares on tradable and nontradable goods are very similar in rich and poor countries, as well as in different regions of the world.

2. The expenditure shares on tradables and nontradables have been stable over time.

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[46] They write, "We define as tradable all goods from sectors where the tradability measure is above a fixed number. To provide comparability with results in the literature, we adopt a 10 percent threshold, as in De Gregorio et al. (1994) and Betts and Kehoe (2001)," (2012, p. 559).

> Average expenditure shares on nontradables have varied between 54-62 percent over the period he studies, 1960-2004.

Working from these results by Bems, if we assume that the variation on non-tradables ranges between 54-62 percent, this means the decline from the high end of the range, at 62 percent, to the low end, at 54 percent, is about 13 percent (8 percentage points decline from a 62 percent base). Because, if anything, we do not want to *underestimate* the potential proportionate decline in domestic content that could result from greatly expanding investments in clean energy activities, we chose to increase the percent decline in domestic content from the 13 percent figure that we extract from the Bems' research to 20 percent.

Based on these assumptions, the figures we report in the second columns of Tables 5.1-5.5, all show domestic content as declining by 20 percent in all tradable activities (i.e. those activities in which domestic content is currently below 90 percent) associated with the clean energy investment project. Thus, again looking at the case of Brazil in Table 5.1, the impact of this adjustment procedure does not affect the domestic content of the bioenergy sector, which remains at 97 percent domestic content or building retrofits, which remains at 100 percent. However, wind power declines from 91 to 88 percent domestic content. Grid upgrades decline from 77 to 67 percent domestic content and industrial energy efficiency falls from 87 to 80 percent domestic content. For the case of South Africa, as reported in Table 5.4, wind falls from 75 to 68 percent domestic content, grid upgrades falls from 64 to 56 percent, and industrial energy efficiency falls from 71 to 67 percent.

Table 5.1: Brazil. Domestic content of alternative energy sectors: Levels in 2005 I-O tables compared to a 20 percent domestic content decline for tradable activities

	Stable domestic content	Domestic content after 20 percent decline for tradable activities
Renewables		
Bioenergy	97%	97%
Hydro	96%	95%
Wind	91%	88%
Solar	85%	79%
Geothermal	94%	90%
Energy efficiency		
Building retrofits	100%	100%
Industrial efficiency	87%	80%
Grid upgrades	77%	67%
Fossil fuels		
Coal	78%	NA
Oil/natural gas	78%	NA

Source: Data sources as noted in Appendix 2.

Table 5.2: Germany. Domestic content of alternative energy sectors: Levels in 2007 I-O tables compared to a 20 percent domestic content decline for tradable activities

	Stable domestic content	Domestic content after 20 percent decline for tradable activities
Renewables		
Bioenergy	78%	67%
Hydro	65%	55%
Wind	75%	65%
Solar	70%	62%
Geothermal	56%	54%
Energy efficiency		
Building retrofits	96%	96%
Industrial efficiency	54%	47%
Grid upgrades	69%	60%
Fossil fuels		
Coal	70%	NA
Oil/natural gas	40%	NA

Source: Data sources as noted in Appendix 2.

Table 5.3: Indonesia. Domestic content of alternative energy sectors: Levels in 2008 I-O tables compared to a 20 percent domestic content decline for tradable activities

	Stable domestic content	Domestic content after 20 percent decline for tradable activities
Renewables		
Bioenergy	96%	94%
Hydro	89%	83%
Wind	83%	75%
Solar	85%	77%
Geothermal	91%	87%
Energy efficiency		
Building retrofits	100%	100%
Industrial efficiency	75%	65%
Grid upgrades	82%	76%
Fossil fuels		
Coal	82%	NA
Oil/natural gas	76%	NA

Source: Data sources as noted in Appendix 2.

Table 5.4: South Africa. Domestic content of alternative energy sectors: Levels in 2005 I-O tables compared to a 20 percent domestic content decline for tradable activities

	Stable domestic content	Domestic content after 20 percent decline for tradable activities
Renewables		
Bioenergy	94%	92%
Hydro	90%	87%
Wind	75%	68%
Solar	83%	74%
Geothermal	92%	88%
Energy efficiency		
Building retrofits	100%	100%
Industrial efficiency	71%	67%
Grid upgrades	64%	56%
Fossil fuels		
Coal	93%	NA
Oil/natural gas	63%	NA

Source: Data sources as noted in Appendix 2.

Table 5.5: Republic of Korea. Domestic content of alternative energy sectors: Levels in 2008 I-O tables compared to a 20 percent domestic content decline for tradable activities

	Stable domestic content	Domestic content after 20 percent decline for tradable activities
Renewables		
Bioenergy	79%	68%
Hydro	91%	82%
Wind	86%	76%
Solar	83%	71%
Geothermal	79%	72%
Energy efficiency		
Building retrofits	100%	100%
Industrial efficiency	83%	70%
Grid upgrades	83%	73%
Fossil fuels		
Coal	42%	NA
Oil/natural gas	46%	NA

Source: Data sources as noted in Appendix 2.

In the next chapter, we show how these alternative assumptions as regards domestic content proportions play out in our estimates of the employment effects of the clean energy investment project.

Fossil Fuel Consumption and Imports/Exports

One factor in enabling the expansion of domestic production in sectors of economies linked to clean energy will be the fact that the fossil fuel sectors in all countries will be correspondingly contracting. The freeing up of economic resources out of the activities tied to the fossil fuel sector will be substantial in all cases. These activities include extracting, transporting, refining, and the retail distribution of fossil fuel energy, along with all of the sectors that provide supplies to support these activities.

The data in Table 5.6 provide a sense of the magnitudes involved. The first column of the table shows the extent to which each of our five selected economies relies on fossil fuels to meet its overall energy consumption levels. As we see, fossil fuels supply more than half of each country's total energy consumption. Brazil has the lowest proportion of fossil fuel consumption, at 53.5 percent of total energy consumption, because of its uniquely high levels of both hydro and biofuel production. Indonesia is next lowest, at 66.1 percent reliance on fossil fuels. But this figure includes Indonesia's still heavy reliance on burning peat as a high-emissions renewable energy source. Exclusive of peat, coal, oil and natural gas provide roughly 90 percent of Indonesia's remaining energy supply. Germany, the ROK and South Africa all rely on fossil fuels for between 78-88 percent of their overall energy supply. These figures show that, as these economies undergo transitions to clean energy sources, major shares of their economies' overall resources will be released from the current demands generated by their fossil fuel sectors.

Table 5.6: Reliance on fossil fuels and imports as energy sources in selected countries, 2011

	Fossil fuels as a share of total energy consumption	Imports as a share of total energy consumption[a]
Brazil	53.5%	8.0%
Germany	78.2%	60.0%
Indonesia	66.1%	-89.0%
South Africa	87.7%	-15.0%
ROK	82.9%	82.0%

Source: World Bank (2014), "World Development Indicators," Table 3.6: Energy production and use and Table 3.8: Energy dependency, efficiency, and carbon dioxide emissions.

Notes: a) Negative figures indicate net export proportion.

We obtain additional perspective as to how such scenarios might play out through the figures shown in column 2 of Table 5.6. Here we show the import shares as a proportion of total energy consumption for our five selected economies as of 2010. As we see, Indonesia and South Africa were energy exporters - Indonesia with oil and South Africa with coal. However, since 2010, Indonesia has become an oil importer. Indeed, in the absence of a successful clean energy investment strategy. Indonesia is projected to become a major oil importer over the next five years (Azwar, 2013). With Brazil, as the table shows, imports constituted a relatively modest 8 percent of its overall energy supply as of 2010, while Germany and the ROK were major energy importers, at 60 and 82 percent of their overall energy supply. These proportions have held steady since 2010.

Of course, the energy-importing countries, Brazil, Germany, and the ROK, are presently utilizing a smaller share of their total domestic resources in the fossil fuel sector. Their share of total economic resources devoted to energy-linked activities could rise as a result of increasing investments in energy efficiency and renewable energy. However, as we saw in Tables 5.1, 5.2 and 5.5, the share of total domestic resources devoted to supplying oil, coal and natural gas are not negligible. In Germany, the shares are 70 percent for the coal sector and 40 percent for oil and gas, as shown in Table 5.2. In the ROK, as we see in Table 5.5, the proportions are 42 percent for coal and 46 percent for oil and gas. Thus, even with Germany and the ROK, as major energy importers, the move out of fossil fuels and into clean energy will entail releasing domestic resources that can be repurposed for the clean energy transition.

South Africa, unlike the case of Indonesia transitioning from oil exporter to importer, is projected to remain as a coal exporter in a global Reference Case scenario over the next 20 years.[47] South Africa would therefore see its market for coal exports contract as the reliance on clean energy sources expand, including in countries currently importing South African coal. This will create problems for their balance of payments as well as the incomes and job opportunities for people attached to the coal sector. But this then also means that for South Africa, as with all other fossil fuel exporting economies, resources will become increasingly available for repurposing in support of a clean energy investment project.

The Impact of Declining Fossil Fuel Export Markets

The contraction of South Africa's coal export market that would result through the clean energy transition does then raise a broader question concerning all five selected countries. That is, considering all fossil fuel sectors in each of the five countries, what is likely to be the effect of the global contraction in fossil fuel trade that will result through a global clean energy transition?

We can obtain some perspective on this question by considering the net trade balance with respect to fossil fuels for our five selected economies. In Table 5.7, we provide figures on net fossil fuel exports as a share of GDP over the decade 2001-2010. As the table shows, four of the five economies, including South Africa, were, on average, net importers of fossil fuels over this decade. In the cases of Brazil, Germany, and the ROK, the share of net fossil fuel imports relative to GDP was also generally stable, since, as the table shows, the decade-long average (mean) figures are all significantly greater than their standard deviations.

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[47] See, for example, the EIA's 2030 Reference Case in the *International Energy Outlook 2013*.

Table 5.7: Net fossil fuel trade balance as share of GDP, 2001–2010

Positive figures = net fossil fuel trade share surpluses;
Negative figures = net fossil fuel trade share deficits

	Mean fossil fuel trade balance/GDP	Standard deviations
Brazil	-0.6	0.3
Germany	-2.3	0.5
Indonesia	4.3	1.1
South Africa	-0.9	1.2
ROK	-6.4	1.8

Sources: Authors' calculations based on U.S. Energy Information Agency (EIA), International Energy Statistics [for fossil fuel trade]; IMF, International Financial Statistics [for GDP].

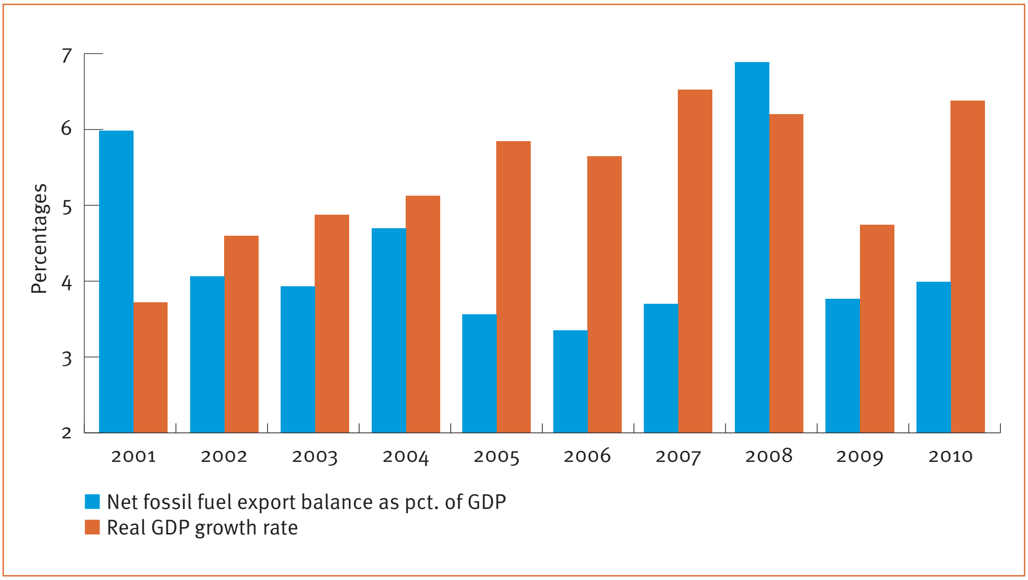
South Africa is also a net fossil fuel importer over the full 2001-2010 decade, but, for two reasons, its situation is different than those for Brazil, Germany and the ROK. The first factor is that its ratio of net fossil fuel imports relative to GDP is not stable over the decade, with the mean value of - 0.9 being less than the standard deviation of 1.2. The second factor is that South Africa has been a net fossil fuel importer overall even though it is also a major exporter of coal. This is because South Africa is an even larger importer of crude oil than it is an exporter of coal. On balance, therefore, South Africa's trade position should improve as it experiences concurrent reductions in both oil imports as well as coal exports. In addition, the share of fossil fuels in the country's trade accounts will contract as both oil imports and coal exports decline. The fossil fuel trade will constitute a smaller share of the economy's overall GDP. This will therefore mean that the impact of fossil fuel imports and exports will have a diminished impact on the economy's overall stability. As discussed above, South Africa's coal sector will of course still experience a substantial retrenchment as the clean energy investment project proceeds. The country will need to implement effective transitional assistance measures for coal miners and the communities dependent on the industry, as one component of the country's overall clean energy industrial policy agenda.

Indonesia is the only economy in our group that is a net exporter of fossil fuels over the 2001-2010 decade, as Table 5.7 shows. A global clean energy investment project will therefore entail a loss of net exports for Indonesia. How significant is this likely to be for the country's overall economic growth and employment trajectory?

One consideration, as we also mentioned above, is that Indonesia had been a major oil exporter but has been losing that position since the mid-2000s. It was a net oil importer as of 2010. The fact that Indonesia is still a net exporter of fossil fuels overall is because of its ongoing high level of coal exports. Coal exports constituted 4.5 percent of Indonesia's GDP as of 2010. How significant would be the impact of losing a major share of its coal export revenues as well as, perhaps, its net export position with fossil fuels overall? As with South Africa, Indonesia's coal sector itself would of course experience a sharp retrenchment. The country will need to implement effective adjustment assistance policies for the impacted communities and workers. But what about the broader impact on the economy's overall growth and employment trajectory?

We can obtain a reasonable sense of how Indonesia's overall economic performance will be affected by the decline of its net fossil fuel export position through its experience over the 2001-2010 decade with respect to its fossil fuel net exports relative to its overall economic growth. In Figure 5.1, we show the pattern of net fossil fuel exports in relationship to the economy's annual real GDP growth rate. As is clear from the figure, there is no consistent relationship between Indonesia's fossil fuel export share and its overall GDP growth rate. For example, between 2001-2002, the export/GDP share declined from 5.8 to 4.0 percent of GDP, while real GDP growth rose from 3.6 to 4.5 percent. Again, between 2004-2005, the fossil fuel export share declined from 4.6 to 3.5 percent of GDP, while real GDP growth increased from 5.0 to 5.7 percent. For the decade as a whole, as we report in Figure 5.1, the correlation coefficient between the fossil fuel export share and GDP growth is -0.19. That is, over 2001-2010, there was a weak *negative* correlation between Indonesia's overall fossil fuel export position and the country's average annual real GDP growth rate.

Figure 5.1: Indonesia. Fossil fuel sector net exports as share of GDP and real GDP growth rate, 2001-2010



Sources: Authors' calculations based on U.S. Energy Information Agency (EIA), International Energy Statistics [for fossil fuel trade]; IMF, International Financial Statistics [for GDP].

Notes: Correlation coefficient between fossil fuel net exports/GDP and real GDP growth is -0.19.

All else equal, the Indonesian economy would likely benefit through being able to sustain a net export position in the fossil fuel sector. But the fact that the decline in Indonesia's net fossil fuel export position does not positively correlate with its economic growth performance means that Indonesia has already demonstrated its capacity to adjust to the decline in its fossil fuel export revenues - the decline in oil exports, in particular. Put another way, Indonesia has not been operating in an "all else equal" environment over the decade 2001-2010 as regards the impact of its fossil fuel export revenues on GDP growth. Indonesia has rather demonstrated over this period its capacity for adaptation to the changing patterns of trade flows in its fossil fuel sector. For the country to transition onto a clean energy investment project will require still further adaptations. But the evidence suggests that the decline of its net fossil fuel export will not itself create a major barrier to the success of Indonesia's clean energy transition.

Oil Curse and Stranded Assets

Two additional sets of issues are relevant within this discussion. The first concerns the long-term economic development prospects of countries with large fossil fuel endowments to operate as net exporters. The relevant literature has not reached a consensus as to whether, in fact, being an oil exporter ends up promoting economic growth at all. Rather, the overall evidence is decidedly mixed. Sachs and Warner (1997, 2001) initiated a line of research on what they termed "the curse of natural resources." They found that economies with a high ratio of oil exports to GDP in 1970 tended to grow relatively slowly in the subsequent 20 years. Other early studies, including Leite and Weidmann (1999) focused on the relationship between oil abundance and the quality of institutions in a given country - finding that ineffective institutional environments engendered by oil abundance in turn acts as a hindrance to economic growth. By contrast, other researchers such as Salai-i-Martin and Subramanian (2003) have found that there is no clear relationship, either positive or negative, between abundant natural resources and growth. Still others, including Alexeev and Conrad (2009) observe a positive association between oil wealth and economic performance.[48]

It is beyond the scope of this report to attempt to adjudicate the results of these various researchers. For our purposes, the central conclusion to take from this literature is that operating as an oil exporter can be supportive of growth under some circumstances, but it is never necessarily beneficial to growth. Rather, there is clearly a wide range of factors at play in determining whether being an oil exporter will be supportive of growth. This, correspondingly, also means that countries that are not oil exporters, or that experience a decline in their oil-exporting sector, can nevertheless consistently find other channels for promoting economic growth. We of course see this with our own group of five selected countries. Germany and the ROK, the two countries with the highest levels of GDP per capita, are also the two countries with the highest ratios of fossil fuel imports as a share of GDP over 2001-2010 - Germany at 2.3 percent of GDP and the ROK at fully 6.4 percent of GDP. It is also evidently true that the ROK's outstanding growth performance over the past 50 years has coincided with many oil exporting countries, including, for example, Mexico, Libya and Ecuador, experiencing mediocre growth or stagnation.[49]

A second important consideration here is that, as we emphasized at the outset of this report, it is simply not possible to control climate change if the global economy continues to burn fossil fuels at anything close to the rate that it has experienced over the past generation. This means that, over the next generation and further into the future, all owners of fossil fuel assets, including public sector entities as well as private oil, coal and natural gas corporations, will, by necessity, experience a major decline in the value of these fossil fuel holdings. Thus, a 2013 study authored jointly by Carbon Tracker and the Grantham Research Institute on Climate Change and the Environment at the London School of Economics examined the current holdings of the largest 200 fossil fuel companies in the world. This study estimated that "60-80

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[48] An excellent survey of this literature and especially a critical replication of the Alexeev and Conrad econometric findings is an unpublished study by Alnusf (2011). Ross (2012) provides a broader perspective on the political as well as the economic issues associated with the oil curse.

[49] Perhaps the leading example of a country that has avoided the resource curse is Norway. Holden (2013) provides a useful discussion as to how Norway achieved this, in contrast with, among other countries The Netherlands - from which the term "The Dutch Disease" originates.

percent of coal, oil and gas reserves of listed firms are unburnable (2013, p. 4).” The study then considered the implications of this finding for the long-term valuations for these companies. They conclude that “The 200 fossil fuel companies analyzed here have a market value of $4 trillion and debt of $1.5 trillion….Equity valuations could be reduced by 40-60 percent in a low emissions scenario. In parallel, the bonds of fossil fuel companies could also be vulnerable to ratings downgrades,” (2013, p.5).

In the context of such findings, what is clear is that even if countries, such as Indonesia, are holding net fossil fuel export positions and these positions are presently making net positive contributions to economic growth, these fossil fuel exporters will still need to undertake major adjustments in recognition of the forthcoming devaluation of their fossil fuel assets.

CHAPTER 6: METHODOLOGICAL ISSUES IN EMPLOYMENT ESTIMATES

Building from National Input-Output Models

Our employment estimates are figures generated directly from data from national surveys of public and private economic enterprises within Brazil, Germany, Indonesia, South Africa and the ROK, and organized systematically within each country's national I-O model. The "inputs" within this model are all the employees, materials, land, energy and other products that are utilized in economic activities of public and private enterprises within the five countries to create goods and services. The "outputs" are the goods and services themselves that result from these activities that are then made available to households, private businesses and governments as consumers within both domestic and global markets. Within the given structure of each national economy, these figures available within the I-O model provide the most accurate evidence available as to what happens within private and public enterprises when they produce the economies' goods and services. In particular, these data enable researchers to observe how many workers were hired to produce a given set of products or services, and what kinds of materials were purchased in the process.

Here is one specific example of how our methodology works. If we invest an additional $1 million on energy efficiency retrofits of an existing building (or its equivalent within each country's national currency) how will the business undertaking this retrofit project utilize that $1 million to actually complete the project? How much of the $1 million will they spend on hiring workers, how much will they spend on non-labor inputs, including materials, energy costs, and renting office space, and how much will be left over for business profits? Moreover, when businesses spend on non-labor inputs, what are the employment effects through giving orders to suppliers, such as lumber and glass producers or trucking companies?

We also ask this same set of questions for investment projects in renewable energy as well as spending on operations within the non-renewable energy sectors. For example, to provide $1 million worth of petroleum that can be sold to consumers at retail stations as a refined product, how many workers will need to be employed, and how much money will need to be spent on non-labor inputs?[50] Through this approach, we have been able to make observations as to the potential job effects of alternative energy investment and spending strategies at a level of detail that is not available through any alternative available approach.

There are certainly limitations with our use of the I-O model. We examine these issues below. But as we also discuss below, these limitations in the I-O model approach need to be considered in the context of alternative approaches, including computable general equilibrium models, which, in our view, contain even more serious deficiencies. In short, we hold that for our particular

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[50] More technically, what we are defining here is the final demand for petroleum to all consumers.

purposes at hand of estimating employment effects of alternative energy spending activities in comparable ways within the national economies of Brazil, Germany, Indonesia, South Africa and the ROK, the I-O approach is the most reliable methodology available. The following discussion provides a broad overview of our methodology for estimating employment effects of clean energy investments in Brazil, Germany, Indonesia, South Africa, and the ROK. We also provide more detailed technical discussions, and full sets of references in Appendices 2-4.

In addition to issues resulting directly from our use of the use of I-O models, we also need to consider here some broader methodological and measurement questions with respect to the employment effects of clean energy investments. A first critical question is whether it is necessarily a favorable development when clean energy investments generate, per dollar of expenditure, a higher level of employment than spending within the fossil fuel sectors. This higher level of employment for clean energy investments could simply reflect a decline in labor productivity. A second set of issues concerns the time dimension of employment. That is, can we accurately observe the extent to which jobs that are created through clean energy investments will last for either short or long periods of time? How, also, should we interpret the relative benefits of the jobs that are created when they last, for example, for one year versus 10 years? A third, related set of questions concerns job quality. An expansion in the overall availability of jobs can, alternatively, produce more lower- or higher-quality jobs. The relative proportions of bad versus good jobs resulting through clean energy investments will obviously matter for assessing the overall welfare effects of these investments.

We address this broader set of questions after first setting out our basic estimating framework. We then discuss the more technical set of concerns emerging from our use of the I-O model.

Aggregate Employment Creation: Direct, Indirect, and Induced Jobs[51]

Spending money in any area of an economy - including regional and national economies as well as the global economy - will create jobs, since people are needed to produce any good or service that the economy supplies. This is true regardless of whether the spending is done by private businesses, households, or a government entity. At the same time, for a given amount of spending within the economy, for example, $1 million, there are differences in the relative levels of job creation through spending that $1 million in different ways. Again, this is true regardless of whether the spending is done by households, private businesses or public sector enterprises.

There are three sources of job creation associated with any expansion of spending - direct, indirect, and induced effects. For purposes of illustration, consider these categories in terms of investments in home retrofitting or building wind turbines:

1. *Direct effects* - the jobs created, for example, by retrofitting buildings to make them more energy efficient or to construct wind turbines;

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[51] Appendix 3 describes in detail our methodology for estimating aggregate employment creation in clean energy and fossil fuel investments in Brazil, Germany, Indonesia, South Africa and the ROK.

2. *Indirect effects* - the jobs associated with industries that supply intermediate goods for the building retrofits or wind turbines, such as lumber, steel, and transportation;

3. *Induced effects* - the expansion of employment that results when people who are paid in the construction or steel industries spend the money they have earned on other products in the economy. These are the multiplier effects within a standard macro model.

In this report, we focus on direct and indirect effects. Estimating induced effects - i.e. multiplier effects - within I-O models is much less reliable than the direct and indirect effects. In addition, induced effects derived from alternative areas of spending within a national economy are likely to be comparable to one another. We therefore do not lose a significant amount of information in terms of relative employment effects between spending on renewable energy and energy efficiency versus fossil fuels when we exclude induced effects from our estimations.

Within the categories of direct plus indirect job creation, how is it that spending a given amount of money in one set of activities in the economy could generate more employment than other activities? As a matter of simple arithmetic, there are only three possibilities, i.e. differences in: 1) compensation per worker; 2) domestic content; and 3) labor intensity. We can illustrate these three possibilities through comparing investment projects in clean energy versus non-renewable sectors.

Compensation per worker. If there is a total of $1 million to be spent within a given year within any given energy sector activity, and one employee earns $1 million per year while employed at this activity, then that obviously means that only one job will be created through spending the $1 million. However, if, at some alternative enterprise, the average pay per worker is $10,000 per year, then the same $1 million will generate 100 jobs at $10,000.

Domestic content. We have reviewed in detail in Chapter 5 issues around differences in domestic content in the alternative national settings. These differences will of course impact the extent of job creation within any given domestic economy for a given level of spending. The degree to which variation in domestic content affects overall job creation will depend on the specifics as to which clean energy sectors are expanding in any given country.

Labor Intensity. When proportionally more money of a given overall amount of funds is spent on hiring people, as opposed to spending on machinery, buildings, energy, land, and other inputs, then spending this given amount of overall funds will create more jobs. As we will see, relative to spending within the non-renewable energy sectors within most national economy settings, investments in clean energy - including the direct spending on specific projects plus the indirect spending on purchasing supplies - entails spending more of its overall budget on hiring people, and relatively less on acquiring machines, supplies, land (either on- or offshore) and energy itself.

It is important to note here that differences in labor intensity are not identical to differences in *labor productivity*. As one important example, with a given level of labor productivity, differences in labor intensity can result through variation in spending on ground rent. This specific factor can be especially relevant in considering the fossil fuel sector, in which ground rent expenditures can be substantial. For the purposes of our discussion, we also need to provide more clarity around issues of labor productivity itself. We turn now to this topic.

Clean Energy, Productivity, and Employment

The most basic purpose of utilizing energy in economic activity is to raise productivity - i.e. with the use of efficient machinery powered by energy, to be able to produce more goods and services at lower costs than would be possible through using human effort alone or through combining human effort with less efficient machinery. Within this context, it is therefore critical to consider whether a clean energy investment project could produce an expansion in employment opportunities simply through lowering productivity, and, correspondingly, whether any such productivity decline also entails a reduction in overall welfare. In addressing such questions, it is first critical that we be clear about what we mean in referring to "productivity," including the separate categories of *energy productivity* and *labor productivity*.

Energy Productivity. In Chapter 1, we presented evidence within different country settings on their *energy intensity* ratios, which we defined as Q-BTUs/GDP. Energy intensity is definitionally the inverse of energy productivity. Investing in energy efficiency measures is, correspondingly, the means through which economies raise energy productivity and lower their energy intensity ratio.

Labor Productivity. By a standard definition, labor productivity simply measures total output per worker, assuming contributions from all other productive inputs remains equal. By this standard definition, if we assume all additional productive input contributions are equal, if we increase labor intensity through clean-energy investments, that also means we will have reduced labor productivity in the energy sector through shifting spending toward clean energy. Within this framework, the project of building a clean-energy economy would therefore entail lowering labor productivity, as defined conventionally, even while we would also be raising energy productivity through efficiency investments.

However, the idea of inverse trajectories for energy and labor productivity within a clean energy investment project does not adequately capture the full story on the movement of labor productivity within this framework. This is because it neglects two crucial considerations. First, through raising overall employment, clean-energy investments can provide new opportunities to previously unemployed workers. This raises the productivity level for the formerly unemployed workers from zero to a positive number. Any *economy-wide* measure of labour productivity has to take account of this effect. Similarly, clean-energy investments can create new opportunities for underemployed workers, thereby also raising their productivity.

Second, within the context of the global climate crisis, we need to begin consistently incorporating environmental effects in the measurement of output and productivity. That is, spending on fossil fuels creates the output 'good' of energy to power machinery. But it also creates the output 'bad' of CO_2 emissions. Thus, with every unit of energy generated by clean-energy investments as opposed to fossil fuels, the net increase in output is greater to the extent that we are not producing the 'bad' of pollution and GHG emissions. This point has long been recognised in discussions of the environmental costs of economic growth, and is included in virtually every introductory economics textbook.

Clean-energy investments therefore have the capacity to raise economy-wide labor productivity - defined appropriately - through two channels: 1) By expanding total employment per dollar of expenditure in the economy, it provides new opportunities for unemployed or underemployed workers to become productive; and 2) by generating energy from clean sources, it increases the level of 'goods' we produce and correspondingly reduces our production of 'bads'.

Overall then, properly considered on a macro scale, the productivity effects of a clean energy investment project - including both energy productivity as well as labor productivity - are likely to be strongly favorable.

Time Dimension in Measuring Job Creation

Any type of spending activity creates employment over a given amount of time. To understand the impact on jobs of a given spending activity, one must therefore incorporate a time dimension into the measurement of employment creation. For example, a project that creates 100 jobs that last for one year only needs to be distinguished from a another project that creates 100 jobs that continue for 10 years each. It is important to keep this time dimension in mind in any assessment of the impact of on job creation of any clean energy investment activity.

There are two straightforward ways in which one can express such distinctions. One is through measuring "job years." This measures cumulative job creation over the total number of years that jobs have been created. Thus, an activity that generates 100 jobs for 1 year would create 100 job years. By contrast, the activity that produces 100 jobs for 10 years would generate 1,000 job years.

The other way to report the same figures would be in terms of jobs-per-year. Through this measure, we are able to provide detail on the year-to-year breakdown of the overall level of job creation. Thus, with the 10-year project we are using in our example, we could express its effects as creating 100 jobs per year for 10 years. This is the basic framework we will utilize when we report on job creation figures within the context of clean energy investment projects on the order of 1.5 percent of GDP per year. This is because, when we present employment impacts in terms of jobs-per-year, we can observe these impacts within the standard units of total employment levels, labor force participation and unemployment rates over the course of a year. Within this framework, we can of course also estimate the number of years in which a given jobs-per-year impact will be sustained. In the case of the clean energy investment project we are developing, what we are proposing should be sustained at the level 1.5 percent of GDP for of at least 20 years. The overall employment impacts, measured on a jobs-per-year basis, should therefore be sustained at least over the course of these 20 years. Their impact would also continue beyond the last year of the 20-year project cycle to the extent that investment projects require more than one year to complete spending cycle, as would be typical. Ongoing operations, maintenance and manufacturing activities would also continue after the period of capital investments has ended.

One specific area where it is important to proceed clearly on this issue is in consideration of construction industry job creation through clean energy investments. Construction sector jobs created by clean energy investments are frequently regarded as being short-term, while manufacturing jobs are seen as inherently longer term. However, especially in evaluating the impact of alternative areas of spending within an overall clean energy investment agenda, the distinctions are not so straightforward. Of course, any single construction project is limited by the amount of time required to complete that project, while manufacturing activity in a single plant can continue indefinitely, as long as the manufacturer is able to sell the goods being produced at a profit. But if we consider any large-scale green construction project, total job creation over time can vary widely, depending precisely on the annual level of expenditure that is laid out to complete the project.

Consider, for example, a project to retrofit the entire publicly-owned building stock within Brazil, in which we assume the entire budget devoted to labor in the project is $50 billion, and each worker on the project receives $5,000 per year in total compensation. This means that, in total, the project will generate 10 million job years, no matter how these job years are divided up over time. If the annual budget for the project is $2.5 billion over 20 years, that means the project will generate 500,000 jobs per year over 20 years, making it a long-term source of job creation. However, if the annual budget could rise to the $5 billion that means the project would generate 1 million job per year over 10 years. In this case, the project is a more intensive source of new job creation, but operating now only over a 10-year horizon rather than 20 years.

Self-Employment, Informal Sector, and Job Quality

In addition to this issue of being clear on how to count job-years, there is also the more familiar question in the time dimension of employment as to whether the jobs are full- or part-time. As purely a matter of measurement, one can of course convert part-time jobs into full-time equivalents. But in terms of assessing the welfare effects of clean energy investments and policy initiatives, one would want to distinguish the creation of full-time from part-time jobs, especially since full-time jobs are generally more stable and of higher quality. While we do not have data on the breakdown of jobs according to hours worked, we do provide an extensive discussion on job quality issues associated with clean energy activities. This includes a consideration of evidence on gender composition of various types of employment; wage versus self-employment; the size of enterprises in which people are employed; and educational attainment levels of workers. The main analytic issues are as follows[52]:

Treatment of self-employment. Countries which include the self-employed along with wage earners tend to have higher employment multipliers, particularly in the agricultural sector.[53] We will show evidence below as to the proportions of self-employed jobs that are generated through the various specific clean energy and fossil fuel sectors.

Informal Labor. Related to the issue of self-employment is that of informal labor, which has a very large presence in developing countries, such as Indonesia, but will also be significant in middle- and upper-middle income countries such as South Africa and Brazil. Informal employment refers to jobs that do not include regular payment of wages and benefits, and that do not fall under a country's system of labor laws and standards. Informal places of employment are more generally unregistered with government authorities and lie outside the formal regulatory and tax structure. Informal workers are frequently agricultural day laborers, urban street vendors,

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[52] Appendix 4 describes our methodology for estimating these various detailed employment effects from clean energy and fossil fuel investments in Brazil, Germany, Indonesia, South Africa, and the ROK.

[53] Even while this statement is accurate, we do also have to recognize a further set of important considerations here. That is, if spending were to increase by $1 billion, then employers will hire more workers to meet this demand in a wage-employment economy (we assume that prices and wages remain fixed in the I-O model). But if self-employment dominates, then it is unclear that the number of employed would increase. Earnings may increase instead while employment remains fixed. More precisely, a boost in final demand will, for certain, raise *total earnings*. But this increase in total earnings could result through: 1) increasing the number of self-employed jobs at the prevailing earnings level; 2) increasing earnings while keeping the level of employment constant, or 3) some combination of the first two possibilities. Working with the national I-O models, we cannot tell how the increase in final demand will play out among the self-employed.

or home-based textile workers. In many countries, women are disproportionately represented in such jobs, which pay poverty-level wages or worse.

For the purposes of our discussion, it would be important to measure the extent to which, for example, investments in building a clean-energy economy create opportunities not just for employment per se for those now in informal jobs, but for higher-quality jobs. This would mean better pay, better conditions, and more stability than informal workers experience at present. We are not able to measure this directly through the data available to us, but we will be able to draw some general inferences.

When there is a large informal labor market, this also means that the measured unemployment rate in a country will be low. Typically, a slack labor market in this situation will not entail a high rate of measured unemployment per se, but rather a larger informal labor market. As such, if we show that clean energy investments are capable of generating net new employment, that net new employment will not be moving people from "unemployed" to "employed," typically. It will rather, for the most part, move people from informal to formal employment. We will need to analyze the impact of this in judging the overall impact of clean energy investments on well-being.

Construction of Clean Energy Industrial Categories

To date, the grouping of industries in national I-O tables do not explicitly include "Renewable Energy" or "Energy Efficiency." They also do not include more specific industries, such as wind, solar, hydro, bioenergy, building retrofits, industrial efficiency or electrical grid upgrades. By contrast, the I-O tables do specifically identify fossil fuel industries, including oil and gas extraction, coal mining, support services for these extraction activities, power generation and distribution, and various petroleum- and coal-based manufacturing activities.

One can nevertheless work with the existing I-O tables to construct synthetic versions of the renewable energy and energy efficiency sectors. The procedure for doing this is to identify the various specific activities that produce inputs for a given renewable energy or energy efficiency industry, and to combine those activities in a way that reflects their actual use in producing renewable energy or energy efficiency outputs. For example, producing solar panels will require electrical equipment and supplies, glass and metal products, research and development, and construction. Producing bioenergy will require, cropping, forestry, refining, construction and R&D. Retrofitting buildings, by contrast, will entail 100 percent construction-industry activity.

Of course, in creating these synthetic renewable energy and energy efficiency industries within the I-O tables, one cannot simply identify the relevant set of activities. We also need to assign relative weights to each of these activities as components of the overall energy-producing process. For example, for building solar panels, what proportions should we assign to producing the electrical equipment, glass and metal products, construction and R&D? Here we have to exercise judgment, based on evidence outside the I-O tables that we can develop on each of the renewable energy and energy efficiency industries. Again, taking the case of the solar industry, we have assigned the following weights to the relevant activities in the specific case of the ROK: 51 percent for electrical equipment and supplies; 5 percent for glass products; 13 percent for various metal products; 16 percent for construction and 15 percent for R&D.

We follow this same procedure for all of the renewable energy and energy efficiency categories for each of our five selected countries. In doing so, we proceed from the methodology developed in Miller and Blair (2009).[54] We provide the details of our methodology, weighting schemes, and data sources underlying these calculations in Appendix 3.

Scaling Job-Creating Activities

The main scalar that we use for reporting employment creation levels through renewable energy and energy efficiency spending is jobs created per $1 million in expenditure. We derive the job-creation figures through calculations performed in using the respective national I-O tables for Brazil, Germany, Indonesia, South Africa, and the ROK. In each of these national I-O tables, the activity reported in the tables is expressed in national currencies. We converted the figures in national currencies into dollar equivalents on the basis of the average market exchange rate between national currencies and dollars in the year that each I-O table is reported.

We used this approach to measuring job creation for all five of the selected countries so as to be able to work with a uniform metric throughout this report. Beyond this, the jobs per $1 million is fully adequate for allowing us to make the most important observation we wish to make with these calculations, which is the *relative* level of job creation for the various clean energy activities in comparison with spending within the fossil fuel and nuclear energy sectors.

At the same time, to be able to compare the total number of jobs created between countries from spending within each of the various energy sectors, it is also useful to scale the jobs within the framework of each country's national wage scale. That is, of course, $1 million can purchase far more labor in, say, Indonesia than Germany. It would therefore be useful to scale our dollar employment estimates relative to the wage scale that operates in each of the selected economies. We have developed an approach to scaling the employment figures in this way, which we describe in Appendix 5. This discussion includes a separate set of employment estimates derived from this alternative scalar.

Assessing Relative Strengths and Weaknesses of I-O Models

Basic I-O models include a number of simplifying assumptions. This enables the models to be relatively transparent and tractable. But these simplifying assumptions also create limitations in the reliability of I-O models.

Linear Model. A basic I-O model is a linear model. That is, the basic I-O models assume that a given amount of spending will have a proportionate effect on employment no matter how much the level of spending changes, either up or down. For example, the impact of spending $1 billion on an energy efficiency project will be exactly 1,000 times greater than spending only $1 million on the exact same project. This will be approximately accurate in many situations, but

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[54] We have employed this methodology in several previous studies (see, e.g. Pollin et al., 2009) and in consulting work with the U.S. Department of Energy. The estimating technique we developed for the U.S. Energy Department have been corroborated through survey work as well as through data collected by the Energy Department as part of the energy provisions of the 2009 American Recovery and Reinvestment Act. At the same time, we recognize that there are other valid methods for defining and measuring job creation through clean energy economic activity. As we note in Chapter 11, Kang et al. (2011) present a useful alternative approach for measuring "green jobs" within the ROK economy. Wei, Patadia, and Kammen (2010) provide a survey of alternative approaches and findings for estimating the job impacts of operating renewable energy and energy efficiency sectors within the U.S. economy.

may not be in other situations. In using the I-O model for our estimation, we are assuming that it is reasonable to work with the assumption of linearity for our purposes.

Absence of supply constraints. The most significant consequence of the linearity assumption is that the I-O model takes no account of potential supply constraints in moving from a $1 million project to a $1 billion project. Under some circumstances, this could be a serious deficiency in the model. However, under the current conditions in the global economy - with widespread slack and slow growth continuing in the aftermath of the Great Recession - it is reasonable to assume that supply constraints are less binding than demand constraints. In the longer-term, these same conditions are not likely to persist. The employment estimations will therefore need to adjust to reflect this reality.

Relative prices fixed. Another result of the assumption of linearity that a basic I-O model assumes that prices remain fixed, regardless of changes in demand. A more fully specified model would take account of such factors. For example, if the prevailing slack economic conditions lead to reduced demand for solar panels, then prices of the panels will fall. This price decline could then perhaps mitigate the decline in demand.

Fixed industrial structures. Basic I-O models also assume that productive relationships remain stable over the period of analysis. But it is certainly the case that industrial structures evolve over time. This issue would seem especially relevant in considering employment conditions within the clean-energy economy, since economies will certainly undergo significant structural changes in the course of a clean energy transformation. How does structural change affect the reliability of employment forecasts?

In fact, the use of workers in clean energy industries and services will not change at an equivalently rapid pace over time, even though clean energy technologies will be advancing substantially. For example, a high proportion of energy-efficiency investments - such as for building retrofits, public transportation, and smart grid electrical transmission systems - will rely heavily on the construction industry. Some aspects of the work involved in retrofitting a building will change as retrofitting methods develop. But other aspects can be expected to remain stable (i.e. the technologies are relatively mature and are not expected to change quickly). Depending on the activity in question, the overall level of demand for workers to conduct retrofits may remain fairly stable, at least in the short- to medium-term.

A similar situation is likely to hold with the production of renewable energy in the short-run, regardless of whether the solar panels, wind turbines, or biofuel refining plants are more or less efficient with technologies that convert their raw materials into useful energy. That is, the need to employ workers to manufacture, transport, and install these newly developed renewable energy products is likely to remain fairly stable as a proportion of overall activity in the industry in the short- to medium-term. Therefore, the use of an I-O model should provide an effective analytic framework for research scenarios in which technology and productive relationships can be assumed to be fairly stable. Beyond this, the I-O model can, under many circumstances, also serve effectively as the foundation for estimating employment impacts even when technology and productive relationships are subject to change over time. This is an important consideration that we explore in some detail in the last section of this chapter.

Treatment of time dimension. The I-O model generates estimates as though everything is happening at one fixed point in time. A more realistic picture of the economy would of course have to recognize that the effects of public- and private-sector spending will take place in sequences over time, and that these timing effects are important. Adding a time dimension would make the model dynamic. If these considerations are of concern, a dynamic I-O model could be used which allow for changes over time.

Overall Assessment of I-O Models

Recognizing all of the above simplifying assumptions of the I-O model, we nevertheless conclude that it is the most effective available tool for estimating the employment effects of a large-scale clean energy investment project in national economies throughout the world.

The model is most reliable when we can reasonably assume that supply-side constraints are relatively insignificant. That is, the clean energy industry is able to expand without assuming that that expansion will be strongly impacted by supply shortages, which in turn could cause major changes in relative prices. We believe that such supply constraints on the expansion of clean energy activities will be relatively insignificant in the foreseeable future. This is especially the case since the expansion of the clean energy sector will occur in conjunction with retrenchments in the non-renewable energy sectors. These retrenchments in the non-renewable energy sectors will free up resources throughout the economy.

I-O vs. Computable General Equilibrium Models

The strengths of the relatively simple and transparent I-O structure can be seen more clearly by comparing this approach with a more complex approach, represented by Computable General Equilibrium (CGE).

In fact, CGE models are simply I-O models with price dynamics, supply-side constraints, and assumptions about technological change incorporated into the basic I-O structure. As such, CGE models typically place a much stronger emphasis on the role that prices play in influencing behavior and determining economic outcomes.

The core of a CGE model is typically an I-O model, showing the various relationships between industrial sectors and final demand. The I-O framework is then typically supplemented by a variety of elasticities, which describe how demand reacts to changes in prices. CGE models also incorporate some kind of equilibrium condition, such as market clearing (prices adjust so that supply must equal demand) or full-employment. This allows for the existence of a unique solution to the system of equations.

CGE models are costly to develop. Moreover, given the high fixed cost of creating the models, CGE models are often proprietary. This means that access to the model is restricted to the organization or researchers that developed the model. This can raise concerns regarding transparency and independent verification of the accuracy of the model's assumptions. The complex and proprietary nature of most CGE models makes it difficult to perform a careful analysis of the assumptions used in different applications and to determine if the assumptions are reasonable for answering any specific research question. This is because detailed descriptions of the models (including the equations which constitute the model) are often not available. The individual assumptions are often difficult, if not impossible, to identify from the general description of such models and the implications of specific assumptions are hard to trace. The reliability of such models therefore depends first and foremost on an assessment of the model's assumptions. That is, are the assumptions realistic? Are they helping us to understand important issues about the likely growth trajectory of the clean energy economy? To give one important case in point, CGE models often assume the economy operates at full employment at all times. Working with this assumption, it will of course be difficult to trace out any possible impacts of clean energy investments as net source of new job creation.

Given these challenges in working with a CGE model, for our purposes of estimating employment effects of clean energy investments, we have, again, concluded that the I-O model is our preferred methodology.

Incorporating Labor Productivity Growth and Variable Coefficients in Employment Estimates

Methodological Issues with I-O Models

Even while recognizing the relative strengths of the I-O approach in estimating the employment effects of clean energy investments, it is also important to consider possible approaches through which we can take account of changing production methods over time. As we have noted above, production technologies do certainly shift over time, so that a different mixture of inputs may be used to produce a given output. New technologies emerge while others become obsolete. Certain inputs may become scarcer, and, as result, firms may substitute other goods and services. The production process could simply become more efficient, so that fewer inputs are needed to produce a given amount of output. Energy efficiency investments do themselves produce a change in production processes - i.e. a reduction in the use of energy inputs to generate a given level of output. In short, we recognize that the I-O relationships in any given economy - including its employment effects of clean energy investments - are likely to look different twenty years from now compared to the results we are presenting in this report.

This raises the question of how we might take into account these kinds of changes in production technologies. Specifically, how would the employment estimates be affected if we were to take into account productivity changes over time?

In principle, a basic approach would be to track changes in the underlying survey data within an I-O model over time, and then use these patterns to forecast future I-O relationships. But the first problem here is that the amount of information needed to construct reasonable I-O tables is very large. This is why survey-based national I-O models are typically generated not more frequently than once every 3-5 years. For some countries, the models are updated only once every decade. In the absence of such detailed data, various forecasting techniques have been used to try to forecast what future I-O models might look like. However, as surveyed in Miller and Blair's standard I-O textbook (2009), these methods for forecasting future I-O relationships have been shown to be unreliable. This discussion draws on Miller and Blair and the underlying literature they survey.

One approach that has been used to predict future I-O coefficients is simple extrapolation. Two, or possibly more, I-O tables, which have been derived from survey data, are compared and the change in the coefficients is calculated. These changes are then extrapolated to some point in the future, assuming the trends observed continue. A first problem with this approach is that it is uncertain that the comparison of I-O coefficients for a limited number of points in time - sometimes as few as two points - truly reflects long-run trends. Various shocks, statistical variation, or survey-related issues could cause coefficients to vary in ways that have nothing to do with the underlying productive relationships. Such errors are then likely to be amplified into the future as these trends are extrapolated. Studies have therefore found that the most recent survey-based I-O models outperform models based on extrapolation techniques, even allowing that the survey model is out-of-date.

An alternative to extrapolation is to use marginal I-O coefficients to predict changes in production over time, given a particular level of final demand. A marginal I-O model is constructed by subtracting the coefficient in time *t-i* from the coefficient in time *t*, where *i* is the number of years between the two survey-based models. The resulting marginal I-O model is then used to predict changes in the output produced for a given level of final demand for goods and services. However, again, marginal I-O models do not appear to perform better than simply using the most recent survey-based model as a basis for estimating future production relationships.

Hybrid approaches have been developed for updating I-O models when some additional information is known, but the full set of survey data needed to construct a new model is not yet available. These techniques are often used to generate interim I-O models between "benchmark" years - that is, years in which the full set of survey data needed to produce a comprehensive I-O model is available. An example of this methodology is the bi-proportional technique (the "RAS procedure") used to update I-O models. This technique requires that the researcher know only the total output of each sector, the total inter-industry sales by sector, and total inter-industry purchases of each sector in order to update the I-O model for the year in which these three pieces of data are available. Using an iterative method, new coefficients are estimated based on the older survey-based I-O tables, but incorporating these new pieces of information. These partial-survey techniques require detailed information, by sector, of output, sales, and purchases. If this information is not available, the technique cannot be used and the most recent I-O tabulations are most likely the most reliable for describing productive relationships between sectors.

For the purposes of this report of estimating employment effects of a given level of expenditure, a simpler approach that may be workable would be to vary only the employment-output ratios in each sector, as opposed to the full set of relationships, or even the more limited set required for interim bi-proportional estimation. The employment-output ratio is simply the inverse of labor productivity, with labor productivity being defined as the amount of output produced per unit of labor. An increase in labor productivity will therefore reduce the employment-output ratio. This in turn would lower the employment multipliers estimated from the I-O model.

In principle, trends in labor productivity could therefore be useful for updating the employment estimates generated through I-O models. The employment-output ratios would then be adjusted to take into account the long-run rate of change in labor productivity. Detailed time series on labor productivity for each of the industrial sectors in a given I-O model may not be available. However, trends in labor productivity for broad sectoral divisions - agriculture, industrial production and services - will normally be available. These trends could then be used to estimate employment levels in an economy experiencing rising labor productivity over time.

Applications of Alternative Methodologies

To consider the impact of variable coefficients and rising labor productivity for our employment estimates, we first examine two different sources of data on I-O relationships and labor productivity. These are 1) output multipliers over time for alternative energy sectors based on figures from annual I-O tables; and 2) data on labor productivity growth by energy sector that we have derived on the basis of average productivity growth rates within agricultural, industry and services. In Appendix 3, we present details on our methods of estimating both output multipliers and labor productivity growth for alternative energy sectors. Following an examination of data from these alternative sources, we then consider a broader set of issues on the relationship between output, labor productivity and employment, in our five selected economies as well as more generally.

Evidence from Output Multipliers

The World Input-Output Database (WIOD), a project of the European Commission, produces annual I-O tables on a country-by-country basis.[55] To date, they have produced tables for 40 countries over the years 1995-2011. The 40 countries include four of our five selected countries, Brazil, Germany, Indonesia, and the ROK. These I-O tables enable us to generate output multipliers for each the relevant energy sectors in each of these four economies. But they do not contain sufficient information through which we can produce employment/output ratios.

We have used the information available to provide comparative output multipliers for the years 1995, the first year of the available WIOD tables, and 2007. We are using the 2007 I-O tables as the end point in our time series, rather than 2011, the last year of available data, because we want to avoid having the patterns we observe be influenced by the impact of the global 2008-2009 financial crisis and Great Recession. Our focus here is longer-term developments in each economy's productive structures, not on cyclical effects.

We present the results of this exercise in Table 6.1, which reports the average annual change in sectoral output multipliers over our 1995-2007 time period. As we can see, for three of our four selected countries, Brazil, Germany and the ROK, the changes in the output multipliers over 1995-2007 are negligible. The median average annual change in the clean energy sector output multipliers are 0.1 percent for Brazil, -0.2 percent for Germany, and 0.3 percent for the ROK. Assuming these figures are accurate, we can conclude that production relationships between the domestic sectors in the I-O tables did not change significantly over the 12-year period between 1995 and 2007. If we were to extrapolate this pattern into the future, we would therefore be on reasonably safe grounds in assuming that output multipliers would change only at a modest pace over the 20 years covering the clean energy investment project we are advancing.

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[55] The full set of WIOD data can be found at: http://www.wiod.org/new_site/home.htm. An extensive discussion of the contents, sources and methods used with WIOD is Timmer (2012).

Table 6.1: Change in energy-sector output multipliers, 1995-2007

Figures are average annual percentage increases

	Brazil	Germany	Indonesia	The ROK
Renewables				
Bioenergy	0.3	-0.2	4	0.6
Hydro	0.1	-0.1	5.2	0.4
Wind	0.1	-0.2	5.3	0.3
Solar	-0.1	-0.3	5.1	0.3
Geothermal	-0.1	-0.1	4.5	0.4
Energy efficiency				
Building retrofits	-0.2	-0.2	4.1	0.3
Grid upgrades	0	-0.4	5.1	0.3
Industrial efficiency	0.1	-0.3	5.2	0.4
Fossil fuels				
Oil and gas	-0.2	0	4.2	0.5
Coal	-0.2	-0.8	3.5	0.2
Range of estimates for clean energy sectors	-0.2 - 0.3	-0.4 - -0.1	4.0-5.3	0.3-0.6
Median estimates for clean energy sectors	0.1	-0.2	5.1	0.3

Sources: Authors' calculations using Timmer (2012) further described in Appendix 3.

The data for Indonesia show a different pattern. As we see in Table 6.1, Indonesia's output multipliers in its energy sectors increased at a very rapid rate across the board. The range in the average annual increase for the clean energy sectors was between 4-5.3 percent, and the median annual rate of increase was 5.1 percent per year. Assuming the data are accurate, such gains in Indonesia's output multipliers between 1995-2007 could reflect two underlying patterns: 1) stronger linkages between domestic sectors as a result of economic development; or 2) major increases in domestic content for the relevant sectors of Indonesia's economy.

In fact, Indonesia did achieve major gains between 1995-2007 in both its overall net export position as well as its net exports for the sectors that serve as inputs to Indonesia's clean energy sectors. We can observe this through the data we present in Table 6.2. As we see there, Indonesia's net export position in total merchandise trade rose from 2.4 to 5.8 percent of GDP between 1995 and 2007. This is a net gain of $15 billion, in 2007 dollars. Further, the biggest single area of gain was in the machinery and transportation sector, which would be a major supplier of components as Indonesia begins to build its clean energy sectors. As Table 6.2 shows, in 1995, Indonesia was a net importer of machinery and transportation equipment at the level of 6.2 percent of GDP. As of 2007, this trade deficit position closed to 0.9 percent of GDP. This is a $23 billion improvement in Indonesia's net trade position, a major achievement over only a 12-year period.

Table 6.2: Indonesia's trade balance, 1995 and 2007

Net exports or imports as percentage of GDP
Positive numbers = net exports; Negative numbers = net imports

	1995	2007
Total merchandise:	2.4	5.8
Manufacturing	-3.3	-2.1
Agriculture	1.0	3.1
Fuels and mining	3.3	1.0
Within manufacturing:		
Machinery and transport	-6.2	-0.9
Chemicals	-2.3	-0.8
Iron and steel	-1.0	-0.7

Sources: Authors calculations using World Trade Organization Statistics Database for trade figures: http://stat.wto.org/Home/WSDBHome.aspx?Language=, World Bank Databank for GDP figures: http://databank.worldbank.org/data/home.aspx.

Nevertheless, even with Indonesia's major gain in the domestic content share in its machinery and transportation sector, it remains the case that, as of 2007, Indonesia's energy sector output multipliers had reached rough parity levels, but had not significantly exceeded, those for Brazil, Germany, and the ROK. We can see this from the figures we present in Table 6.3, showing the median *levels* of the output multipliers in the clean energy and fossil fuel sectors for Brazil, Germany, Indonesia, and the ROK. As Table 6.3 shows, the Indonesian 2007 median clean energy output multiplier, at 2.2, is modestly higher than that for the ROK, at 2, and somewhat higher still than those for Brazil, at 1.8 and Germany, at 1.6. Indonesia's median fossil fuel output multiplier for 2007 is nearly identical to those of the other three countries. Thus, even with Indonesia achieving major increases in its energy-sector multipliers between 1995-2007, it would still be unlikely that this kind of pattern would continue in subsequent decades.

Table 6.3: Median energy-sector output multiplier levels, 2007

	Clean energy	Fossil fuels
Brazil	1.8	1.9
Germany	1.6	1.7
Indonesia	2.2	1.8
ROK	2.0	1.5

Source: Authors' calculations using Timmer (2012), further described in Appendix 3.

Evidence from Sectoral Labor Productivity Growth Estimates

In Table 6.4, we present figures on sectoral labor productivity growth rates for our alternative energy sectors in each country. We calculated these figures based on the labor productivity growth rates for agriculture, industry and services in each of the countries. That is, in each of the energy sectors, we estimated the relative proportions of industry, agriculture and services that contribute as inputs to each of the sectors, then use these proportions as weights in assigning overall productivity rates for each sector. The figures are derived from the World Bank's World Development Indicators.

Table 6.4: Estimated energy sector labour productivity growth rates

Figures are weighted averages derived from annual growth in per capita value added in agriculture, industry and services

	Brazil	Germany	Indonesia	South Africa	ROK
	1995-2007	1995-2007	1995-2007	2001-2010	1995-2007
	(percentages)				
Renewables					
Bioenergy	2.1	3.0	1.1	5.0	4.9
Hydro	-0.4	1.8	1.1	1.6	4.4
Wind	-0.4	1.2	0.5	0.7	3.0
Solar	-0.7	2.3	1.0	1.4	5.8
Geothermal	-0.6	2.0	1.0	1.5	5.1
Energy efficiency					
Building retrofits	-0.9	2.5	0.9	1.2	6.8
Grid upgrades	-0.9	2.5	0.9	1.2	6.8
Fossil fuels					
Oil and gas	-0.9	2.5	1.2	1.2	6.8
Coal	-0.6	2.0	1.5	1.5	5.1
Range of estimates for clean energy sectors	-0.9-2.1	1.2-3.0	0.5-1.1	0.7-5.0	3.0-6.8
Median estimates for clean energy sectors	-0.7	2.3	1.0	1.2	5.1

Sources: See Appendix 3.

In reviewing Table 6.4, the first pattern to note is that the labor productivity growth figures for Indonesia are not especially high, unlike the pattern with Indonesia's output multipliers. For the clean energy sectors, we estimate that average annual labor productivity growth ranges between 0.5-1.1 percent. The median clean energy sectoral productivity growth rate is 1.0 percent. These patterns underscore the fact that, for achieving major improvements in a country's output multipliers, labor productivity growth does not need to be especially strong as long as 1) the country's domestic content is rising sharply; or 2) linkages between a country's domestic industrial sectors become stronger and denser as a result of economic development and diversification.

However, we do now see a second major outlier pattern with the labor productivity data, in this case with the ROK. Our average annual labor productivity growth estimates between 1995-2007 for the ROK's clean energy sectors are very high, ranging between 3 and 6.8 percent, with a median annual productivity growth figure of 5.1 percent. This contrasts with the slow rate of increase in the ROK's clean energy sector's output multiplier, where, as we saw in Table 6.1, the median clean energy output multiplier rate of increase was 0.3 percent. In the case of the ROK, assuming the data are roughly accurate, this could be explained by the fact that major structural changes in the ROK economy occurred prior to 1995, during the country's period of rapid industrialization. After 1995, the pace of structural change slowed and this is reflected in the minimal change in the output multipliers. By contrast, the ROK's rapid increases in sectoral labor productivity conveys a pattern of rapid gains in labor-saving production processes as opposed to structural changes that alter the relationship between the country's industrial sectors.

Overall, in assessing the figures we have estimated for output multipliers and labor productivity growth, we can still reach some basic conclusions for our purposes, even after allowing for the prospect of inaccuracies in some of the estimates. That is, it is reasonable to conclude that, under most circumstances over the next 20 years, we are likely to see gains in labor productivity growth in the clean energy sectors for Brazil, Germany, Indonesia, South Africa and the ROK that are within the range of 1-2.5 percent per year. We are confident, in other words, that Brazil's clean energy sectors will not likely continue to experience zero, or even slightly negative, productivity growth over the next 20 years, or that the ROK is likely to sustain a productivity growth rate in the range of 5 percent per year in its clean energy sectors (assuming that this range is accurate for 1995-2007).

There will still almost certainly be situations in which labor productivity growth will outside the range of between 1 and 2.5 percent per year. For example, labor productivity in Brazil's existing large bioenergy sector will certainly be rising in the coming years through mechanization (De Almeda et al., 2007). Mechanization, and thus productivity gains will be encouraged through recent legislation in Brazil that prohibits direct burning of sugar cane on fields. Nevertheless, on balance, assuming that long-run sectoral labor productivity growth will range between 1 and 2.5 percent is a reasonable framework for generating broad macroeconomic trends.

It is similarly unlikely that there will be further dramatic shifts in the extent of domestic content in the clean energy sectors for our five selected countries comparable to what we have observed in the Indonesian case over 1995-2007. In Chapter 5, we have reviewed at some length the prospects for shifts in domestic content as the clean energy project proceeds. As we saw there, after allowing for declines in domestic tradable activities on the order of 20 percent as a result of expanded activity in the clean energy sectors, the range of potential shifts in domestic content would be modest for all five countries. This, in turn, means that changes in each country's employment/output multipliers resulting from shifts in domestic content would be correspondingly modest. Similarly, we do not expect the countries considered here to undergo widespread structural changes that would raise their output or employment multipliers significantly.

Overall again, the most likely scenario for all five countries would be for labor productivity to increase in their clean energy sectors at an average rate of between 1 and 2.5 percent per year. Because domestic content is unlikely to change dramatically over this period, the consequent employment/output ratios in each country would also most likely decrease at a rate of growth that reflects the sectors' rate of productivity growth - at a rate within the range of 1-2.5 percent. As such, the next question to consider, to which we now turn, is what the impact is likely to be on employment creation through the clean energy investment project when average labor productivity growth does generally increase at rates between 1-2.5 percent per year.

Broader Issues with Productivity Growth and Employment

Working from the evidence we have presented on output multipliers and productivity growth, there is a basic reason to conclude that, certainly as a first approximation, employment gains through clean energy investments will likely grow over a 20-year time trend, even after taking account of productivity effects on employment levels. This is true because, in addition to each of our five economies experiencing productivity growth over time in their clean energy sectors, most likely in the range of 1-2.5 percent per year, they will also be experiencing *output growth* in their clean energy sectors, and GDP growth for their overall economies.

As we mentioned in Chapter 1, in the country-by-country estimation models that we present in Chapter 8-12, we assume that, in each of our five selected countries, clean energy investments will be maintained every year at 1.5 percent of GDP over the full 20-year project period. Moreover, in generating both our output and employment estimates in Chapters 8-12, and as we discuss further in these later chapters, we make assumptions as to the average annual rate of GDP growth for each of the five countries over the 20-year period. These average annual GDP growth projections are, respectively: 3.7 percent for Brazil; 2.0 percent for Germany; 5.0 percent for Indonesia; 4.0 percent for South Africa; and 3.3 percent for the ROK.[56] We present these growth projections in Table 6.5, along with actual GDP growth figures for each of these countries from 1995 to 2007; and from 2001 to 2010. Table 6.5 also presents the median figures for growth in labor productivity and output multipliers for the various countries' clean energy sectors, as already presented in Tables 6.1 and 6.4.

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[56] As we discuss for each specific country case in Chapters 8-12, the 20-year GDP growth projections presented in Table 6.5 are conservative estimates either taken directly from, or derived from various official sources. These sources include the International Energy Agency for Brazil, the IMF and OECD for Germany and South African, the EIA for the ROK and the Indonesian government's own growth projections. Such long-term GDP growth projections can of course end up being inaccurate as actual economic activity proceeds over time. Nevertheless, these projections are useful for our purposes, in that they provide reasonable broad parameters within which to assess each country's 20-year clean energy investment prospects.

Table 6.5: Growth rates of national GDP and clean energy sector labor productivity and output multipliers

	GDP growth rates			Clean energy sector growth of median labor productivity and output multipliers	
	Projected 20-year rates	**Actual 1995 – 2007**	**Actual 2001 - 2010**	**1995-2007, except for South Africa, which is 2001-2010**	
				Labor productivity growth	Output multiplier growth
Brazil	3.7%	2.8%	3.5%	-0.7%	0.1%
Germany	2.0%	1.6%	2.0%	2.3%	-0.2%
Indonesia	5.0%	3.2%	5.0%	1.0%	5.1%
South Africa	4.0%	4.6%	4.0%	1.2%	NA
ROK	3.3%	3.7%	3.3%	5.1%	0.3%

Sources: Sources for projected GDP growth presented in Chapters 8-12. Actual GDP growth rates from IMF *International Financial Statistics*. See Tables 6.1 and 6.4 for output multipliers and productivity growth.

Because we are assuming that clean energy investments will be sustained at 1.5 percent of GDP throughout the full period, it follows that we are also assuming that clean energy investments will be growing annually at exactly the same rate as each country's annual GDP growth rate. That is, we assume that, over a 20-year investment cycle, clean energy investments will increase at average annual rates of 3.7 percent in Brazil; 2.0 percent in Germany; 5.0 percent in Indonesia; 4.0 percent in South Africa; and 3.3 percent in the ROK.

What therefore is likely to be the combined effects of GDP growth and labor productivity growth on the employment effects of clean energy investments? The answer is that it depends on the relative rates of output and labor productivity growth. The data we have presented in Table 6.5 will therefore be valuable for addressing this question. But, even before considering these data further, it will be useful to consider three broad sets of possibilities for both GDP and labor productivity growth trajectories over time: that both GDP and productivity grow, alternatively, at low, medium and high rates. As we present in Table 6.6, these three sets of possibilities then produce nine alternative possibilities for employment growth, based on the alternative trajectories for both GDP and labor productivity growth.

Table 6.6: Possible impacts on employment from varying rates of GDP and labor productivity growth

	Rate of labor productivity growth			
		Low	**Medium**	**High**
Rate of GDP growth	**Low**	No employment impact	Small employment decline	Large employment decline
	Medium	Small employment increase	No employment impact	Small employment decline
	High	Large employment increase	Small employment increase	No employment impact

Source: Authors' own presentation.

As Table 6.6 shows, if output and labor productivity are both growing at the same rate - that is, if both are growing at either low, medium, or high rates - there will be no change in employment over the 20-year investment period relative to the effects that we estimate for year one. Each additional unit of GDP will have been produced as a result of an exactly equal increase in productivity.

However, as Table 6.6 also shows, in all cases in which output growth exceeds labor productivity growth, the net effect will be that employment will expand over time relative to the effects that we estimate in year one. For example, assume that Indonesia's GDP growth is indeed maintained at 5 percent per year over the 20-year investment period. Let us then also assume that its rate of labor productivity growth in the clean energy sectors is maintained at a rate equal to its median sectoral rate over 1995-2007, of 1.0 percent. This then means that employment growth in Indonesia's clean energy sector will grow by 4.0 percent per year over the 20-year investment cycle.

As we show in Table 6.6, the only way in which employment from clean energy investments will decline significantly over the 20-year investment period is when labor productivity growth exceeds output growth by a significant amount. Consider the case of the ROK, which we project as maintaining a 20-year average GDP growth rate of 3.3 percent per year. Then let us also assume that labor productivity growth in the clean energy sectors is maintained at the median annual rate of 5.1 percent that we estimated for 1995-2007. This would then mean that employment growth for clean energy investments will be declining over time by 1.8 percent per year.

However, the broader set of evidence suggests that the ROK will not sustain labor productivity growth in its clean energy sectors in the 5 percent range that we estimated for 1995-2007. Indeed, when we consider as a whole the labor productivity growth patterns presented in Table 6.5 on the respective growth rates of GDP along with those for productivity and output multipliers in the clean energy sectors, what emerges as the typical situation is that GDP growth rises faster than labor productivity growth.

More generally, the literature on the relationship between labor productivity and output growth shows that these two growth rates do generally move together, with output growth typically increasing at a faster rate than productivity growth. This is for the simple reason that, as an arithmetic identity, output can increase through both a rise in the number of people working and the number of hours people are employed at jobs, as well as through raising workers' productivity levels during their time on the job. As such, when demand for a product increases, this will lead to increases in the production of that product, and hence, more people employed more hours to produce the product. An expansion in the demand for clean energy will therefore produce an expansion in output and employment in these sectors that should exceed increases in labor productivity generated within these sectors.

The issue of the general relationship between output and labor productivity growth is generally referred to in the literature as the Kaldor-Verdoorn effect. Overall, the empirical results from this literature are robust in finding that increases in labor productivity growth are between 30-60 percent as large as any given increase in output growth. This would mean, for example, if output grows by 4 percent over a given period of time, productivity should then typically increase over this same period by between 1.2 and 2.4 percent.[57] In the Indonesia case as we discussed above, if output were to grow over our 20-year clean energy investment period by 5 percent per year, then we would typically expect labor productivity to increase at between 1.5 and 3 percent per year over this same period.

Overall then, if we operate broadly within the analytic framework of the Kaldor-Verdoorn law, which is generally supported by the output and labor productivity growth figures we have reviewed here, it is reasonable for us to conclude that the levels of employment that we estimate in terms of the 2012 I-O relationships will be typically increasing over the 20-year investment period. We should finally also add that the rate of increase in employment will also likely be faster than the growth in each country's population. As such, if anything, the employment estimates that we generate from our estimates with the 2012 data will grow both in absolute terms and relative to each country's population beyond 2012, over the full 20-year clean energy investment period.

We will return to these issues in Chapters 8-12, when we review our country-by-country estimates for employment gains through each country's 20-year clean energy investment project. In these discussions, we provide projections of employment creation for clean energy investments both for Year 1 and Year 20 in our 20-year investment cycle. Our Year1 estimates are generated directly from each country's recent I-O tables. For our Year 20 projections, we assume two separate rates for average annual labor productivity growth in each country's clean energy sectors, 1 percent and 2.5 percent per year. We derive this 1-2.5 percent range from the actual labor productivity data over 1995-2007 that we have reviewed above. From this range of assumptions on average labor productivity growth, in combination with our assumption for average GDP growth in each country over the 20-year cycle, we are then able to generate a range of estimates as to how much employment will be created after 20 years in each country

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[57] Storm and Naastepad (2012) review the empirical research on the Kaldor-Verdoorn effect from the original work of Verdooorn through studies published in 2010. Observing primarily studies focused on OECD economies, they report that the relationship "has been confirmed in the overwhelming majority of these studies, irrespective of the differences in econometric methods and data employed. The effect is found statistically significant for cross-section estimations across countries or regions and for specific industries, but also for time series econometric studies for single countries or regions (2012, p. 82). The evidence for developing countries also generally supports this result (Timmer and Szirmani, 2000). However, even where the results for developing countries appear to be more mixed (e.g. Mamgain, 1999), the issue is that labor productivity growth may not consistently accelerate along with output growth, not that productivity growth is consistently exceeding output growth. Recognizing this robust general pattern between aggregate output and productivity growth does not imply that the relationship should hold constantly over all industries and all time periods. For example, Baily and Bosworth (2014) show that with the U.S. manufacturing sector over 1987-2011, a sharp disparity emerged between the very rapid rates of productivity growth in the computer and electronics industry, and the non-computer manufacturing industries, in which productivity growth was below the economy-wide average. Similarly, Haraguchi and Rezonja (2013) document how the relationship between the growth rates of productivity, employment, output in manufacturing vary at different stages in a country's development and according to whether the economy's growth trajectory is either profit-led or wage led.

through its clean energy investment project. As we will review in Chapters 8-12, we find that employment creation through clean energy investments will increase over time under almost all the scenarios we consider. This is precisely because, under most of the scenarios we consider - including when we assume labor productivity growth at its high-end figure of 2.5 percent per year - GDP is still increasing, by our assumptions, at a faster pace.

CHAPTER 7: EMPLOYMENT CREATION THROUGH CLEAN ENERGY INVESTMENTS

In this chapter, we present the results of our estimates on employment creation through spending on renewable energy and energy efficiency within Brazil, Germany, Indonesia, South Africa, and the ROK. The specific renewable energy and energy efficiency sectors that we have modeled within each country's national I-O model are bioenergy, hydro, wind, solar, and geothermal power among the renewable sectors; and building retrofits, industrial efficiency and electrical grid upgrades within energy efficiency. In Appendix 3, we show the specific weighting of inputs through which we define each of these sectors within the national I-O models. We then also report employment figures on coal and oil/gas production in each of the five countries. Finally, to provide broader reference points for our discussion, we also show employment generation figures through spending within each country's overall economy.

We report two sets of estimates for each of the five selected countries. The first set is comprised of estimates of overall job creation generated by spending within the respective energy-producing sectors. This includes both direct and indirect employment. We present these overall job creation estimates within two scenarios. Under the first, we assume domestic content is stable as renewable energy and energy efficiency investments expand significantly. Under the second, we assume that a country will need to increase its proportion of imported inputs to meet the demands within the rapidly expanding renewable energy and energy efficiency sectors. In Chapter 5, we described in detail our methodology for estimating these alternative scenarios with respect to domestic content and imports. Our basic calculation is to assume that, with all tradable activities linked to each of our renewable energy and energy efficiency sectors, import content rises by 20 percent relative to its current level. This is in response to the expansion of demand in that sector and our assumption, with this second set of calculations, that domestic resources will not be adequate for meeting the increased demand.

We first present our full set of results in terms of jobs created per $1 million spent. To facilitate comparisons on job creation levels across sectors, we then present summary tables, focusing on weighted averages of the employment creation figures for renewables, energy efficiency and fossil fuels under the stable domestic content assumption.

We have used the following weighting scheme in aggregating the specific sectors within each energy-producing industry: With renewable energy, all sectors - bioenergy, hydro, wind, solar, and geothermal - are weighted equally. With energy efficiency, we have assigned a 50 percent weight to building retrofits, to reflect the centrality of this area of energy efficiency. We then weighted the other two energy efficiency sectors, industrial efficiency and electrical grid upgrades, at 25 percent each. With fossil fuels, we have weighted coal and oil/gas equally. We recognize that, in any given country setting, the actual size of any given sector in all energy-producing areas, will depend on the specific conditions in each country. But we have assigned this one basic weighting scheme in the interests of simplicity and clarity across all of our selected countries here.[58]

In the second set of employment estimates, we then decompose the overall job creation figures - including, again, both direct and indirect jobs - in order to provide some specificity as to the features of employment in each sector and the quality of jobs.

Data on wages and other income indicators were not uniformly reliable across our five countries. As such, we utilized four alternative indicators for describing the types of jobs linked to each energy sector. These four indicators are: 1) the proportions of female employment; 2) the levels of educational attainment; and the proportions 3) in self-employment and 4) working in micro-enterprises. The educational attainment levels associated with each energy sector provide a measure of the quality of jobs available in each sector. The proportions of workers linked to each energy-producing sector that are self-employed as opposed to earning wages; and that work in micro-enterprises, as opposed to larger-scale operations, provide measures of the extent of informal employment as a share of total employment. Details of the methodology we used to generate these disaggregated employment estimates are presented in Appendix 4.

In Appendix 4, we also provide additional evidence on the occupational characteristics within the various industries that are engaged in both clean energy and the fossil fuel sectors. That is, we show within, for example, the agricultural, construction and machinery industries in all five countries the proportions of self-employment, microenterprise employment and educational attainment relative to economy-wide averages for these sectors. We also report in Appendix 4 figures on economy-wide average earning levels in each of the five countries, and what we estimate the approximate range of earnings is likely to be in the relevant clean-energy and fossil-fuel sectors relative to these economy-wide averages.

The figures we report in this chapter are based fully on the methodologies we describe in Chapter 6 concerning the I-O tables, and our discussion in Appendix 4 for decomposing the total job creation into categories. We do not attempt to incorporate into this discussion broader considerations, such as skill needs for workers in each country as clean energy investments expand. We also do not consider here issues of how to most equitably handle the transitional issues facing workers who are currently dependent on the fossil fuel sectors, as these sectors contract. We rather have taken up these more qualitative matters in our Chapter 5 discussion on labor market issues within industrial policies.

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[58] At the same time, in Appendix 6, we examine the impact on our employment multiplier estimates from varying the relative weights within the renewable energy sectors. We also shift the relative weights between renewables and energy efficiency to equal proportions. As we show in Appendix 6, for the most part, these shifts in the weighting schemes do not exert a significant influence on our overall findings with respect to employment levels generated by clean energy investments.

Brazil

Overall Employment Creation

In Table 7.1, we show our full set of estimates in terms of employment per $1 million. Considering initially our estimates on renewables, it is first of all clear that by far, the most labor-intensive sector is bioenergy, in which direct jobs for producing bioenergy is at 73.1 per $1 million. This contrasts with a range of about 14-19 for hydro, wind, solar, and geothermal. Of course, the difference here is that, with bioenergy, the basic input is agricultural products. Producing these in Brazil - and as we will see, in most other countries as well - is significantly more labor intensive than, for example, the manufacturing, transportation and construction activities that are major inputs in the other renewable areas. As we will discuss more below, the quality of jobs in bioenergy also tends to be poor, due to low wages and bad working conditions for most agricultural workers in Brazil. But as we also discuss below, working conditions in Brazil's bioenergy sector are likely to improve over time as the sector becomes more mechanized. This will also mean that the employment levels per dollar of expenditure will decline.

Table 7.1: Brazil. Employment creation through spending in alternative energy sectors, 2005

Jobs per $1 million

	Domestic content stable			**Domestic content declines**		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	73.1	8.7	81.8	73.1	8.5	81.6
Hydro	13.9	11.7	25.5	13.7	11.5	25.2
Wind	18.9	10.3	29.2	18.5	10.1	28.6
Solar	14	11.7	25.7	13.5	11.6	25.1
Geothermal	17.7	11.1	28.7	17.5	10.9	28.4
Weighted average for renewables	27.5	10.7	38.2	27.3	10.5	37.8
Energy efficiency						
Building retrofits	34.2	12	46.2	34.2	11.9	46.0
Industrial efficiency	13.6	11.6	25.1	12.0	11.8	23.9
Grid upgrades	13.0	13.2	26.2	12.1	13.0	25.1
Weighted average for efficiency	23.7	12.2	35.9	23.1	12.1	35.2
Fossil fuels						
Coal	10.0	12.3	22.4	NA	NA	NA
Oil/natural gas	10.6	9.3	20	NA	NA	NA
Weighted average for fossil fuels	10.3	10.8	21.2	NA	NA	NA
Overall economy	20.1	16.0	36.1	NA	NA	NA

Source: See Appendix 3.

In terms of indirect jobs - those jobs generated through the supply chains associated with renewable energy production - we see that the range is narrow across all renewable sectors, at about 9-12 jobs per $1 million.

We average the overall employment effects within renewable energy based on our simple weighting scheme in which each of the five renewable sectors each account equally for 20 percent of the total amount of employment generation. Based on this weighting approach, we then generate the result that spending $1 million in Brazil on renewable energy generates about 38 jobs, including 27 direct and 11 indirect jobs. When we recalculate these figures assuming that domestic content declines in these sectors according to our criteria that domestic inputs decline by 20 percent in all tradable activities, the impact is modest - i.e. the overall job creation figure falls only from 38.2 to 37.8 jobs per $1 million.

Our estimates for energy efficiency spending in Brazil are not dramatically different than those for renewable energy. Considering our three energy efficiency categories, spending on building retrofits is significantly more labor intensive than electrical grid upgrades. Retrofits require about 46 jobs per $1 million, while grid upgrades and industrial efficiency entail, respectively, only 26 jobs and 23 jobs per $1 million. But in aggregating an “energy efficiency” sector, because we assume that building retrofits accounts for 50 percent of our total energy efficiency category, with industrial efficiency and grid upgrades each accounting for 25 percent, overall job creation through energy efficiency is about 36 jobs per $1 million in spending. In this case as well, we see that allowing for a decline in domestic content in these activities according to our criteria has only a minor impact on overall job creation through energy efficiency spending activities.

With respect to fossil fuels, in the case of Brazil as well as the other four economies, we can work with data that comes directly out of the national I-O model. In generating overall employment figures for the fossil fuel sector, we assume that spending levels for coal and oil/gas are equal, so that they receive equal weights in our calculations. The result of these calculations is that overall spending on both coal and oil/gas range between about 20-22 jobs per $1 million.

In the last row of Table 7.1, we show our estimated employment multipliers for the overall Brazilian economy. As we see, that figure is 36.1 jobs per $1 million, only slightly less than the weighted average figures for Brazil’s renewables and efficiency sectors.

Table 7.2 provides summary figures on these job estimates for Brazil. As the table shows, first the aggregated clean energy sector generates, on average about 37 jobs per $1 million, while the fossil fuel sector produces about 21 jobs per $1 million. The basic story then is, for Brazil, spending on the clean energy economy will produce about twice as many jobs per dollar of expenditure than an equal amount of spending on fossil fuels. A clean energy investment strategy will not increase or decrease job creation significantly relative to overall spending within the Brazilian economy. As such, the major benefits for Brazil through advancing a clean energy investment strategy are focused within the energy system itself and the related environmental impacts. Clean energy investments will produce both major reductions in CO_2 emissions and increase job opportunities relative to maintaining the country’s existing fossil fuel based energy systems.

Table 7.2: Brazil. Summary employment figures, 2005

Direct + indirect employment with stable domestic content

	Jobs per $1 million
Renewable energy	38.2
Energy efficiency	35.9
Clean energy total *(with equal renewables and efficiency weights)*	37.1
Fossil fuels	21.2
Clean energy relative to fossil fuels *(percentage)*	75.2%
Overall economy	36.1
Clean energy relative to overall economy *(percentage)*	2.8%

Source: Generated from Table 7.1. Underlying calculations from Appendix 3.

Composition of Employment

We present our results on the composition of employment in Brazil's clean energy and fossil fuel sectors in Tables 7.3 and 7.4, including our four measures of employment composition: female share of employment; percentages in self-employment and working in micro-enterprises; and educational attainment levels.

Table 7.3: Brazil. Composition of employment generated through alternative energy sector spending, 2005

- *Gender composition of workforce*
- *Wage vs. self-employment*
- *Micro vs. non-micro enterprises*
- *Educational attainment levels (separate table below)*

	Total employment	**Female employment**	**Self-employment**	**Micro enterprise employment**
	(Jobs per $1 million)	*(Percentage)*		
Renewables				
Bioenergy	81.8	34%	66%	41%
Hydro	25.5	21%	31%	41%
Wind	29.2	19%	32%	42%
Solar	25.7	20%	36%	47%
Geothermal	28.7	15%	40%	53%
Energy efficiency				
Building retrofits	46.2	10%	45%	60%
Industrial efficiency	25.1	19%	32%	41%
Grid upgrades	26.2	21%	33%	43%
Fossil fuels				
Coal	22.4	21%	33%	37%
Oil/natural gas	20.0	23%	30%	38%

Source: See Appendix 4.

Table 7.4: Brazil. Educational profile of employment generated through alternative energy sector spending, 2005

	No education or less than primary level	Primary level	Secondary level	Tertiary level
	(Percentage)			
Renewables				
Bioenergy	13%	62%	19%	6%
Hydro	4%	56%	35%	5%
Wind	4%	56%	35%	4%
Solar	4%	56%	35%	5%
Geothermal	5%	61%	30%	4%
Energy efficiency				
Building retrofits	6%	66%	26%	3%
Industrial efficiency	4%	54%	37%	5%
Grid upgrades	4%	54%	37%	5%
Fossil fuels				
Coal	7%	56%	32%	5%
Oil/natural gas	3%	51%	40%	6%

Source: See Appendix 4.

Gender Balance. As a first indicator of the composition of jobs in Brazil's various energy sectors, we see in Table 7.3 that all sectors disproportionately employ males over females. With renewables, the highest proportion of female employment is in bioenergy, at 34 percent of total employment. This relatively large figure reflects the high representation of female workers employed in domestic agricultural production. With all other renewable energy sectors, female employment ranges between only about 15-20 percent.

The female representation is lower still in building retrofits, with only 10 percent female employment. This is due to the construction industry being dominated by males, in Brazil and elsewhere. With industrial efficiency and grid upgrades, the female share is, as with most renewables, in the range of 20 percent of total employment. We also see that this same roughly 20 percent female share holds in both of our fossil fuel sectors, coal and oil/gas.

Broadly speaking, it is clear that job opportunities in all areas of Brazil's energy economy are weighted heavily towards males. Bioenergy is the only exception. But here the higher proportion of jobs for females are in agriculture, where incomes, opportunities and security are relatively low.

This point is worth highlighting more here, since Brazil operates with a major bioenergy sector. A 2007 joint study sponsored by the OECD and the International Transit Forum describes conditions in Brazil's biofuels industry as follows:

> *The majority of jobs created are for sugarcane plantation and harvesting activities, which are low quality jobs, since they involve insalubrious activities (manual harvesting). Another problem of the sugarcane plantation is the seasonality of the production process. Therefore, a large part of the workers dedicated to sugarcane harvesting work only 7 months per year. The Ministry of Labor has strengthened the regulation on working conditions. Although working conditions have improved considerably in the last decades, it is still a controversial subject. The mechanization of harvesting is expected to improve working conditions. Harvesting machines will replace unskilled temporary workers. The average productivity and salary tend to rise. However, the labor intensity of ethanol production will decrease with a substantial impact on the unemployment rate (De Almeida, Bomtempo and De Souza E Silva, 2007, p. 7).*[59]

Self-Employment and Micro Enterprises. In terms, first, of self-employment, we see that only in bioenergy are the majority of workers - in fact, 66 percent - self-employed. Building retrofits are next highest, at 45 percent self-employment. Otherwise, with respect to other clean energy sectors as well as fossil fuels, self-employment constitutes about 30-40 percent of total employment.

In both building retrofits and geothermal energy, the majority of workers are employed in micro-enterprises. Otherwise, the proportion in the remaining clean energy and fossil-fuel sectors that work in micro-enterprises is mostly about 30-40 percent again - a minority, but a significant minority nonetheless.

Educational attainment. As we see in Table 7.4, educational attainment levels are also mostly comparable across both the clean and fossil fuel energy sectors in Brazil. Here again, the one exception is bioenergy, in which 13 percent of workers have had either no education or less than a primary education level. In the other clean energy sectors, those with less than primary level range between 3 and 7 percent, with no strong differences between any of the individual energy sectors. Primary education attainment ranges between about 50 and 60 percent across both clean energy and fossil fuel sectors, and secondary is mainly in the range of between 30 and 40 percent. Workers having tertiary educational attainment levels are also basically comparable across energy sectors, at between 4 and 6 percent. Building retrofits is lower at 3 percent and industrial efficiency is somewhat higher at 10 percent.

As an overall assessment on employment issues for Brazil's clean energy sectors, six general points seem most salient here:

1. Building a clean energy economy will be a major source of new job creation in Brazil relative to expanding or maintaining the existing level of operations in the fossil fuel sectors. It will have no discernable impact on job opportunities relative to spending overall within the Brazilian economy.

2. Expanding the clean energy sector in Brazil will greatly favor male over female workers, unless areas such as construction and manufacturing open up employment opportunities to women to a significant extent. A major expansion in clean energy investments could be seen as an opportunity to break down gender-based employment patterns if appropriate complementary policies are advanced concurrently.

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[59] See also the study by Barros (2010) for the U.S. Department of Agriculture.

3. The share of informal employment in clean energy appears to be high, though, for the most part, the majority of workers are employed in non-micro enterprises, and are paid in wages. Nevertheless, the expansion of the clean energy economy could be seen here as well as an opportunity to formalize the very high percentage of workplaces that are still informal.

4. Educational attainment levels are not especially high in the clean energy sectors. Given this current distribution of education levels among the relevant working pool, there should not be significant supply constraints in building a clean energy economy in terms of facing shortages of higher-credentialed workers.

5. The profile of workers and workplaces employed in the renewable energy and energy efficiency sectors is not substantially different than those for coal and oil/gas. As such, undertaking a large-scale transition from fossil fuel energy sources to clean energy should not create major supply bottlenecks in terms of the availability of workers at the various levels of credentials and experience. In particular, the proportion of workers with tertiary educational levels is roughly the same in clean energy and the fossil fuel sectors. It should therefore not place special demands on Brazil's higher educational system when the clean energy economy grows amid the contraction of the fossil fuel sector.

6. Bioenergy is clearly the outlier among both clean energy and fossil fuel energy sources. The level of employment per $1 million in expenditures is much higher than other sectors, as are the shares of both female workers and those with lower educational attainment levels. Expanding the biofuel sector could be seen as an opportunity to raise productivity in agriculture, and thereby to create more opportunities for women, and those with fewer educational credentials. At the same time, the expected significant rise in agricultural productivity will of course mean fewer jobs per level of production. But employment levels should still be maintained at a high level as the level of production of bioenergy rises.

Germany

Overall Employment Creation

We present the full set of figures on employment multipliers for Germany in Tables 7.5 and 7.6. As with Brazil, the differences in employment generation between the cases of a stable level of domestic content and the case when domestic content declines as clean energy investments expand are not dramatic. With renewable energy the overall difference is about 1 job per $1 million in spending, from 9.3 to 8.4 jobs. With energy efficiency, the difference is more modest, from 10.0 to 9.5 jobs. Relying increasingly on imports within Germany's tradable sectors should not therefore have major effects on the employment opportunities generated through the German clean energy investment project.

Table 7.5: Germany. Employment creation through spending in alternative energy sectors, 2007

Jobs per $1 million

	Domestic content stable			Domestic content declines		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
	(Jobs per $1 million)					
Renewables						
Bioenergy	8.3	2.7	11.0	7.0	2.5	9.5
Hydro	5.3	3.5	8.8	4.5	3.3	7.8
Wind	5.5	2.9	8.4	4.9	2.6	7.5
Solar	5.7	3.1	8.8	5.1	2.9	7.9
Geothermal	6.3	3.4	9.7	5.8	3.1	8.9
Weighted average for renewables	6.2	3.1	9.3	5.5	2.9	8.4
Energy efficiency						
Building retrofits	8.7	3.1	11.8	8.7	2.8	11.5
Industrial efficiency	5.5	3.2	8.6	4.0	3.7	7.7
Grid upgrades	5.3	2.8	8.1	4.7	2.6	7.3
Weighted average for efficiency	7.0	3.1	10.1	6.5	3.0	9.5
Fossil fuels						
Coal	6.1	3.8	10	NA	NA	NA
Oil/natural gas	2.8	2.5	5.3	NA	NA	NA
Weighted average for fossil fuels	4.5	3.2	7.6	NA	NA	NA
Overall economy	6.2	2.7	8.9	NA	NA	NA

Source: See Appendix 3.

In terms of individual clean energy sectors, the overall differences in employment creation between the sectors are relatively modest. With renewable energy, bioenergy is again more labor intensive, but in this case only modestly more than the other renewable sectors. In the stable domestic content case, bioenergy generates 11 direct and indirect jobs per $1 million, while the other renewable sectors generate between 8.4 and 9.7 jobs. With energy efficiency, building retrofits is again more labor intensive, as these are all construction sector-linked jobs. We estimate that industrial efficiency and grid upgrades generate about 8-9 jobs per $1 million in spending.

With fossil fuels, coal is still relatively labor intensive in Germany, at 10.0 jobs per $1 million. This figure is nearly twice as high as that for oil and gas, which generate 5.3 jobs per $1 million. The weighted average for both fossil fuel sectors is therefore 7.6 jobs per $1 million.

In the last row of Table 7.5, we show our estimated employment multipliers for the overall German economy. As we see, that figure is 8.9 jobs per $1 million, which is about 9 percent less than the 9.7 figure weighted average figure for Germany's renewables and efficiency sectors.

Table 7.6 provides a summary comparison between clean energy and fossil fuel employment in Germany. As we see, overall, clean energy generates about 27 percent more jobs per $1 million. This differential is far less than that for Brazil. Nevertheless, it is clear from these figures that, overall, employment levels in the energy sector will not fall, and almost certainly will rise by a significant amount as Germany continues its ongoing aggressive transition toward a clean energy economy. A clean energy investment project will increase job creation only modestly relative to overall spending within the German economy. As such, the major benefits for Germany through advancing a clean energy investment project are focused within the energy system itself and the related environmental impacts. Clean energy investments will produce both major reductions in CO_2 emissions and increase job opportunities relative to maintaining the country's existing fossil-fuel based energy systems.

Table 7.6: Germany. Summary employment figures, 2007

Direct + indirect employment with stable domestic content

	Jobs per $1 million
Renewable energy	9.3
Energy efficiency	10.1
Clean energy total	9.7
Fossil fuels	7.6
Clean energy relative to fossil fuels *(percentage)*	27.6%
Overall economy	8.9
Clean energy relative to overall economy *(percentage)*	9.0%

Source: Generated from Table 7.5. Underlying calculations from Appendix 3.

Notes: The clean energy total is calculated with equal renewables and efficiency weights.

Composition of Employment

We present the German figures on composition of employment in Tables 7.7 and 7.8. The main findings are as follows:

Gender balance. The clean energy sectors of the German economy, are, like the case of Brazil, dominated by male workers, though the female proportions tend to be somewhat higher in Germany than Brazil. For the most part, in all renewable and energy efficiency areas, the female share of employment ranges between about 25 and 35 percent. The two areas where the female ratios are significantly lower are in building retrofits, at 18 percent and coal, at 19 percent. These figures reflect the almost entirely male workforce in both construction and coal mining.

Table 7.7: Germany. Composition of employment generated through alternative energy sector spending, 2007

- *Gender composition of workforce*
- *Wage vs. self-employment*
- *Micro vs. non-micro enterprises*
- *Educational attainment levels (separate table below)*

	Total employment	**Female employment**	**Self-employment**	**Micro enterprise employment**
	Jobs per $1 million	*(Percentage)*		
Renewables				
Bioenergy	11.0	29%	27%	36%
Hydro	8.8	36%	10%	13%
Wind	8.4	25%	9%	13%
Solar	8.8	29%	10%	14%
Geothermal	9.7	29%	14%	22%
Energy efficiency				
Building retrofits	11.8	18%	17%	25%
Industrial efficiency	8.6	33%	11%	16%
Grid upgrades	8.1	26%	10%	14%
Fossil fuels				
Coal	10.0	19%	5%	8%
Oil/natural gas	5.3	27%	11%	17%

Source: See Appendix 4.

Self-employment and Micro Enterprises. Not surprisingly, in the case of Germany, our indicators of informal employment are generally low. In most cases, self-employment constitutes only about 10 -15 percent of jobs linked to either renewable energy or energy efficiency. The one standout-case here is bioenergy, where self-employment is at 27 percent. With size of firms, bioenergy stands out again, with 36 percent of employment is at the level of micro-enterprises. The micro-enterprise proportions are between 13 and 25 percent otherwise. With fossil fuels, the coal industry has only 8 percent of employment coming from micro-enterprises. Oil and natural gas are comparable to most clean energy areas, at 17 percent.

Educational attainment. Note, first of all, that the reporting on educational attainment categories is different in Germany than with Brazil, Indonesia, South Africa and the ROK. In the German case, the lowest attainment category includes up to a middle-school education. The second category includes those with secondary and non-secondary educational levels, including those graduating from vocational colleges. The highest category includes those with university-level education, including advanced degrees. The results are shown in Table 7.8

Table 7.8: Germany. Educational profile of employment generated through alternative energy sector spending, 2007

	Middle school or less	Secondary and non-university post-secondary	University and post-graduate
		(Percentage)	
Renewables			
Bioenergy	16%	61%	23%
Hydro	11%	51%	38%
Wind	15%	60%	24%
Solar	14%	57%	29%
Geothermal	12%	56%	31%
Energy efficiency			
Building retrofits	16%	64%	20%
Industrial efficiency	12%	54%	34%
Grid upgrades	15%	60%	25%
Fossil fuels			
Coal	16%	66%	18%
Oil/natural gas	13%	64%	24%

Source: See Appendix 4.

We see in Table 7.8 that there are no large differences in the educational attainment patterns across the clean energy sectors. About 60 percent of all workers are in the middle educational attainment category - i.e. secondary or vocational school educational levels. For the most part, about 20-30 percent have either university or graduate level educational attainment levels. Between about 11-16 percent are in the lowest category, in which people have middle-school levels of education or less. The only standout is in hydropower, where 38 percent of workers are at high attainment levels. These same patterns also follow with coal, oil and natural gas.

As we discuss elsewhere in this report in more detail, Germany is already advancing strongly toward building a clean energy economy through large-scale investments in renewable energy and energy efficiency. It will continue to create more job opportunities through expanding these investment areas as opposed to either expanding or maintaining its existing fossil fuel sectors at their current scales. It is not surprising that the composition of the workforce employed in clean energy is fairly stable across specific sectors and that there are also no large differences relative to the workforce employed in the fossil fuel industries. Thus, there is no evidence that building a clean energy economy in Germany will be constrained by shortages in terms of workforce experience or educational levels.

At the same time, the continued expansion of a clean energy economy in Germany should be seen as providing an opportunity to create a broader set of employment prospects for women. Women constitute 46 percent of the overall German workforce, but only about 25-35 percent of the clean energy workforce in most areas.

Indonesia

Overall Employment Creation

As we see in Tables 7.9 and 7.10, overall employment creation in Indonesia through spending in renewable energy and energy efficiency investments will be much higher than the current level of employment generation within the fossil fuel economy. This is true across all renewable energy and energy efficiency sectors. In the Indonesian case as well, the results are not significantly affected by a decline in domestic content as investment in clean energy expands. That is, following our assumption that domestic content in tradable sectors declines by 20 percent due to the expanded demand for clean-energy based inputs, the overall effect is to reduce direct and indirect employment by about 2 jobs per $1 million of spending in both renewable energy and energy efficiency - from 118.8 to 116.2 jobs per $1 million in renewables and 79.4 to 77.3 jobs in energy efficiency.

Table 7.9: Indonesia. Employment creation through spending in alternative energy sectors, 2008

Jobs per $1 million

	Domestic content stable			**Domestic content declines**		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	237.0	73.5	310.5	237.0	72.7	309.7
Hydro	29.4	46.5	75.9	24.9	45.3	70.2
Wind	19.6	60.1	79.7	18.1	59.2	77.3
Solar	18.9	44.5	63.4	17.4	43.4	60.8
Geothermal	18.4	46.2	64.7	18.1	44.9	62.9
Weighted average for renewables	64.7	54.2	118.8	63.1	53.1	116.2
Energy efficiency						
Building retrofits	36.3	61.7	97.9	36.3	60	96.3
Industrial efficiency	12.8	46.8	59.6	11.8	45.5	57.3
Grid upgrades	17.0	45.2	62.2	15.5	44.1	59.6
Weighted average for efficiency	25.6	53.8	79.4	25	52.4	77.3
Fossil fuels						
Coal	7.1	33.5	40.6	NA	NA	NA
Oil/natural gas	2.7	0.8	3.5	NA	NA	NA
Weighted average for fossil fuels	4.9	17.1	22.0	NA	NA	NA
Overall economy	155.1	27.2	182.2	NA	NA	NA

Source: See Appendix 3.

Focusing then on the case of stable domestic content, we do here see, even more so than Brazil, that the bioenergy sector is by far the largest proportional source of job creation, with 310 jobs generated per $1 million in spending. These, again, will be mostly jobs with low compensation and poor working conditions in agriculture. In the other renewable energy areas - hydro, wind, solar and geothermal - total direct and indirect job creation ranges fairly narrowly, between 64 and 79 jobs per $1 million.

With our energy efficiency categories, building retrofits generates substantially more jobs per $1 million in spending, at 97.9 jobs. Here again, these are all jobs linked to the construction industry. With industrial efficiency and grid upgrades, the range is narrow, between 60 and 62 jobs per $1 million.

These job figures are far greater than those for coal, oil and natural gas. The coal industry, at 40 jobs per $1 million in spending, is relatively capital intensive in Indonesia compared with even the more capital-intensive renewable energy and energy efficiency sectors, such as solar and industrial efficiency. But even more so, oil and natural gas are highly capital intensive even by global standards, at 3.5 jobs per $1 million. As we saw, in Germany, the comparable figure is 5.3 jobs per $1 million.

In the last row of Table 7.9, we show our estimated employment multipliers for the overall Indonesian economy. As we see, that figure is 182.2 jobs per $1 million. This is fully 46 percent greater than the 99.1 jobs per $1 million weighted average figure for Indonesia's renewables and efficiency sectors.

The overall result in terms of job creation, as we see in Table 7.10, is that a combined renewable energy and energy efficiency investment agenda will create 350 percent more jobs in Indonesia than comparable levels of spending in the current fossil fuel industries. At the same time, we have to also recognize that a clean energy investment project will not increase job creation relative to overall spending within the Indonesian economy. Rather, for Indonesia to invest in the clean energy economy will generate nearly 50 percent fewer jobs per dollar of expenditure than simply expanding overall spending within Indonesia.

But of course, Indonesia, as with all other economies, cannot function without operating a large-scale energy sector. As such, the critical comparison here is between the clean energy vs. fossil fuel energy systems as a source of job creation, in which clean energy clearly offers far greater opportunities. Thus, as with the other countries, the major benefits for Indonesia through advancing a clean energy investment project are focused within the energy system itself and the related environmental impacts. Clean energy investments will produce both major reductions in CO_2 emissions and increase job opportunities relative to maintaining the country's existing fossil fuel based energy systems. Of course, we do need to also consider the quality of these jobs, the issue to which we now turn.

Table 7.10: Indonesia. Summary employment figures, 2008

Direct + indirect employment with stable domestic content

	Jobs per $1 million
Renewable energy	118.8
Energy efficiency	79.4
Clean energy total (with equal renewables and efficiency weights)	99.1
Fossil fuels	22.0
Clean energy relative to fossil fuels *(percentage)*	350.3%
Overall economy	182.2
Clean Energy relative to Overall Economy *(percentage)*	-45.6%

Source: Generated from Table 7.9. Underlying calculations from Appendix 3.

Composition of Employment

Tables 7.11 and 7.12 present our results on the composition of employment in Indonesia's various energy sectors.

Gender composition. As in the cases of Brazil and Germany, employment in the clean energy sectors is male dominated. The highest proportion of female employment is in bioenergy, at 37 percent. Otherwise, the percentages range between 22 and 32 percent. As in the other cases, investments to build a clean energy economy should be seen as an occasion to provide a whole range of new opportunities for women. Employment opportunities for women in fossil fuels is overall worse than in the various clean energy sectors.

Table 7.11: Indonesia. Composition of employment generated through alternative energy sector spending, 2008

- Gender composition of workforce
- Wage vs. Self-Employment
- Micro vs. Non-Micro Enterprises
- Educational attainment levels (separate table below)

	Total employment	**Female employment**	**Self-employment**	**Micro enterprise employment**
	(Jobs per $1 million)	*(Percentage)*		
Renewables				
Bioenergy	310.5	37%	91%	NA
Hydro	75.9	31%	62%	NA
Wind	79.7	32%	65%	NA
Solar	63.4	29%	61%	NA
Geothermal	64.7	26%	64%	NA
Energy efficiency				
Building retrofits	97.9	22%	65%	NA
Industrial efficiency	59.6	32%	62%	NA
Grid upgrades	62.2	32%	60%	NA
Fossil fuels				
Coal	40.6	33%	63%	NA
Oil/natural gas	3.5	12%	22%	NA

Source: See Appendix 4.

Wage employment and micro enterprises. Unfortunately, the Indonesian labor force survey data do not provide a breakdown according to the size of the enterprises at which workers are employed. We will therefore need to rely more on the self-employment data as an indicator of the extent of informalization in the clean energy sectors. As we see, self-employment is dominant in the Indonesian bioenergy sector, at 91 percent of total employment. It is also prevalent in all the rest of the renewable energy and energy efficiency sectors, at around 60 percent in all cases. Indeed, the oil and gas sector is the only one in the energy area in which wage employment is prevalent, with self-employment constituting only 22 percent of the total.

Most likely, the self-employed jobs are mainly in low-income and low-productivity work situations. These conditions could create some supply bottlenecks, assuming the Indonesian clean energy economy does begin growing at a rapid rate. At the same time, the high proportion of informal employment in the Indonesian clean energy sectors does also establish major opportunities for Indonesia to formalize these workplaces as clean energy-linked sectors undergo a major expansion.

Educational attainment. Not surprisingly, the educational attainment levels in the clean energy sectors are relatively low, though basically not less so than in the fossil fuel sectors.

Throughout the renewable and energy efficiency areas, between about 15 and 20 percent of workers have less than a primary education (See Table 7.12). If we combine those with no more than a primary education, the percentages range between 70 and 90 percent. This is also true for Indonesia's coal sector. The oil and gas sector is the only one in which more than half of the workers have either secondary or tertiary educational attainment levels. In short, here again, we see an indication of a high degree of informalization and probably relatively low productivity levels in the clean energy sectors. At the same time, if we just consider those with tertiary educational attainment levels, this ranges narrowly between 5 and 6 percent of total employment. The one exception is bioenergy, where only 1 percent of workers have tertiary education levels. But generally, this level of tertiary education attainment in the clean energy sectors is equal to that of Brazil. As such, the relatively low level of workers with middle levels of educational attainment may not pose a significant supply constraint for expanding Indonesia's clean energy economy, as long as the higher-level managerial positions include a reasonable share of technically trained workers.

Table 7.12: Indonesia. Educational profile of employment generated through alternative energy sector spending, 2008

	No education or less than primary level	Primary level	Secondary level	Tertiary level
	(Percentages)			
Renewables				
Bioenergy	15%	74%	10%	1%
Hydro	20%	53%	22%	5%
Wind	21%	52%	23%	5%
Solar	21%	48%	25%	6%
Geothermal	21%	52%	22%	5%
Energy efficiency				
Building retrofits	22%	54%	20%	5%
Industrial efficiency	20%	48%	26%	6%
Grid upgrades	20%	46%	28%	6%
Fossil fuels				
Coal	20%	52%	22%	6%
Oil/natural gas	13%	15%	51%	21%

Source: See Appendix 4.

Overall, building a clean energy economy in Indonesia, as opposed to maintaining or expanding its existing fossil-fuel dominated energy system, will generate both major opportunities and challenges in terms of its employment effects. The opportunities exist because, even allowing that productivity would grow rapidly as the clean energy sectors mature, the overall level of employment will still be far greater than that for fossil fuels. The challenge then will be precisely to encourage these workplaces to become increasingly formalized. This, in turn, will allow for higher productivity and, thereby, a more rapidly growing clean energy sector in Indonesia.

South Africa

As we show in Tables 7.13-7.14, employment creation in South Africa linked to the clean energy investment agenda will generate a major increase in employment opportunities across all renewable energy and energy efficiency sectors relative to spending within the fossil fuel sectors. Moreover, as we will see in Tables 7.15 and 7.16, our estimates suggest that the quality of employment within most renewable and energy efficiency industries is comparable to job quality in fossil fuel industries. Job quality is, on average, relatively low in the key clean energy areas of building retrofits and bioenergy, but these patterns are balanced by the relatively high level of formality and educational attainment levels in the other clean energy sectors.

Overall Employment Creation

Tables 7.13 and 7.14 show that the range of employment creation in South Africa through renewable energy investments is narrow, excepting the usual case of bioenergy. With bioenergy, the estimate we generated is that $1 million in investments will generate 78 jobs. With the other renewable sectors - hydro, wind, solar, and geothermal - we estimate that between 55-70 jobs are generated directly and indirectly through spending $1 million. As a weighted average, spending in the renewable energy sectors generate about 65 jobs per $1 million.

Table 7.13: South Africa. Employment creation through spending in alternative energy sectors, 2005

Jobs per $1 million

	Domestic content stable			Domestic content declines		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	50.1	28.1	78.2	50.0	26.5	76.5
Hydro	25.4	36.2	61.6	24.9	34.4	59.3
Wind	29.9	30.6	60.5	27.8	29.2	56.9
Solar	19.6	35.9	55.6	18.3	34.1	52.4
Geothermal	31.2	38.2	69.5	30.8	36.4	67.2
Weighted average for renewables	31.3	33.8	65.1	30.3	32.1	62.5
Energy efficiency						
Building retrofits	56.5	37.5	94.0	56.5	35.7	92.1
Industrial efficiency	24.6	35.9	60.5	22.8	34.5	57.2
Grid upgrades	24.3	31.6	55.9	22.9	29.8	52.7
Weighted average for efficiency	40.5	35.6	76.1	39.7	33.9	73.5
Fossil fuels						
Coal	5.3	24.1	29.4	NA	NA	NA
Oil/natural gas	11.7	25.1	36.8	NA	NA	NA
Weighted average for fossil fuels	8.5	24.6	33.1	NA	NA	NA
Overall economy	52.2	70.1	122.3	NA	NA	NA

Source: See Appendix 3.

Table 7.14: South Africa. Summary employment figures, 2005

Direct + indirect employment with stable domestic content

	Jobs per $1 million
Renewable energy	65.1
Energy efficiency	76.1
Clean energy total *(with equal renewables and efficiency weights)*	70.6
Fossil fuels	33.1
Clean energy relative to fossil fuels *(percentage)*	113.2%
Overall economy	122.3
Clean energy relative to overall economy *(percentage)*	-42.3%

Source: Generated from Table 7.13. Underlying calculations from Appendix 3.

The range is greater in our respective energy efficiency sectors. That is, the employment levels are high with building retrofits, at 94 jobs per $1 million. This reflects the low wage levels for construction industry jobs in South Africa. Industrial efficiency and grid upgrades generate, by our estimates, between 56-61 jobs per $1 million in spending. Given that we are weighting building retrofits as 50 percent of all energy efficiency spending, with the other two sectors as 25 percent each, this generates a weighted average for job creation in energy efficiency at 76.1 jobs per $1 million.

In terms of our consideration of domestic capacity constraints as clean energy investments expand, we find in the case of South Africa, as with the situations in Brazil, Germany and Indonesia, that increasing the import content of inputs by 20 percent for tradable activities does not generate a large decrease in employment. Renewable energy job creation falls from 65.1 to 62.5 jobs while energy efficiency job creation falls from 76.1 to 73.5 jobs.

Overall then, as Table 7.14 shows, we estimate that the overall clean energy investment package produces a weighted average of 70.6 jobs, which is 113 percent higher than the 33.1 jobs generated, on average, in coal, oil and gas. Moreover, in the case of South Africa, the levels of employment creation in coal versus oil and gas are relatively modest. In short, again, our estimates show that South Africa will certainly gain in terms of overall levels of employment through undertaking a transformation out of fossil fuels and into renewable energy and energy efficiency.

At the same time, similar to the case of Indonesia, we have to also recognize that clean energy investment project will not increase job creation relative to overall spending within the South African economy. Rather, as we see in Tables 7.13 and 7.14, for South Africa to invest in the clean energy economy will generate about 40 percent fewer jobs per dollar of expenditure than simply expanding overall spending within South Africa. Of course, South Africa, as with all other economies, cannot function without operating a large-scale energy sector. As such, the critical comparison here is between the clean energy vs. fossil fuel energy systems as a source of job creation, in which clean energy clearly offers far greater opportunities. Thus, as with the other countries, the major benefits for South Africa through advancing a clean energy investment project are focused within the energy system itself and the related environmental impacts.

Clean energy investments will produce both major reductions in CO_2 emissions and increase job opportunities relative to maintaining the country's existing fossil fuel based energy system.

Composition of Employment

Tables 7.15 and 7.16 report on our estimates for job composition for the various energy sectors in South Africa. Our main findings are as follows:

Table 7.15: South Africa. Composition of employment generated through alternative energy sector spending, 2005

- Gender composition of workforce
- Wage vs. self-employment
- Micro vs. non-micro enterprises
- Educational attainment levels (separate table below)

	Total employment	**Female employment**	**Self-employment**	**Micro enterprise employment**
	(Jobs per $1 million)	*(Percentage)*		
Renewables				
Bioenergy	78.2	29%	19%	33%
Hydro	61.6	30%	15%	33%
Wind	60.5	24%	12%	27%
Solar	55.5	28%	14%	32%
Geothermal	69.4	24%	15%	32%
Energy efficiency				
Building retrofits	94.0	15%	11%	24%
Industrial efficiency	60.5	27%	13%	29%
Grid upgrades	55.9	25%	11%	28%
Fossil fuels				
Coal	29.4	28%	10%	26%
Oil/natural gas	36.8	28%	13%	34%

Source: See Appendix 4.

Table 7.16: South Africa. Educational profile of employment generated through alternative energy sector spending, 2005

	No education or less than primary level	Primary level	Secondary level	Tertiary level
	(Percentages)			
Renewables				
Bioenergy	28%	44%	24%	4%
Hydro	17%	40%	35%	8%
Wind	14%	48%	33%	5%
Solar	16%	41%	36%	7%
Geothermal	18%	43%	33%	7%
Energy efficiency				
Building retrofits	15%	61%	22%	3%
Industrial efficiency	13%	45%	35%	7%
Grid upgrades	14%	48%	33%	5%
Fossil fuels				
Coal	15%	43%	36%	6%
Oil/natural gas	15%	43%	36%	6%

Source: See Appendix 4.

Gender composition. As with Brazil, Germany, and Indonesia, the proportion of women working in the renewable energy and energy efficiency sectors is low. With the exception of building retrofits, there is a narrow range between all of the sectors, at between 24 and 35 percent female employment as a share of total employment. The disparity is even more pronounced with building retrofits, which, as discussed before, we have defined as being 100 percent construction industry activity. Women hold only 15 percent of the direct plus indirect jobs in the construction industry. Thus, once again, a major expansion of activity in renewable energy and energy efficiency should be seen as an occasion to open up job opportunities for women, in areas such as manufacturing, transportation and construction.

Self-employment and micro enterprises. According to our estimates, the proportions of self-employment and employment at micro-enterprises - our indicators of informal employment conditions - appear to be relatively low for the South African case. As we see, less than 20 percent of workers whose jobs are directly or indirectly linked to the renewable energy and energy efficiency sectors are self-employed - i.e., across the board, more than 80 percent are wage-earners. These figures, for example, are significantly higher than those for Brazil. The proportions working in micro-enterprises in the various clean energy sectors is between 24 and 33 percent in most cases. Overall, as with the case of Brazil, the presence of micro-enterprises is not insignificant in the clean energy sectors, even while most workers are employed at larger enterprises. However, the fact that most workers are also receiving wages, as opposed to being self-employed, suggests that these micro-enterprises may be somewhat less informal establishments than would be the case, say, in Brazil.

Educational attainment. As we see in Table 7.16, the levels of educational attainment are basically stable here, across all renewable energy and energy efficiency sectors, with the two exceptions of bioenergy and building retrofits. In most of the clean energy sectors, between 40 and 48 percent of workers have primary educations, between 14 and 18 percent have less than a primary education, 24-36 percent have secondary educations, and 5-8 percent have higher educations. With bioenergy, we estimate that nearly 30 percent of workers have less than a primary education. The percentages of workers in bioenergy with secondary educations, at 24 percent, and tertiary levels, at 4 percent, are somewhat lower than those in the other clean energy sectors. With building retrofits, the proportion having received secondary-level education is relatively low, at 22 percent, while those with primary educations only is higher, at 61 percent. The patterns of educational levels for coal and oil and natural gas are basically the same as those for hydro, wind, solar, geothermal, industrial efficiency and grid updates.

Overall, our evidence shows, again, that South Africa would benefit substantially in terms of numbers of employment opportunities created through a large-scale expansion of clean energy investments. This is because spending within the clean energy sectors creates, according to our estimates, 114 percent more jobs than the same level of spending on coal, oil and natural gas. In terms of composition of employment, the level of formalization within the clean energy sectors - as measured by the proportions of workers who are self-employed and are working in micro-enterprises - is already relatively high. The share of formal employment should therefore not be expected to change dramatically through a large-scale expansion of clean energy investments. Finally, again, it will be important to create more job opportunities for women in the areas of the South African economy that are linked to renewable energy and energy efficiency, as these sectors expand.

The Republic of Korea

Overall Employment Creation

As we show in Tables 7.17 and 7.18, our estimates for the level of job creation for most renewable energy and energy efficiency sectors range fairly narrowly. Again, the one big exception is bioenergy. With the other renewable sectors - hydro, wind, solar, and geothermal - we estimate direct plus indirect job creation as being between about 11-15 jobs per $1 million in spending in our first scenario, in which domestic content proportions are stable. With bioenergy, we estimate direct plus indirect job creation at about 28 jobs per $1 million. As with our four other selected countries, this is because agriculture accounts for 50 percent of all value added in bioenergy in our model, and the compensation levels in agriculture in the ROK are well below those for other sectors, such as manufacturing, refining, and transportation, that are heavily represented in clean energy. These figures produce a weighted average estimate for all renewable sectors at 16.2 jobs per $1 million.

Table 7.17: Republic of Korea. Employment creation through spending in alternative energy sectors, 2008

Jobs per $1 million

	Domestic content stable			Domestic content declines		
	Direct jobs	Indirect jobs	Direct + indirect jobs	Direct jobs	Indirect jobs	Direct + indirect jobs
	(Jobs per $1 million)					
Renewables						
Bioenergy	23,1	4,8	27,9	18,8	4,6	23,3
Hydro	7,5	7,8	15,2	6,9	7,3	14,3
Wind	5,9	6,5	12,4	5,2	6,1	11,3
Solar	4,7	6,3	11,0	4,1	5,8	9,9
Geothermal	7,2	7,2	14,3	6,3	6,7	12,9
Weighted average for renewables	9,6	6,5	16,2	8,3	6,1	14,3
Energy efficiency						
Building retrofits	5,9	8,0	13,9	5,9	7,4	13,2
Industrial efficiency	5,3	7,1	12,3	3,8	7,3	11,1
Grid upgrades	5,2	6,7	12,0	4,7	6,2	10,9
Weighted average for efficiency	5,6	7,5	13,0	5,0	7,1	12,1
Fossil fuels						
Coal	10,1	4,0	14,1	NA	NA	NA
Oil/natural gas	9,9	3,3	13,1	NA	NA	NA
Weighted average for fossil fuels	10,0	3,6	13,6	NA	NA	NA
Overall economy	9,9	7,5	17,5	NA	NA	NA

Source: See Appendix 3.

Table 7.18: Republic of Korea. Summary employment figures, 2008

Direct + indirect employment with stable domestic content

	Jobs per $1 million
Renewable energy	16.2
Energy efficiency	13
Clean energy total *(with equal renewables and efficiency weights)*	14.6
Fossil fuels	13.6
Clean energy relative to fossil fuels *(percentages)*	7.1%
Overall economy	17.5
Clean energy relative to overall economy *(percentages)*	-16.6%

Source: Generated from Table 7.17. Underlying calculations from Appendix 3.

With energy efficiency, in our stable domestic content scenario, we estimate that about 12 jobs per $1 million will be generated in both industrial efficiency and grid upgrades. With building retrofits - which accounts for half of all spending on efficiency within our framework - at about 14 jobs per $1 million, our estimated weighted average for the three efficiency categories is 14.8 jobs per $1 million.

The case of the ROK is the only one in which our second scenario, of a 20 percent domestic content decline in the relevant tradable sectors generates a noticeable impact on our overall employment estimates, specifically within the renewable sectors. For example, the direct job creation in bioenergy falls from 23 to 19 jobs per $1 million. Our estimated weighted average for renewables falls from 16.2 to 14.3 jobs per $1 million. These downward effects on job creation reflect the ROK's status as an advanced economy with high tradable proportions in major sectors.

Another unique feature of the ROK case is that our estimated employment multipliers for coal, oil and natural gas are basically comparable to those for the clean energy sectors. Once we take account, in our second scenario, of an increase in imports tied to clean energy investments, our estimated aggregated employment ratios for clean energy and fossil fuels are basically at parity - both are at basically 14 jobs per $1 million in spending.

Considering these estimates, we can conclude that, in the case of the ROK, there is not likely to be any significant overall level of positive job creation through advancing a clean energy agenda as opposed to maintaining the existing fossil fuel energy infrastructure. But this does also mean that there should not be any significant sacrifice in job creation as clean energy investments expand and fossil fuel spending contracts. It is also the case that advancing a clean energy investment agenda will favor certain sectors over others in the ROK as elsewhere. Agriculture is a clear case in point with bioenergy. To the extent the ROK may want to see an expansion in job opportunities and perhaps an accompanying rise in conditions in agriculture, generating a high productivity bioenergy sector could thereby provide broad benefits.

In the last row of Table 7.17, we show our estimated employment multipliers for the overall the ROK economy. As we see, that figure is 17.5 jobs per $1 million. This is about 17 percent more than the weighted average figures for the ROK's renewables and efficiency sectors. What this figure shows is that a clean energy investment project would modestly decrease job creation in the ROK relative to overall spending within the ROK economy. As such, the benefits for the ROK through advancing a clean energy investment project are focused within the energy system itself and the related environmental impacts. Clean energy investments will produce both major reductions in CO_2 emissions and can achieve this without entailing any sacrifice in job opportunities relative to maintaining the country's existing fossil-fuel based energy systems.

Composition of Employment

We report our estimates for employment composition in the ROK in Tables 7.19 and 7.20. Our main findings are as follows:

Table 7.19: Republic of Korea. Composition of employment generated through alternative energy sector spending, 2008

- Gender composition of workforce
- Wage vs. self-employment
- Micro vs. non-micro enterprises
- Educational attainment levels (separate table below)

	Total employment	**Female employment**	**Self-employment**	**Micro enterprise employment**
	Jobs per $1 million	(Percentage)		
Renewables				
Bioenergy	27.9	45%	74%	NA
Hydro	15.2	27%	27%	NA
Wind	12.4	28%	23%	NA
Solar	10.9	32%	23%	NA
Geothermal	14.3	24%	19%	NA
Energy efficiency				
Building retrofits	13.9	24%	20%	NA
Industrial efficiency	12.3	30%	24%	NA
Grid upgrades	12.0	30%	21%	NA
Fossil fuels				
Coal	14.1	11%	9%	NA
Oil/natural gas	13.1	11%	8%	NA

Source: See Appendix 4.

Table 7.20: Republic of Korea. Educational profile of employment generated through alternative energy sector spending, 2008

	No education or less than primary level	Primary level	Secondary level	Tertiary level
	(Percentage)			
Renewables				
Bioenergy	14%	33%	39%	14%
Hydro	1%	7%	51%	41%
Wind	1%	6%	52%	41%
Solar	1%	6%	50%	42%
Geothermal	1%	7%	51%	40%
Energy efficiency				
Building retrofits	1%	8%	52%	39%
Industrial efficiency	1%	6%	48%	44%
Grid upgrades	1%	6%	51%	43%
Fossil fuels				
Coal	1%	7%	63%	29%
Oil/natural gas	1%	6%	62%	31%

Source: See Appendix 4.

Gender composition. As we can see in Table 7.19, we find that, as Brazil, Germany, Indonesia and South Africa, most renewable energy and energy efficiency sectors in the ROK are male dominated. Again, the one exception is bioenergy, in which females occupy fully 45 percent of the direct and indirect jobs associated with this sector. Otherwise, we estimate that female employment ranges between 24-30 percent in the other clean energy sectors. This is substantially below the national average of 41 percent female employment. Nevertheless, it is well above the proportions for the coal, oil and natural gas sectors, which are at 11 percent female. As such, expanding spending in clean energy sectors while reducing spending on fossil fuels should encourage some improvement in the gender composition of employment in the ROK's energy-based sectors.

Self-employment and micro enterprises. The figures reported in the ROK's labor force survey did not enable us to produce results for micro-enterprise employment. Working then just with the estimates for self-employment in the clean energy sectors, we see, overall, that wage employment is predominant in all sectors other than bioenergy. Self-employment ranges between 19-27 percent in hydro, wind, solar and geothermal, among the other renewable sectors. In the energy efficiency sectors, we estimate self-employment as being between 21-24 percent. With bioenergy, by contrast, we estimate self-employment to be quite high, at 74 percent.

The figures on self-employment are lower still for fossil fuels, at only 9 percent for coal and 8 percent for oil and gas. As such, the shift from fossil fuels to clean energy would likely entail some increase in the extent of informalization, most especially to the extent that the ROK was to begin producing bioenergy to a significant extent.

Educational attainment. Overall, we estimate that educational attainment levels for the ROK workers in the clean energy sectors is quite high, once again with the one exception of bioenergy. Outside of bioenergy, we estimate the percentages of workers with either secondary or tertiary educational attainment levels are in the range of 90 percent in all cases. With bioenergy, the attainment levels are much more spread out, with 14 percent having less than a primary level, 33 percent with primary education, 39 percent with secondary, and 14 percent with tertiary.

The attainment levels in the fossil fuel sectors vary somewhat higher than the average for clean energy, with 92-93 percent of workers having either secondary or tertiary educational levels. But these figures are not substantially different than those for clean energy other than bioenergy.

Overall, the transition to a clean energy economy in the ROK would not generate dramatic shifts in either the level or composition of its employment opportunities. The increased demand for agricultural products as inputs in the bioenergy sector is the one exception here. This one shift toward a large-scale bioenergy sector would raise the share of women and self-employed workers as well as those with lower educational attainment levels. Depending on how the ROK was to manage this shift, it could be seen as generating benefits for less well-off segments of the labor force as well as an opportunity to increase agricultural productivity. But it could also produce supply bottlenecks if the ROK were to seek to expand bioenergy production significantly without also improving agricultural productivity concurrently.

SECTION 3

INDIVIDUAL COUNTRY STUDIES

CHAPTER 8: BRAZIL – CLEAN ENERGY INVESTMENTS, EMISSIONS REDUCTIONS AND EMPLOYMENT EXPANSION

Level of Development and CO2 Emissions

In Table 8.1, we review the basic statistics from Chapter 1 indicating Brazil's current level of development and the operations of its energy system. According to the World Bank Indicators, Brazil is an upper-middle income country, with, as we see in Table 8.1, average income per capita at $11,600 as of 2010. Overall energy consumption is at 11.3 Q-BTUs and overall CO_2 emissions are at 450 mmt.[60]

Table 8.1: Brazil. Basic energy indicators, 2010

	Brazil	**World**
Per capita GDP *(2005 PPP dollar)*	$11,600	$10,300
Total energy consumption *(Q-BTUs)*	11.3 Q-BTUs	510.5 Q-BTUs
Per capita energy consumption *(M-BTUs/population)*	58 M-BTUs	74.0 M-BTUs
Total CO_2 emissions *(mmt)*	450 mmt	31,502 mmt
Per capita CO_2 emissions *(mmt of emissions/population)*	2.3 mt	4.6 mt
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	5.1 Q-BTUs	7.1 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	39.9 mmt	65.9 mmt

Source: See Tables 1.1 and 1.4.

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[60] The figures in Table 8.1 are compiled from two sources, the World Bank Indicators and the EIA International Energy Statistics, as noted at the bottom of Table 1.1. We also draw on two other statistical sources in this chapter: the IEA's 2013 *World Energy Outlook* and the 2011 *Brazilian Energy Balances*, published annually by the Brazilian Ministry of Mines and Energy. There are discrepancies between these various sources. One major factor appears to be that measurement of the energy supplied from traditional biomass sources is treated differently by the different sources. For the purposes of this report, we have relied primarily on the data sources that provide statistics on an international scale, i.e. the EIA, IEA and World Bank figures. This is not because we assume these figures are necessarily more reliable than those published by national data sources, such as that for Brazil, but rather to maintain consistency in methodology as much as possible between the different countries we are examining.

The Brazilian economy operates with a unique energy infrastructure. We have already obtained a sense of this in the figures we presented in Chapter 1. In particular, Brazil's per capita emissions level, at 2.3 mt, is half the world average of 4.6 mt, and basically equal already to the target 2.4 mt level that is needed throughout the globe to reach the 20-year emissions reduction goal. This is while Brazil is still producing domestic output at an upper-middle income level. Brazil has achieved this very low level of emissions per capita level among upper-income countries through both relying heavily on clean renewable energy sources and operating at a high efficiency level. Thus, as Table 8.1 shows, Brazil's energy intensity ratio, at 5.1 Q-BTUs per $1 trillion of GDP, is nearly 30 percent below the global average of 7.1. Its emissions intensity ratio - i.e. CO_2 emissions per Q-BTU - at 39.9 is 42 percent below the global average of 69.1.

We can see more clearly how Brazil has achieved its low level of CO_2 emissions through considering its present energy mix, as shown in Table 8.2. The key feature in this mix is that hydro power provides 14 percent of all of Brazil's energy supply, while the share going to coal is correspondingly small, at 6 percent. We note also, and discuss more later, that Brazil operates a very large bioenergy sector, providing 29 percent of Brazil's total energy supply. However, to date this sector contributes only modestly to reducing Brazil's emissions, since the most prevalent feedstock for Brazil's bioenergy supply is sugarcane. As we saw in Chapter 3, ethanol from sugarcane feedstock generates only 26 percent fewer CO_2 emissions than gasoline over a 30-year cycle. Still the fact that Brazil already has a large bioenergy sector should enable it to transition more readily from high- to low-emissions bioenergy over the next 20 years.

Table 8.2: Brazil. Energy consumption and emissions, 2010

Total energy consumption	11.3 Q-BTUs
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	5.1 Q-BTUs
Energy mix:	
Oil	41.0%
Coal	6.0%
Natural gas	9.0%
Nuclear	1.0%
Renewables	43.0%
• Hydro	14.0%
• Bio - High emissions	29.0%
• Bio - Low emissions	0.0%
• All others	0.1%
Total CO_2 emissions	450 mmt
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	39.8 mmt
CO_2 emissions per capita *(with population = 195 million)*	2.3 mt

Sources: See Tables 1.1 and 1.4; IEA (2013), "World Energy Outlook 2013" Tables for Scenario Projections, pp. 640-643; EIA 2013b "International Energy Outlook 2013."

At the same time, Brazil is also unique in that its share of total GHG emissions generated by CO_2 is substantially less than that the world average. As we discussed in Chapter 1, for the world as a whole, CO_2 emissions constitute 75 percent of all GHG emissions, including methane, nitrous oxide and other GHG emission sources in addition to CO_2.[61] In Brazil, this proportion is only 39 percent. This is not only because Brazil relies more heavily on hydro power, thereby reducing the share of emissions than would otherwise result through generating electricity by burning fossil fuels. The less favorable factor here is that Brazil generates high levels of methane and nitrous oxide emissions from deforestation of the Amazon and the corresponding growth in agriculture. We summarize these two unique features of the Brazilian energy infrastructure - its production of hydropower and its high share of other GHG emissions as a share of total emissions - in Table 8.3.

Table 8.3: Brazil relative to world averages in share of hydro power and CO2 emissions, 2010

	Brazil	World average
Hydro power as share of total energy supply	14.1%	3.2%
CO_2 emissions as share of total GHG emissions	39.0%	75.0%

Sources: Authors' calculations based on IEA (2013), "World Energy Outlook 2013" Tables for Scenario Projections, p. 640 (for hydro shares); World Bank (2014), "World Bank Indicators" Table 3.9.

Thus, as a project for mitigating overall GHG emissions, it is appropriate in the short term for Brazil to devote a relatively large share of its overall resources to issues other than the energy sector. D'Avignon (2013) summarizes the key features of Brazil's current GHG emissions mitigation program as follows:

- Under the 2009 Copenhagen Accord, Brazil voluntarily committed to reducing emissions by between 36.1 and 38.9 percent relative to BAU by 2020;
- The Brazilian government made an unconditional pledge to curb deforestation in Amazonia by 80 percent in 2020 relative to 2005. Recent data show that Brazil is keeping to this commitment;
- After the 2020 mitigation target is achieved, d'Avignon's assessment is that emissions may begin to rise again due to an increase in energy-related GHG emissions.

What is clear here is that, given both the high levels of renewable supply and efficiency already achieved, as well as the very high percentage of overall emissions in Brazil resulting from non-energy sources, Brazil should be devoting a large share of its resources through 2020 in bringing down GHG from sources other than the energy sector. That is, it may be that a somewhat smaller share of GDP should go to clean energy investments, at least through 2020, than the 1.5 percent of GDP that we have assigned in our country-specific discussions on Indonesia, South Africa and the ROK. This would free up more funds to address other projects aimed at mitigating GHG emissions. At the same time, the final point raised by d'Avignon on the prospects for rising energy-based emissions after 2020 provides a strong motivation for us to also focus on reducing energy-based CO_2 emissions in Brazil over a 20-year cycle.

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[61] Other greenhouse gas emissions, which provide a relatively small share of the emissions total, are by-product emissions of hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

We turn now to reviewing how we might address effectively both sets of concerns. Before doing so, it is perhaps also useful to underscore again a point we emphasized in Chapter 1: that none of Brazil's emissions reduction strategies or goals should be altered at all as a consequence of the large-scale "pre-salt" oil deposits that have been discovered offshore. Indeed, if Brazil were to increase its oil consumption levels due to the development of these new resources, the impact will be to only raise Brazil's emissions levels. More generally, as we have emphasized, the burning of oil, coal and natural gas will need to contract substantially in absolute terms throughout the globe to achieve the IPCC's emissions reduction targets. This conclusion is unaffected by whether new fossil fuel reserves are discovered, including the "pre-salt" deposits in Brazil or elsewhere. It is also unaffected by whether new technologies, such as fracking, are employed to produce fossil fuel energy more cheaply.

BAU vs. Low-Carbon 20-year Scenarios

Table 8.4 reports on two 2030 scenarios for Brazil's energy consumption, published by the IEA in its *2013 World Energy Outlook*. These figures are from the same set of estimates we described in Chapter 1, regarding world emissions projections for 2030. We now show these two 2030 scenarios for Brazil along with actual energy consumption in 2010. The IEA describes these alternative scenarios - which they themselves term the "Current Policies Scenario" and the "450 Scenario", but we will call them the BAU and Low Carbon Scenarios respectively - as follows:

> ***BAU (Current Policies) Scenario*** is based on the implementation of the government policies and measures that had been enacted by mid-2013.
>
> ***Low Carbon (450) Scenario*** sets out an energy pathway that is consistent with a 50 percent chance of meeting the goal of limiting the increase in average global temperature to 2° C compared with pre-industrial levels (p. 645).

Table 8.4: Brazil. Energy consumption and emissions: 2010 actuals and alternative official projections

	2010 actuals	2030 IEA BAU scenario	2030 IEA Low Carbon scenario
Total energy consumption	11.3 Q-BTUs	18.2 Q-BTUs	15.7 Q-BTUs
Energy intensity ratio *Q-BTUs/$1 trillion GDP;* *Assumes 2030 GDP is $4.8 trillion via 3.7 percent GDP growth*	5.1 Q-BTUs	3.8 Q-BTUs	3.3 Q-BTUs
Energy mix:			
Oil	41%	35%	27%
Coal	6%	6%	4%
Natural gas	9%	18%	12%
Nuclear	1%	2%	3%
Renewables	43%	41%	52%
• Hydro	14%	12%	14%
• Bio - High emissions	29%	22%	18%
• Bio - Low emissions	0%	7%	18%
• All others	0.1%	2%	2%
Total CO_2 emissions	450 mmt	702 mmt	435 mmt
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	39.8 mmt	38.6 mmt	27.7 mmt
CO_2 emissions per capita *(with population = 195 million for 2010 and 220 for 2030)*	2.3 mt	3.2 mt	2.0 mt

Sources: See Tables 1.1 and 1.4; IEA (2013), "World Energy Outlook 2013" Tables for Scenario Projections, pp. 640-643.

Note: For the IEA's 2030 BAU projection we assume a breakdown of 80 percent high-emissions bioenergy/20 percent low-emissions bioenergy. In this BAU scenario, that amounts to 3.9 Q-BTUs, with 1 Q-BTU of low-emissions bioenergy. For the IEA's Low Carbon scenario, we assume the breakdown becomes 50 percent each for high- and low-emissions bioenergy sources.

As we noted in Chapter 1, in assessing the IEA's Low Carbon scenario, we should, to begin with, not be satisfied with its goal of advancing a project that is consistent with only *a 50 percent chance* of meeting the overall emissions targets for controlling climate change. As such, we should consider this Low Carbon scenario for Brazil as representing a most conservative version of what could be considered an acceptable emissions mitigation path. At the same time, throughout this report we have tried to work with conservative assumptions in advancing clean energy investment projects. In this sense therefore, the IEA's scenario serves us well here.[62]

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[62] As with our methodological point noted in footnote 1, here again, for two reasons, we focus on the IEA's model rather than the Brazilian Ministry and Mine's 10- and 20- year projections - the Plano Decenal de Expansao de Energia and its *National Energy Plan 2030*. The first is because the IEA's projections are for all regions of the world and a range of countries, and therefore is more conducive to international comparisons. In addition, the IEA's projections for 2030 are more conservative, and therefore consistent with our general approach in this report. We do, however, refer to the figures from the *National Energy Plan* 2030 below.

As we see under this Low Carbon scenario, overall energy consumption is at 15.7 Q-BTUs in Brazil as of 2030. This is 4.4 Q-BTUs more than the actual level for 2010, a 39 percent increase. But it is also 2.5 Q-BTUs, or 14 percent, lower than the BAU case, at 18.2 Q-BTUs.[63] We can interpret this 14 percent reduction in consumption relative to the BAU case as a result of increasing investments in energy efficiency. This is not a dramatic improvement in efficiency. But one must recognize that because Brazil is already operating at a very high efficiency level, further gains are more challenging to achieve.

According to the IEA, the sector with the largest potential for significant efficiency gains is transportation. Within transportation, the biggest potential source of improvements is with raising fuel efficiency standards for automobiles. The IEA also stresses that large efficiency improvements can be achieved through moving freight transportation out of trucks and onto rail and waterway systems.

In addition to these efficiency gains, a major change in the Low Carbon Emissions scenario relative to the 2010 actual figure and the 2030 BAU case is the large increase in the share of renewables. We do see hydro, wind, solar all growing relative to 2010, while geothermal is not projected to be a significant energy resource in Brazil at any point. Hydro's growth from 2010-2013 is in rough proportion to the overall rise in consumption, since it represents 14 percent of overall consumption in both 2010 and the 2030 Low Carbon case. Wind and solar rise from a negligible base in 2010 to 0.3 Q-BTUs, or 2 percent of total supply. But the critical source of new renewable supply is bioenergy. Combining both high- and low-emissions bioenergy, they account for 36 percent of total supply as of 2030.

On this point, we need to emphasize that the breakdown shown in Table 8.4 between these two sources of bioenergy - at 18 percent each of total supply in the Low Carbon scenario - is an assumption that we have built into the scenario. This breakdown is not explicitly stated in the IEA's presentation of the scenario. But something like this breakdown is implicit in their qualitative discussion of developments in Brazil's bioenergy sector. It is worth reviewing the IEA's perspective on this in some detail, as in the following:

> *Interest in advanced biofuels is increasing in Brazil. As productivity improvements in first generation biofuels show signs of diminishing, advanced (second generation) ethanol has the potential to generate another leap in output without expanding the harvested area. The existence of an established biofuels industry, the availability of low cost cellulosic feedstock such as bagasse, a move towards mechanized harvesting (and a ban on field burning) and a desire to move into higher value-added sectors all contribute to making advanced ethanol production an attractive proposition in Brazil. Another form of advanced biofuels is biodiesel from palm oil, with potential yields per land area that are an order of magnitude higher than soybean-based biodiesel, potentially reducing the future land demand for biodiesel by millions of hectares.*
>
> *International companies are becoming increasingly visible in Brazil's ethanol business and some have clear plans relating to advanced biofuels, drawing on international expertise and technology to build demonstration and commercial plants….Advanced biofuels production costs are currently well above those of other fuels, due to the early*

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[63] The 2030 estimates from Brazil's *National Energy Plan 2030* are 18.8 Q-BTUs of total energy consumption under its BAU scenario and 12.3 Q-BTUs under its Low Carbon scenario. Thus under the National Energy Plan's estimates, overall energy consumption in 2030 is 0.6 Q-BTUs higher than the IEA's estimate under the respective BAU scenarios, but 3.4 Q-BTUs lower under the Low Carbon scenarios.

> *stage of technology development and small scale of production. Efforts to develop the sector are expected to focus on building capacity and reducing investment costs, reducing the costs and enhancing the productivity of the enzymes and improving the efficiency of feedstock collection. With significant support from BNDES (Brazil's development bank), the first commercial-scale advanced ethanol plant is scheduled to be operational in 2014. Given the supportive growing conditions, policy environment, and funding programs, several more commercial-scale production facilities can reasonably be expected by the end of the decade (IEA, 2013a, p. 390).*

In terms of overall emissions, we see that with the IEA's low carbon case, Brazil's overall CO_2 emissions basically remains flat as of 2030 relative to 2010. Emissions per capita fall from 2.3 to 2 mt, a level that is 17 percent below the average global target of 2.4 mt per person within 20 years. This is while, according to the IEA's assumptions, GDP is growing at an average annual rate of 3.7 percent, to reach $4.8 trillion by 2030. Average per capita incomes thereby roughly double by 2030, to $22,000 per person. In short, this Low Carbon scenario developed by the IEA is a reasonable framework for advancing a viable clean energy investment project in Brazil over the next 20 years.

Cost Estimates for Low Carbon Case

We do still need to establish some cost parameters for achieving the IEA's Low Carbon Case for Brazil. As we see in Table 8.5, the total reduction in energy consumption in the IEA's Low Carbon case versus the BAU for 2030 is 7.8 Q-BTUs. This includes 2.5 Q-BTUs in efficiency savings and a 5.3 Q-BTU expansion of clean renewables.

We based our estimates for the costs of achieving these gains in both efficiency and renewables at $11 billion per Q-BTU for efficiency investments and $125 per Q-BTU for expanding clean renewable capacity. We derived these two rough average cost figures as follows.

First, as presented in Chapter 4, in particular in Table 4.2 and the accompanying discussion, the $11 billion per Q-BTU figure for savings from efficiency investments is the middle-range figure in Table 4.2, which comes out of the 2010 McKinsey and Company study discussed in Chapter 4 along with other estimates from the World Bank and the U.S. National Academy of Sciences respectively. McKinsey reported that their average figure is derived from a wide sample of projects throughout Africa, India, the Middle East, South East Asia, Eastern Europe and China.

The $125 billion per Q-BTU for expanding clean renewable capacity is derived from the U.S. Low Technology Cost case for the bioenergy sector, as developed by the EIA, for 2035, and presented in Table 3.9 and the accompanying text. For various reasons, this figure is an appropriate rough, if conservative, benchmark for renewable energy investment costs in Brazil over our full 20-year investment cycle. To begin with, as we have seen in Table 8.4, within the framework of the IEA's 2030 Low Carbon Scenario, most of Brazil's clean renewable expansion will be concentrated in the area of clean bioenergy. Moreover, the costs of expanding clean renewables in Brazil will certainly be well below those for the U.S., since expanding the clean bioenergy sector will be concentrated within Brazil's agricultural sector. Labor costs in Brazil's agricultural sector are themselves certainly well below those for the U.S. We do not have reliable figures for relative unit labor costs in Brazil's agricultural sector, but in manufacturing, as we report in Appendix 5 (Table A5.1), wages are about 12 percent those in the U.S. Hence, by using the U.S. Low Cost Technology figure for 2035, we are more likely to have a reasonable high-end approximation of Brazil's average costs to expand clean bioenergy capacity over the full 20-year investment cycle. The IEA's Low Carbon scenario does also anticipate major expansions in wind, solar, and geothermal power. But these other clean renewable sectors are most likely to begin expanding substantially when the costs of expansion begin to reach rough parity with clean bioenergy. Overall then, $125 billion per Q-BTU is a reasonable rough benchmark approximation for the costs of expanding clean renewables capacity in Brazil over our 20-year investment cycle.

Working with these figures - i.e. $11 billion per Q-BTU of efficiency gains and $125 billion, on average, to expand clean renewable capacity by 1 Q-BTU - we then generate results for total costs to reach the IEA's Low Carbon case for Brazil. As we see in Table 8.5, we estimate these total costs as $28 billion for the efficiency gains and $663 billion for the renewable supply expansion, for a total of $691 billion over 20 years. This then equals $34.4 billion per year over 20 years, with $1.4 allocated to efficiency investments and $33 billion to renewables. Considered over the full 20-year investment period, this level of annual investment would be equal to about 0.9 percent of the midrange figure for Brazil's GDP over this time span. We note that this relatively low level of clean energy investment spending as a share of GDP will free resources that Brazil can used to definitively control emissions from methane and nitrous oxide, as well as undertaking positive measures for preserving the Amazon.

Table 8.5: Brazil. Estimated cost for Brazil to move from IEA's 2030 BAU to Low Carbon case

Costs per Q-BTU of renewable energy expansion and efficiency gains

	1. Q-BTUs	**2. Assumed cost per Q-BTU**	**3. Total costs *(= column 1 x 3)***	**4. Average annual costs for 20 years *(= column 3/20)***
Expansion of clean renewables: Low carbon vs BAU	5.3 Q-BTUs	$125 billion per Q- BTU	$663 billion	$33.0 billion per year
Gains in energy efficiency: Low carbon vs BAU	2.5 Q-BTUs	$11 billion per Q-BTU	$28 billion	$1.4 billion per year
Totals	7.8 Q-BTUs	-	$691 billion	$34.4 billion per year

Costs as a share of midrange GDP for 2012 - 2032

2012 GDP	$2.3 trillion
Projected 20-year average annual GDP growth rate	3.7%
Projected 2032 GDP *(with 3.7 percent average annual GDP growth)*	$4.8 trillion
Midrange GDP value for investment spending estimates *(= (2012 GDP + 2032 GDP)/2)*	$3.6 trillion
Average annual clean renewable investments	$33 billion
Average annual energy efficiency investments	$1.4 billion
Total annual clean energy investments	$34.4 billion
Renewables + efficiency investments as share of midrange GDP	0.9%

Source: Authors' calculations based on Table 8.4 and text in Chapter 8.

Employment Generation through Clean Energy Investments

Table 8.6 presents our estimates as to the effects on overall annual employment levels through a clean energy investment project in Brazil in keeping with the IEA's Low Carbon scenario for 2030. Our estimates of employment impacts follow from the employment modeling results we generated in Chapter 7. We focus for this analysis on the Domestic Content Stable scenario, as opposed to assuming Brazil's imports will have to rise to meet the demands of its clean energy investment project. This is because Brazil is a strongly industrializing economy, with well-established and innovative clean energy sectors. The fact that its clean energy investment project is also relatively small, at 0.9 percent of GDP, also means that the increased demands on domestic resources will also be relatively modest.

Table 8.6: Brazil. Employment impact of clean energy investments vs. fossil fuel spending

Figures are jobs in Year 1 of 20-year project

- **Assumptions of IEA Low-Carbon Program:**
    - Total investment = 0.9 percent of GDP
    - 94 percent clean renewables;
    - 6 percent energy efficiency
- **"Domestic Content Stable" scenario**
- **Additional assumptions:**
    - 70 percent of investment for capacity creation/production
    - 30 percent for financing costs

Brazilian labor force, 2011 = 103 million

	Clean energy investments	**Fossil fuel spending**	**Net employment effects of clean energy investments**
Direct + indirect total employment in Year 1	542,000	307,000	235,000
Direct + indirect employment as share of total labor force in Year 1	0.5%	0.3%	0.2%

Source: See Chapter 7 and Appendix 3.

We have estimated the costs of the IEA's Low Carbon scenario to be in the range of $34.4 billion per year in spending above what would have been needed under the IEA's BAU scenario. This is equal to about 0.9 percent of the midrange GDP figure for Brazil over the 2010-2030 period, assuming a 3.7 percent average annual GDP growth rate.

Of course, given the relatively modest level of investment in clean renewables and energy efficiency as a share of Brazil's GDP, it follows that the extent of job creation will also be modest relative to the size of Brazil's overall labor force of 103 million. The impact on job creation will be further diminished by the fact that, of the total annual budgetary allocation for clean energy investments, we assume that only 70 percent is used for the activities linked to either generating energy or raising efficiency standards, while 30 percent covers financing costs.

Considering these factors, it is nevertheless the case, as we see in Table 8.6, that the clean energy investment project at this level will generate about 542,000 jobs for Brazilians. In absolute terms, this is clearly a large number of jobs. By comparison, we estimate that spending the same amount of money in Brazil on maintaining the economy's existing fossil fuel energy system would create about 307,000 jobs. As such, to the extent that we considered this project as a process of shifting resources out of fossil fuels and into clean energy, the net impact will be an expansion of employment opportunities throughout Brazil of about 235,000 jobs.

In Table 8.7, we present our projections for employment creation in Year 20 of Brazil's 20-year clean energy investment project. These figures are based on two separate assumptions as to the average growth rate of labor productivity in Brazil's clean energy sectors over this 20-year period - a 1 percent low-end average annual labor productivity growth rate assumption and a 2.5 percent high-end assumption.

Table 8.7: Brazil. Projected employment impacts of clean energy investments after 20 Years under alternative labor productivity assumptions

Figures are jobs per year

Assumptions for 20-year employment projections:

- Baseline year-one employment levels given in Table 8.6
- 20-year average annual GDP growth is 3.7 percent
- Average annual labor productivity growth ranges between 1-2.5 percent
- Population figure is projected 2035 population
- Labor force/population ratio at end of 20-year investment cycle equals 2011 ratio

Labor force at end of 20-year investment cycle = 118 million

	Scenario with 1 percent average annual labor productivity growth	**Scenario with 2.5 percent average annual labor productivity growth**	**Midpoint between 1 percent and 2.5 percent productivity growth scenarios**
Year 20 direct + indirect total employment	923,400	688,000	805,700
Year 20 direct + indirect employment relative to Year 1 employment	70.4%	26.9%	48.7%
Direct + indirect employment as share of Year 20 labor force	0.8%	0.6%	0.7%

Sources: See Chapter 7 and Appendix 3.

Working with these assumptions, as well as with the other assumptions on GDP growth, population and labor force participation listed above Table 8.7, we generate the following results:

1. Assuming labor productivity increases at 1 percent per year, total employment creation through clean energy investments will rise to about 923,000 in Year 20. This is a 70 percent increase relative to employment creation in Year 1.

2. Under this 1 percent labor productivity growth assumption, employment creation through clean energy investments will rise to about 0.8 percent of Brazil's Year 20 labor force relative to the 0.5 percent figure as of Year 1.

3. Assuming average labor productivity in Brazil's clean energy sectors increases at the higher-end rate of 2.5 percent over the 20-year investment cycle, employment creation

will then be reduced. Year 20 employment creation through clean energy investments then reaches about 688,000. This is still a 27 percent increase over the Year 1 figure. Under this scenario, employment creation through clean energy investments still rises modestly as a share of Brazil's overall labor force in Year 20, to around 0.6 percent.

4. In the last column of Table 8.7, we report midpoint employment creation figures, that are simply based on averaging the Year 20 employment levels derived from both the 1 percent and 2.5 percent labor productivity growth assumptions. These figures give some additional perspective on the extent of job opportunities that will result through Brazil's 20-year clean energy investment project. As we see, this midpoint figure is about 806,000 jobs, which is about 0.7 percent of Brazil's Year 20 labor force.

Overall, as we see, employment creation through Brazil's clean energy investment project operating at 0.9 percent of GDP per year will expand over time under a wide range of plausible assumptions as to the growth of labor productivity over the 20-year investment cycle.

Conclusion

Brazil has long been highly innovative in the operations and development of its energy system. As we have seen, it is already a world leader both in terms of its level of energy efficiency and in its low level of emissions relative to its aggregate output. At the same time, Brazil is also high in the global rankings in terms of generating GHG emissions from sources other than the burning of oil, coal and natural gas. Given this combination of circumstances, a reasonable strategy for Brazil at present is to spend relatively less money on clean energy investments than other countries. This will allow Brazil to focus on reducing emissions from methane and nitrous oxide and to preserving the Amazon, in addition to keeping CO_2 emission levels low.

The IEA's Low Carbon scenario for Brazil for 2030 provides a valuable framework for Brazil in proceeding with a clean energy investment agenda through 2030. The plan is relatively modest in terms of its costs. We estimate them to be in the range of $34 billion per year for 20 years. But at this level of spending, we do still see emissions fall by 38 percent relative to the 2030 BAU case, and decline by 13 percent relative to 2010. As a result, Brazil will continue to operate with one of the lowest emissions per capita ratios, at 2 mt. This figure is significantly below the target level of 2.4 mt for the world as a whole within the next 20 years.

Meanwhile, in accomplishing these emissions reduction goals, Brazil's clean energy investment project will also generate an expansion of job opportunities throughout the country – 542,000 in total for advancing the Low Carbon scenario relative to the BAU case in Year 1; and 235,000 more jobs than would be created through spending the same funds on oil, coal, and natural gas rather than on hydro, clean bioenergy, wind and solar power. Assuming a wide range of growth rates for labor productivity in Brazil's clean energy sectors, the gains in employment creation will also then increase over time throughout the 20-year clean energy investment cycle.

CHAPTER 9: GERMANY - CLEAN ENERGY INVESTMENTS, EMISSIONS REDUCTIONS AND EMPLOYMENT EXPANSION

Level of Development and CO2 Emissions

As is well-known, Germany occupies a unique place in the global project of building a clean-energy economy and controlling climate change. It is fair to say that Germany has made the most thoroughgoing commitment to this project among the world's large high-income countries, and perhaps among all countries at all levels of development. Germany has, first, committed to creating a nearly emissions-free economy as of 2050, i.e. a level of CO_2 emissions at 156 mmt. This would represent an 85 percent decline in emissions relative to the 1990 level of 1,042 mmt, and a per capita emissions level of 2.1 mt (assuming 2050 population at about 75 million). They have also embraced this ambitious project while also aiming to eliminate entirely their reliance on nuclear energy over this same period. It is evident that the German case is of great importance, both in terms of its impact within Germany itself, and through advancing a set of ideas, products, and experiences from which the rest of the world can learn.

In Table 9.1, we review the basic statistics from Chapter 1 indicating Germany's current level of development and the operations of its energy system. According to the World Bank Indicators, Germany is a high-income country, with, as we see in Table 9.1, average per capita income at $41,500 as of 2010. Overall energy consumption was at 13.9 Q-BTUs in 2010, and overall CO_2 emissions were at 793 mmt.

Table 9.1: Germany. Basic energy indicators, 2010

	Germany	World
Per capita GDP *(2005 $PPP)*	$41,500	$10,300
Total energy consumption *(Q-BTUs)*	13.9 Q-BTUs	510.5 Q-BTUs
Per capita energy consumption *(M-BTUs/population)*	170.4 M-BTUs	74.0 M-BTUs
Total CO_2 emissions *(mmt)*	793 mmt	31,502 mmt
Per capita CO_2 emissions *(mt of emissions/population)*	9.7 mt	4.6 mt
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	4.1 Q-BTUs	7.1 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	57.1 mmt	65.9 mmt

Source: See Tables 1.1 and 1.4.

Per capita CO_2 emissions were at 9.7 mt, which is a bit more than twice as high as the global average of 4.6 mt, and four times higher than the global 20-year goal of 2.4 mt per person necessary for the globe to achieve an adequate path for stabilizing global average temperatures by 2050. Nevertheless, as we had reviewed in Chapter 1, Germany's per capita emissions levels are far below those of other high-income countries. The figure for the U.S., as we saw in Chapter 1, is 18.2 mt per person.

The main factor responsible for Germany's low emissions levels is the high level of energy efficiency at which the economy operates. This is evident through its energy intensity ratio, which measures Q-BTUs of energy per $1 trillion in GDP. As we have seen, Germany's index is 4.1. This is 73 percent below the world average of 7.1. It is also 50 percent lower than the U.S. figure of 6.1 and 1/3 of China's ratio of 12.1.

To date, Germany's energy mix is not unusually weighted toward clean energy. Its emissions intensity ratio - the ratio of CO_2 emissions per Q-BTU - is 57.1. This is only modestly lower than the global average of 65.9 and basically at parity with the U.S.

We get a more fully specified picture of Germany's energy mix in Table 9.2. As we see, Germany's consumption is dominated by traditional non-renewable sources, with oil at 34.4 percent, coal at 23.7 percent, natural gas at 21.6 percent, and nuclear at 11.4 percent. The only renewable source that makes a significant contribution as of 2010 is bioenergy. But to date, Germany's bioenergy sources are generated almost entirely through high-emissions processes. Hydro, wind, solar and geothermal power combined account for less than 2 percent of Germany's total energy supply as of 2010.

Table 9.2: Germany. Energy consumption and emissions, 2010

Total energy consumption	13.9 Q-BTUs
Total CO_2 emissions	793 mmt
CO_2 emissions per capita *(with population = 82.3 million)*	9.7 mt
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	4.1 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	57.1 mmt
Energy mix (2008):	
Oil	34.4%
Coal	23.7%
Natural gas	21.6%
Nuclear	11.4%
All renewables	8.0%
• Bio - High emissions	6.3%
• Bio - Low emissions	0.0%
• Hydro	0.5%
• Wind	1.0%
• Solar	0.2%
• Geothermal	0.01%

Sources: See Tables 1.1 and 1.4; EIA (2013b) "International Energy Outlook 2013"; Schlesinger, Lindenberger and Lutz (2010), Table A 1-2.

Germany's Transformational Project: The Energiewende

As is evident from the figures reviewed above, Germany has both made major advances in reducing CO_2 emissions relative to other high-income countries, but equally, still faces major challenges ahead to become a low-emissions economy as of 2050. Germany faces two basic problems moving forward. The first is that most of its emissions reductions achievements to date have been achieved through energy efficiency investments. Precisely because Germany already operates at a high level of efficiency, it could be more difficult for them to obtain further major efficiency improvements. The second problem is that, moving forward, Germany intends to rely to a major extent on clean renewable energy supplies. This is despite the fact that, to date, the contributions of all clean renewables as a share of overall energy supply remains negligible. It is therefore critical to review the project Germany has set and the opportunities available to them with respect to new large-scale investments both in energy efficiency and clean renewable energy sources.[64]

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[64] See Hockenos (2013a) for a valuable overview assessment of the *Energiewende* to date, as well as an analysis of the major challenges ahead.

Alternative 2030 Scenarios

We can obtain a good sense of the basics of Germany's transformational project through 2030 via the government's projections of energy supply and consumption patterns within two scenarios set out in its 2010 *Energy Concept* document (BMUB, 2010). We present below two of the scenarios developed in that document. The first is the government's Reference case, to which we refer as their "BAU scenario." The second is its 1A case, through which Germany reaches its 2050 target level of 156 mmt in CO_2 emissions, i.e. the target of an 85 percent emissions decline relative to the 1990 level. We refer to their 1A case as the "Low Carbon scenario." We present these two scenarios, along with the actual figures for 2008, in Table 9.3 below.

Table 9.3: Germany. Energy consumption and emissions: 2008 actuals and alternative official projections

		German Environmental Ministry, Energy Concept	
	2008 actuals	**2030 BAU Scenario**	**2030 Low Carbon Scenario**
Total energy consumption	14.4 Q-BTUs	10.4 Q-BTUs	9.3 Q-BTUs
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*[a]	5.1 Q-BTUs	2.1 Q-BTUs	1.9 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	52.9 mmt	55.5 mmt	47.2 mmt
Total CO_2 emissions	732 mmt[b]	577 mmt[c]	439 mmt
CO_2 emissions per capita	8.9 mt	7.2 mt	5.5 mt
Energy mix:			
Oil	34.4%	35.8%	32.3%
Coal	23.7%	17.3%	16.1%
Natural gas	21.6%	23.9%	21.9%
Nuclear	11.4%	0.0%	0.0%
All renewables	8.0%	22.8%	30.0%
• Bio - High[d] emissions	6.3%	0.0%	0.0%
• Bio - Low emissions	0.0%	14.6%	19.6%
• Hydro	0.5%	0.9%	1.0%
• Wind	1.0%	4.2%	5.4%
• Solar	0.2%	2.0%	2.4%
• Geothermal	0.0%	1.1%	1.2%

Sources: BMUB (2010), "Energy Concept of 2010"; EIA (2013b), "International Energy Outlook 2013"; Schlesinger, Lindenberger, and Lutz (2010), Table A 1-2.

Notes: a) Calculations based on assumption of 2 percent real GDP growth from 2010 base of $3.3 trillion. b) The emission figures for 2008 come from the World Bank Indicators. They are lower than those reported above for 2010, which come from the EIA International Energy Outlook. This is one case where the need to rely on more than one source creates some statistical inconsistencies. But it was necessary to use these various sources for the purposes of internal consistency within each separate table of figures. c) These figures were derived from the levels of energy consumption assigned to oil, coal, and natural gas, with the emissions per Q-BTU figures presented in Table 2.2. The figures taken directly from the Energy Concept source are somewhat lower: 503 mmt under the BAU case and 403 under the Low Carbon case. d) As discussed in the text, we assume that, by 2030, the entire supply of bioenergy in Germany comes from low-emissions sources. This is not explicitly stated as a feature of the 2030 projections.

The first thing to note is that Germany achieves major advances in energy efficiency under *both* its BAU and Low Carbon scenarios for 2030. Thus, under the BAU scenario, Germany's energy intensity falls from 5.1 Q-BTUs per $1 trillion in 2008 to 2.1 in 2030, a nearly 60 percent improvement in efficiency. The additional efficiency gains from the BAU to the Low Carbon case are modest, from a 2.1 to a 1.9 energy intensity ratio.

The major difference between the BAU and Low Carbon cases is with the change in the energy mix. As we see in Table 9.3, under the BAU case, the emissions intensity ratio - i.e. emissions per Q-BTU - actually rises modestly as of 2030 relative to 2008, from 52.9 to 55.5 mmt of emissions per Q-BTU. However, with the Low Carbon scenario, the emissions intensity ratio falls to 47.2 mmt per Q-BTU, a 15 percent decline relative to the BAU case.

We see the overall impact of both the gains in efficiency and the expansion of clean renewables supply through the trajectory for overall emissions and emissions per capita as of 2030. In the 2030 BAU scenario, total emissions do fall by a substantial 21 percent relative to 2008, from 732 to 577 mmt. With the Low Carbon scenario, the emissions decline is to 439 mmt, a 40 percent reduction relative to 2008.

We obtain further perspectives on these two 2030 scenarios by examining the changes in the specific energy mix in both cases. In both cases, the main changes with respect to non-renewable sources are the absolute elimination of nuclear energy, from having contributed over 11 percent to Germany's total energy supply in 2008. The share of energy supplied by coal, also declines significantly - from nearly 24 percent of total supply in 2008 to 17 percent under the 2030 BAU scenario and 16 percent with the Low Carbon scenario.

The relative declines for nuclear power and coal are then matched by a large expansion in renewables supply. Wind, solar and geothermal all grow substantially, both under the BAU and Low Carbon cases. The share from wind rises from 1 percent in 2008 to 4.2 percent under the 2030 BAU case and to 5.4 percent in the Low Carbon case. Solar rises from only 0.2 percent in 2008 to 2.0 percent in the 2030 BAU case and 2.4 percent under the Low Carbon scenario. These are all large proportional increases. But they all remain as relatively modest contributions to Germany's overall energy supply in 2030, under both the BAU and Low Carbon scenarios.

The most important factor in terms of renewables is the large expansion in bioenergy - from 6.3 percent of total supply in 2008 to 14.6 percent in 2030 under the BAU scenario and to 19.6 percent under the Low Carbon scenario. What is also critical here is that, between 2008 and 2030, Table 9.3 shows that the bioenergy supply shifts entirely from high-emissions to low-emissions processes. That is, the table shows that low-emissions bioenergy is at zero percent of total supply as of 2008, but then, as of 2030, under both the BAU and Low Carbon scenarios, high-emissions bioenergy is at zero percent, while low-emissions bioenergy provide 100 percent of the bioenergy supply. In fact, this breakdown in the relative proportions of high- and low-emissions bioenergy is not explicitly stated in the BMUB's *Energy Concept* document. We have, instead, inferred these shifts in the shares of high- and low-emissions bioenergy sources based on changes in emission levels in the 2030 scenarios relative to 2008. That is, it would not be possible for overall emissions to fall to the extent presented in the Energy Concept document if Germany were to continue to generate bioenergy through the high-emissions practices that dominated as of 2008.

We discuss this issue of bioenergy sources further below, as part of our discussion of Germany's strategies for achieving its highly ambitious emissions reductions goals for 2030. We first consider developments in the area of energy efficiency, then take up investments in renewable energy.

Energy Efficiency

Despite the fact that Germany is already operating at a very high efficiency level, the government's policy framework, the 2010 *Energy Concept* document developed by the BMUB, has developed a path through which its energy intensity ratio will still fall much further, from the 2008 level of about 5 Q-BTUs per $1 trillion in GDP to about 2 as of 2030 - a roughly 60 percent efficiency improvement. Germany's efficiency strategy to date and future plans are well summarized in the IEA's 2013 *Energy Efficiency Market Report*. The IEA's study begins by noting that "Germany's state-owned development bank, KfW, plays a crucial role by providing loans and subsidies for investment in energy efficiency measures in buildings and industry, which have leveraged significant private funds," (2013, p. 149). The IEA study also believes that Germany's progress to date can indeed continue into the foreseeable future, as long as government policies continue to support efficiency investments on a large-scale basis. The IEA's assessment of Germany's prospects is as follows:

> *The outlook is bright for energy efficiency markets in Germany, where a combination of government policy requiring better energy performance, a history of industry engaged in providing energy efficient products, and financial support available to consumers for energy efficiency, mean that significant investment is expected to continue. European carbon dioxide emissions regulations for cars will require the large German car industry to continue investing in fuel-efficient technology. Potential opportunities for energy efficiency investment can also be found in industry, where energy management programmes are now necessary to access certain tax relief programmes.*
>
> *Buildings are likely to remain an area with further potential for investment in energy efficiency. The 2 percent renovation rate target set in the Energy Concept strategy should translate into further investment opportunities for energy efficiency refurbishments, involving both a larger number of buildings and deeper retrofits. Although much progress has been made, significant investment opportunities remain in the buildings sector over the next five to ten years.*
>
> *Markets for energy efficiency services, notably energy advice, energy management and energy contracting, have experienced steady growth over the last five years in Germany. However, they are not considered to have met their potential, and further growth will likely be driven by policy in the medium term. Continuing barriers to market development are also largely related to policy; moves to facilitate market activity, such as through certification and determining transparent definitions of products and services, are expected to spur continued growth in energy efficiency markets (IEA,* 2013b, *p. 159).*

Renewables

As documented by Eichhammer (2013), the expansion in the supply of wind and solar energy production in Germany have been substantial. Germany has also been a major exporter in both areas. Prospects are also favorable for a major development in concentrated solar power systems for the Middle East and North Africa, with the energy generated there potentially being transported back to Europe.

To date, the major driver behind the successful expansion of the solar and wind sectors has been the provision of feed-in tariffs, which guarantee a sale price for electricity generated through the renewable sources and preferential access to the grid. The 2012 OECD economic report on Germany provides a favorable overall assessment of the impact of Germany's feed-in tariff policies, while also suggesting the need for further policy innovations over time:

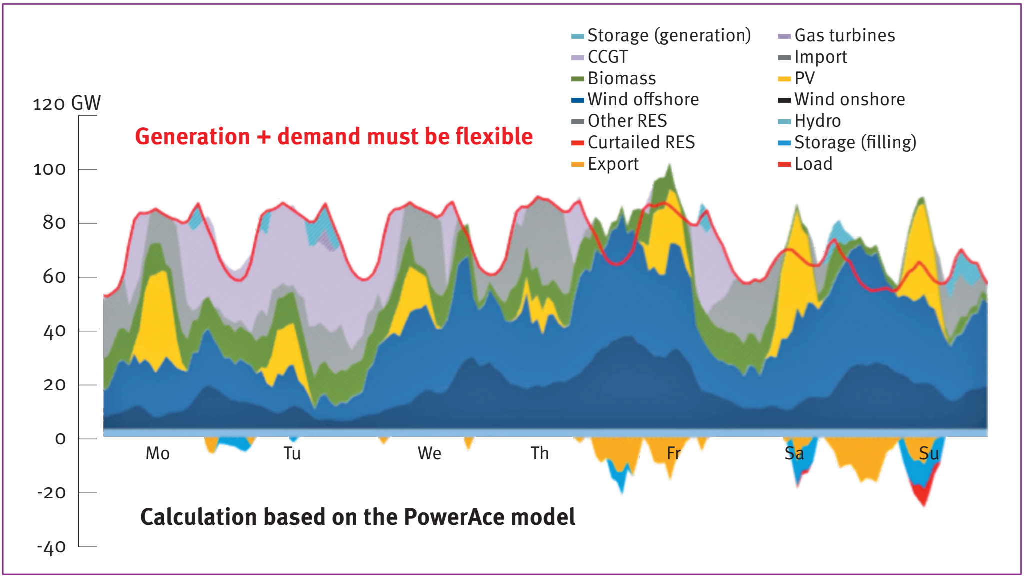
> *These tariffs are in general well designed; they are transparent and predictable (thus fostering long-term investment) and are decreasing over time (thus encouraging innovation). Tariffs also vary across technologies; while this is potentially supporting non-mature but promising power sources more than others, it increases CO_2 abatement costs for certain technologies to excessive levels. Given the relatively high costs of feed-in tariffs, efficiency improving adjustments to the system should be considered. It is thus welcome that the government revised the photovoltaic tariffs; it should continue to monitor the generosity of the feed-in tariffs and adjust them tightly in line with market developments (OECD, 2012, p. 21).*

Another major factor supporting developments in the solar and wind sectors has been technical innovations. The OECD study reports that the number of triadic patents - i.e. those filed simultaneously within the European Union, the U.S. and Japan - for renewable energy technologies was second only to Japan between 1996 to 2008. The share of GDP allocated in Germany to R&D in renewable energy is fourth among OECD economies, after only the ROK, Finland and Japan, and is roughly twice as high as the US.

One important area of R&D development in Germany is creating a flexible energy supply load curve for renewables, as the demand for energy varies over the course of days, weeks, and seasons. Figure 9.1 below, reproduced from Eichhammer (2013), provides an example of the type of flexible load management systems being developed for Germany's renewable energy mix as of 2050. As we can see, the management systems will have to take account of the relative capacities of domestically produced wind, bioenergy, solar, and hydro to contribute at any given time, the capacity to store renewable energy supplies over time, the prospects for developing export markets, and the potential residual demand for imports.

Figure 9.1: Germany. A model of a flexible renewable energy supply system for Germany, 2050

The figure depicts a possible load curve and supply in Germany in 2050, week 42.



Source: Eichhammer (2013).

However, the single largest set of issues with respect to developing a large-scale supply of clean renewable sources by 2030 will be in the area of bioenergy. As we have discussed elsewhere in this report, in particular in our Chapter 3 overview with respect to Brazil's major bioenergy sector, the environmental impacts of generating bioenergy vary greatly, depending on feedstocks and energy-producing processes involved. For example, as we have seen, emissions generated by burning corn ethanol that has been refined through coal-firing processes actually generates 34 percent greater emissions over a 30-year cycle than burning gasoline. By contrast, using corn stover or switchgrass as the feedstock for ethanol, and using renewable energy in refining processes, is actually a *net absorber* of atmospheric CO_2. At present, Germany relies almost entirely on high-emissions bioenergy sources in supplying 6.3 percent of its total energy supply. But the Low Carbon scenario in the BMUB's Energy Concept has bioenergy as providing nearly 20 percent of Germany's total energy supply in 2030. It will be imperative for Germany to transform its bioenergy sector into low-emissions methods in order to meet its overall 2030 emissions reduction targets.

These issues have recently been debated intensively in Germany. Thus, an analysis published in 2012 by the German National Academy of Sciences Leopoldina, *Bioenergy - Chances and Limits* - argues that the negative impacts of bioenergy outweigh the positives, and that the realistic prospects for expanding a low-emissions bioenergy sector are limited. One observer of Germany's energy project Paul Hockenos reported on this study as follows in a January 2013 *European Energy Review* article:

> *A group of 20 experts from various disciplines branded the sector as a bit player in the transition to renewables and charged that the net environmental impact is negative.*

> *The cultivation and use of energy crops, it concluded, leads to high emissions of greenhouse gases, damages ecosystems, and competes with food crops. Germany's biomass imports…effectively export the harmful impact of intensive bioenergy-based agriculture. The report recommends bolstering other renewables like PV solar power and wind power, as well as finding strategies for increasing energy efficiency rather than investing further in the bioenergy branch. Bioenergy makes sense, it concludes, only in the limited circumstances when animal or other kinds of waste (residuals) serve as the biomass (Hockenos,* 2013b*).*

However, Hockenos also reports that Germany has developed highly stringent and, to date, effective certification schemes that were designed explicitly to address bioenergy's environmental shortcomings. Indeed, he writes that "Germany has been the pioneer in designing and implementing these controls at home as well as having standards turned into law for the EU-27." Most critically, Hockenos reports that, following Germany's lead, the European Commission is aiming to phase out bioenergy generated with food crops altogether and to use only bioenergy produced from residual biomass, waste and selected dedicated crops grown on surplus land that cannot be used for the cultivation of food or animal feedstocks. According to Hockenos, the authors of the National Academy study did not take adequate account of these policy innovations that are already underway in Germany.

Cost Estimates for Clean Energy Investments

It is evident that Germany does face major challenges in implementing its clean energy transformation. The costs of this project are likely to be in the range of 1.5 percent of GDP per year, at least through 2030. The *Energy Concept* document which developed the two 2030 scenarios we have described estimates that the total costs for Germany to move from the BAU to the Low Carbon scenario is likely to be in the range of $500 billion through 2050. That would be an average annual cost of $12.5 billion over 40 years. This in turn would represent about 0.4 percent of Germany's current GDP level of $3.3 trillion. However, as we have seen, the differences between the BAU and Low Carbon scenarios for 2030 are much smaller than either scenario relative to the actual figures for 2008. Indeed, with respect to energy efficiency gains, there is only a modest difference between the BAU and Low Carbon scenarios. The major transformations are already embedded in the BAU case.

The differences between the BAU and Low Carbon cases are larger with respect to renewables. Still, even in the BAU case, solar power goes from 0.03 to 0.2 Q-BTUs and wind goes from 0.14 to 0.44 between 2008 and 2030. Most significantly, at least as we have interpreted the 2030 BAU case, clean bioenergy goes from a zero baseline in 2008 to fully 1.5 Q-BTUs in 2030.

Overall then, if the Concept estimates that the costs of moving from the BAU to the Low Carbon case at about 0.4 percent of Germany's 2010 GDP of $3.3 trillion, it is reasonable to expect that moving from the 2008 baseline to the BAU case will entail roughly another 1.1 percent of GDP. This means roughly another $36 billion per year, for a total of about $50 billion.

This figure would then rise annually in correspondence with the economy's growing GDP. Over the full 20-year period from 2010-2030, the midrange level of spending would be $62 billion, assuming Germany's GDP grew at an average annual rate of 2 percent per year.

Employment Generation through Clean Energy Investments

Table 9.4 presents our estimates as to the effects on overall annual employment levels through a clean energy investment project corresponding with the Low Carbon case in Germany's *Energy Concept* document. Our employment estimates are based on the results of the employment models we presented in Chapter 7. We focus for this analysis on the Domestic Content Stable scenario, as opposed to assuming Germany's imports will have to rise to meet the resource demands of its clean energy investment project. This is because Germany is an advanced economy, which has already built the most innovative clean energy sector among large advanced economies.

Table 9.4: Germany. Employment impact of clean energy investments vs. fossil fuel spending

Figures are jobs in Year 1 of 20-year clean energy investment strategy

- **Assumptions of IEA Low-Carbon Investment Strategy:**
  - Total investment = 1.5 percent of GDP;
  - 67 percent clean renewables;
  - 33 percent energy efficiency
- **"Domestic Content Stable" scenario**
- **Additional assumptions:**
  - 70 percent of investment for capacity creation/production;
  - 30 percent for financing costs.

German labor force in 2011 = 42.3 million

	Clean energy investments	**Fossil fuel spending**	**Net employment effects of clean energy investments**
Direct + indirect total employment at Year 1	331,500	263,300	68,200
Direct + indirect employment as share of total labor force at Year 1	0.8%	0.6%	0.2%

Source: See Chapter 7 and Appendix 3.

We have roughly estimated the costs of achieving the goals of the Low Carbon case as being about 1.5 percent of Germany's GDP through 2030. We then also assume that, of the total annual budgetary allocation for clean energy investments, 70 percent is used for the activities linked to either generating energy or raising efficiency standards, while 30 percent covers financing costs. We estimate employment creation only on the basis of the 70 percent of spending going towards expanding renewable energy capacity or raising efficiency standards as opposed to the financing costs of undertaking those investment activities.

Considering these factors, we see that Germany's clean energy investment project, as we have specified it, will generate about 330,000 jobs within Germany in Year 1 of the 20-year investment project. This represents about 0.8 percent of Germany's total workforce. By comparison, if Germany were to spend that same 1.5 percent of GDP within its existing fossil fuel sectors, the level of employment creation would be about 263,000 jobs, or 0.6 percent of Germany's workforce. The net effect from shifting funds out of fossil fuels and into energy efficiency and renewables would be to increase the overall number of jobs within the German economy by close to 70,000 jobs.

In Table 9.5, we present our projections for employment creation in Year 20 of Germany's 20-year clean energy investment project. These figures are based on two separate assumptions as to the average growth rate of labor productivity in Germany's clean energy sectors over this 20-year period - a 1 percent low-end average annual labor productivity growth rate assumption and a 2.5 percent high-end assumption.

Table 9.5: Germany. Projected employment impacts of clean energy investments after 20 years under alternative labor productivity assumptions

Figures are jobs per year

Assumptions for 20-year employment projections

- Baseline year-one employment levels given in Table 9.4
- 20-year average annual GDP growth is 2 percent
- Average annual labor productivity growth ranges between 1-2.5 percent
- Population figure is projected 2035 population
- Labor force/population ratio at end of 20-year investment cycle equals 2011 ratio

Labor force at end of 20-year investment cycle = 40 million

	Scenario with 1 percent average annual labor productivity growth	**Scenario with 2.5 percent average annual labor productivity growth**	**Midpoint between 1 percent and 2.5 percent productivity growth scenarios**
Direct + indirect total employment	404,500	299,900	352,000
Year 20 direct + indirect employment relative to Year 1 employment	22.0%	-9.5%	6.2%
Direct + indirect employment as share of total labor force	1.0%	0.7%	0.9%

Sources: See Chapter 7 and Appendix 3.

Working with these assumptions, as well as with the other assumptions on GDP growth, population and labor force participation listed above Table 9.5, we generate the following results:

1. Assuming labor productivity increases at 1 percent per year, total employment creation through clean energy investments will rise to about 404,000 in Year 20. This is a 22 percent increase relative to employment creation in Year 1.

2. Under this 1 percent labor productivity growth assumption, employment creation through clean energy investments will rise to about 1 percent of Germany's Year 20 labor force relative to the 0.8 percent figure as of Year 1.

3. Assuming average labor productivity in Germany's clean energy sectors increases at the higher-end rate of 2.5 percent over the 20-year investment cycle, employment creation will then be reduced. Year 20 employment creation through clean energy investments then reaches about 300,000. This is about a 9 percent reduction over the Year 1 figure. The reason that employment contracts through clean energy investments in this scenario is that we are assuming Germany's average annual GDP growth is a relatively slow 2 percent. GDP growth would thereby be below our assumed high-end labor productivity growth assumption of 2.5 percent. Under this scenario, employment creation through clean energy investments declines by 0.1 percent as a share of Germany's overall labor force in Year 20, to around 0.7 percent.

4. In the last column of Table 9.5, we report midpoint employment creation figures that are based on averaging the Year 20 employment estimates derived from both the 1 percent and 2.5 percent labor productivity growth assumptions. These figures give some additional perspective on the extent of job opportunities that will result through Germany's 20-year clean energy investment project. As we see, the midpoint employment level for Year 20 is about 350,000. This would represent about 0.9 percent of Germany's Year 20 workforce.

Overall, employment creation through Germany's clean energy investment project operating at 1.5 percent of percent of GDP per year will expand over time under most scenarios as to the growth of labor productivity over the 20-year investment cycle. It is only when labor productivity in Germany's clean energy sectors rise at a rate faster than our assumed relatively slow average annual GDP growth rate of 2 percent that the gains in employment through clean energy investments decline over time. Nevertheless, even under such scenarios of labor productivity rising faster than GDP growth, the clean energy investment strategy will still generate positive gains in employment, both absolutely as well as relative to spending within Germany's fossil fuel sectors.

Considering these employment estimates as a whole, the impact on job opportunities of the German clean energy investment project will be favorable. On their own, they will not generate a dramatic improvement in employment opportunities throughout the German economy. But there will positive job benefits that accrue while Germany undertakes its transformational project of building a clean energy economy.

CHAPTER 10: INDONESIA - CLEAN ENERGY INVESTMENTS, EMISSIONS REDUCTIONS AND EMPLOYMENT EXPANSION

Growth Trajectory and Emissions

We begin by reviewing in Table 10.1 the basic statistics from Chapter 1 indicating Indonesia's current level of development and the operations of their energy system. As we see in Table 10.1, Indonesia is at present a lower-middle income country, with average per capita GDP at $3,600 as of 2012. Overall energy consumption is at 6.0 Q-BTUs, and overall CO_2 emissions are at 415 mmt. Emissions per capita are at 1.7 mt, which is roughly one-third the global average of 4.6 mt. It is also below the targeted global average figure of 2.4 mt needed for achieving the 20-year global CO_2 emissions reduction target. In terms of both the energy intensity and emissions intensity ratios, Table 10.1 shows that Indonesia is presently close to the global average.

Table 10.1: Indonesia. Basic energy indicators, 2010

	Indonesia	**World**
Per capita GDP *(2005 $PPP)*	$3,600	$10,300
Total energy consumption *(Q-BTUs)*	6.0 Q-BTUs	510.5 Q-BTUs
Per capita energy consumption *(M-BTUs/population)*	25.2 M-BTUs	74.0 M-BTUs
Total CO_2 emissions *(mmt)*	414.6 mmt	31,502 mmt
Per capita CO_2 emissions *(mt of emissions/population)*	1.7 mt	4.6 mt
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	6.8 Q-BTUs	7.1 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	69.1 mmt	65.9 mmt

Source: See Tables 1.1 and 1.4.

Between 2003-2012, the Indonesian economy has grown at an average annual rate of 5.7 percent. This sustained strong growth performance has also generated rapid increases in energy consumption throughout the country. Nevertheless, the country's provisioning of energy services is still seriously underdeveloped. As of 2012, 35 percent of households do not have access to electricity. The country experiences daily power blackouts averaging 4 hours a day.

The economic growth target of the State Ministry of National Planning (BAPPENAS) is for Indonesia to move onto a long-term GDP growth path of around 7 percent per year through 2030 (Republic of Indonesia, 2011). This would represent a very rapid long-term growth trajectory, roughly comparable to Japan, the ROK, China and the smaller Asian Tiger economies during their strongest growth phases. This growth trajectory would generate a rough tripling of average per capita incomes in the country, to around $10,000 per person. If such average income gains from growth were equitably distributed, the impact would be a dramatic reduction in poverty.

Of course, we cannot know whether Indonesia will be able to achieve this kind of growth performance. But we do know that if they attain anything roughly along these lines while also maintaining its existing energy infrastructure more or less intact, the result will be to generate a huge increase in the country's CO_2 emissions. This is precisely the quandary that will confront not only Indonesia, but all low and lower-middle income countries that aim to achieve a rapid growth rate on a foundation of fossil-fuel dominated energy systems.

In Table 10.2, we can see the impact of Indonesia's rapid growth path under what the government assumes as its BAU energy consumption assumptions through 2030, as presented in its 2010 document, *Indonesia's Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC)*. Thus, as we see in the top row of the second column of Table 10.2, under the BAU assumptions, Indonesia's overall energy consumption rises to 25.8 Q-BTUs by 2030, a 330 percent increase relative to the actual 2010 level. Moving down the second column, we can also see how Indonesia's energy mix is projected to change over this time period, with most of the expansion in overall supply coming from coal. The proportion of overall energy supplied by coal rises from 32.6 to 47.3 percent.

Table 10.2: Indonesia. Energy consumption and emissions: 2010 actuals and alternative official projections

	2010 actuals	2030 BAU scenario	2030 "Low Carbon" scenario
Total energy consumption	6.0 Q-BTUs	25.8 Q-BTUs	19.7 Q-BTUs
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*[a]	6.8 Q-BTUs	11.2 Q-BTUs	8.6 Q-BTUs
Energy mix:			
Oil	39.1%	21.4%	25.7%
Coal	32.6%	52.0%	30.5%
Natural gas	19.2%	20.2%	30.4%
Nuclear	0.0%	0.0%	0.3%
High-emissions renewables	4.0%	2.5%	5.4%[b]
Clean renewables	5.1%	3.8%	7.9%
• Hydro	4.2%	2.7%	4.0%
• All others	0.9%	1.1%	3.9%[c]
Total CO_2 emissions	415 mmt	2,200 mmt	1,450 mmt
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	69.2 mmt	85.3 mmt	73.6 mmt
CO_2 emissions per capita *(with population = 280 million)*	1.7 mt	7.8 mt	5.2 mt

Source: See Tables 1.1 and 1.4; Republic of Indonesia (2010), "Indonesia's Second National Communication to the United Nations Framework Convention on Climate Change"; EIA (2013b), "International Energy Outlook 2013."

Note: a) Calculations based on average annual GDP growth of 5 percent; b-c) Assumption is that clean bioenergy supplies 20 percent of all bioenergy under 2030 "low carbon" scenario.

The impact of this large increase in energy consumption with a rising proportion supplied through burning coal, the most heavily emitting CO_2 energy source, is that overall emissions will rise from 415 mmt in 2010 to 2,200 mmt in 2030 under the 2030 BAU scenario, a 430 percent increase. Assuming Indonesia's population in 2030 is around 280 million, this then also means that per capita CO_2 emissions rise from 1.7 to 7.8 mt. This figure is 70 percent higher the current global average per capita emissions level of 4.6 mt, and more than three times higher than the 2.4 mt average per capita level that the world needs to achieve as its 20-year emissions reduction target.

The Indonesian government fully recognizes the problem. Thus, its 2010 communication to the UNFCCC also presents alternatives to the BAU scenario, which seek to reduce the rise in CO_2 emissions within the context of the country's growth process (Republic of Indonesia, 2010). The third column of Table 10.2 presents the results of the government's most ambitious scenario, which we have termed its "Low Carbon" case (the document itself terms this scenario "Climate II"). In this case, overall emissions in 2030, at 1,450 mmt, are 50 percent lower than in the BAU case. Most of the improvement here is the result of fuel-switching from coal to natural gas. As Table 10.2 shows, in the Low Carbon scenario, natural gas rises from 18.1 to 27.4 percent of overall supply relative to the BAU case while coal falls from 47.3 to 30.5 percent.

Clean renewables also rises relative to the BAU case, from 3.8 to 5.4 percent. The Low Carbon case also assumes a first-time contribution from nuclear power, if at a still quite modest level of 0.3 percent of total supply.

The most critical result emerging out of Indonesia's Low Carbon scenario is that per capita emissions are still at 5.2 mt in 2030. That is, with this Low Carbon case, per capita emissions as of 2030 are still more than twice as high as the 2.4 mt global average emissions level needed to reach the 20-year emissions reduction target. Clearly, as a framework for beginning to control climate change over the next 20 years, even this Low Carbon scenario is not viable for either Indonesia itself or other low- to lower-middle income economies aiming for rapid economic growth.

Emissions Reductions through Clean Energy Investments

In Table 10.3, we present our alternative framework, in which Indonesia's growth process incorporates clean energy investments - i.e. investments in renewable energy and energy efficiency - at a rate of 1.5 percent of GDP annually over a full 20-year period. For the purposes of our discussion, as sketched earlier in this chapter, we assume that this 1.5 percent of GDP is allocated with 1 percent of GDP funding the expansion of clean renewable production while 0.5 percent of GDP is channeled into energy efficiency investments.

Table 10.3: Indonesia. Clean energy 20-year investment growth trajectory

2012 GDP	$880 billion
Projected 20-year average annual GDP growth rate	5.0% per year
Projected 2032 GDP *(with 5 percent average annual GDP growth)*	$2.3 trillion
Midrange GDP value for investment spending estimates *(= (2012 GDP + 2032 GDP)/2)*	$1.6 trillion
Average annual clean renewable investments *(= 1 percent of midrange GDP)*	$16 billion
Average annual energy efficiency investments *(= 0.5 percent of midrange GDP)*	$8 billion

Source: Authors' calculations based on World Bank (2014) "World Development Indicators," GDP (current dollars).

Growth assumptions for clean energy project. For the purposes of our discussion, we are assuming that Indonesia's average annual GDP growth rate over this 20-year period is 5 percent rather than 7 percent. For our purposes, it is reasonable to work with a more conservative, if still rapid, projection for long-term GDP growth. But note that, in any case, even under a 7 percent average growth scenario over 20 years, if Indonesia were to devote 1.5 percent of its more rapidly growing GDP levels to expanding its clean energy sector, the absolute expansion of this clean energy sector would be faster with a 7 percent GDP growth rate.

As Table 10.3 shows, when we assume a 5 percent average annual growth rate over 20 years, this would mean that Indonesia's GDP in 20 years would be $2.3 trillion. To then estimate an average level of clean-energy investment spending over this 20-year period, we simply calculate the midrange GDP value between 2012 GDP at $880 billion and 2032 GDP at $2.3

trillion. That figure is \$1.6 trillion. This then means that the average level of annual spending on clean energy would be 1 percent of \$1.6 trillion per year for renewables, which is \$16 billion, and 0.5 percent for energy efficiency, which is \$8 billion per year.

Capacity for Clean Energy Project. Indonesia has an existing well-developed energy infrastructure based around the production of oil, coal and natural gas. Indonesia had long been an oil-exporting country and member of OPEC, before the rapid increases in its domestic energy consumption converted the country into an oil importer in 2011. Nevertheless, Indonesia is still the world's 20th largest oil-producing country in 2011. It was also the world's largest exporter of coal by weight and its 18th largest exporter of natural gas. In short, Indonesia has a demonstrated record of maintaining a large-scale energy infrastructure, capable, among other things, of servicing major global export markets.

Clean Renewables. Indonesia's level of clean renewable production is still modest, even while significant projects are active in selected parts of the country (Satyakti, 2013). Traditional high-emissions biomass is a major source of energy, generating about 2 Q-BTUs in 2011 (EIA, 2013a). Much of this biomass supply frequently goes unreported in surveys since it is produced in the residential sectors of the country's more remote areas. These are regions of the country that remain, to a large extent, unconnected to the electrical grid. In addition, Indonesia is currently the world's third largest generator of geothermal energy, after the U.S. and the Philippines. This geothermal production still amounts to only about 0.02 Q-BTUs. However, Indonesia also has about 40 percent of the world's potential geothermal supply, located mostly in Bali and Java. The Ministry of Energy itself estimates that the country has the natural resources to expand geothermal supply to nearly 1 Q-BTU - a more than 20-fold expansion. Indonesia's solar radiation is also 50 percent higher than in Europe, offering the prospect for a solar sector that, with efficient technologies, could generate large-scale amounts of energy at costs that are closer to the low end of the range that we cited for "other Asia" in our Chapter 3 discussion. That range, at present is between 14-70 cents per kWh, but these figures, as they apply to Indonesia specifically, should be coming down rapidly as technologies mature over the next decade. Large-scale hydro is operating at about 0.25 Q-BTUs. The government estimates that there is room for significant expansion here, including through small-scale projects.

Energy Efficiency. As we have seen, the government's own Low Carbon scenario for 2030 includes a 24 percent decline in energy consumption relative to its 2030 BAU projection. This is close to the level of savings we estimate to be attainable through investing 0.5 percent of GDP per year in efficiency.

As described by Indonesia's Directorate General of New Renewable Energy and Energy Conservation (2012) as well as in recent reports issued by the IEA (2013), Mudiantoro (2013), United States AID (Anastasia and du Pont, 2007) and the European Commission's most recent Indonesia country report (Macdonald, 2010), the potential is substantial for large-scale gains through energy efficiency investments in Indonesia. This includes investments in all major areas of buildings, industry, and transportation. The only issue is what the cost levels are likely to be needed to achieve major efficiency gains. We will work with the cost assumption of \$11 billion per Q-BTU, based on the 2010 McKinsey study described in Chapter 4. As we saw in Chapter 4, the World Bank provided a much lower cost range, on the order of \$1.9 billion per Q-BTU. The broader point is that various sources do appear to converge in support of the idea that widespread efficiency gains are attainable in Indonesia at reasonable costs.

Clean Energy Capacity and Emissions

In Table 10.4, we estimate the levels of capacity expansion for both clean renewables and energy efficiency. We based our estimates for the costs of achieving these gains in both efficiency and renewables at $11 billion per Q-BTU for efficiency investments, as noted above, and $125 per Q-BTU for expanding clean renewable capacity. These are the same average cost figures we used for the case of Brazil. The reasoning for using these figures as rough benchmarks is the same as we presented for the Brazilian case in Chapter 8. Given that labor costs in Indonesia are significantly lower than those for Brazil, if anything, these cost assumptions for achieving energy efficiency savings and expanding clean renewable productive capacity in Indonesia are likely to be high-end figures.

Working with these assumptions, we then estimate the two alternative cases. Under Case 1, the clean energy investment project begins promptly, which means that Indonesia begins accumulating a growing capital stock of renewable energy and energy efficient processes over the full 20-year time period. Under Case 2, a more conservative scenario, we assume a 3-year delay from the time the investment project begins until when Indonesia first sees renewable energy and energy efficiency capacity expand. Thus, under Case 2, the accumulation of new capacity grows for only 17 years of the full 20-year investment cycle. We are assuming that the second scenario is more realistic, and therefore we focus our discussion on this case.

Table 10.4: Indonesia. Cost assumptions and capacity expansion for clean renewables and energy efficiency investments

	Clean renewable energy	**Energy efficiency**
1) Cost assumptions	$125 billion per Q-BTU of capacity	$11 billion per Q-BTU of energy savings
2) Annual spending levels	$16 billion per year *(= 1 % of midrange GDP)*	$8 billion per year *(= 0.5 % of midrange GDP)*
CASE 1: No delay in implementing program: 20- year spending cycle		
3) Total spending with 20- year spending cycle[a]	$320 billion	$160 billion
4) Total capacity expansion or energy savings through 20 year spending cycle[b]	2.6 Q-BTUs of new capacity	14.6 Q-BTUs of energy savings
CASE 2: 3-year delay in implementing program: 17- year spending cycle		
5) Total spending with 17-year spending cycle[c]	$272 billion	$136 billion
6) Total capacity expansion or energy savings through 17- year spending cycled	2.2 Q-BTUs of new capacity	12.4 Q-BTUs of energy savings

Notes: a) Calculated as row 2 multiplied by 20; b) Calculated as row 3 divided by row 1; c) Calculated as row 2 multiplied by 17; d) Calculated as row 5 divided by row 1.

Source: Authors' calculations.

We see under Case 2 that total investment spending on renewables would be $272 billion over 20 years, with a 17-year spending cycle after the 3-year start-up period. Energy efficiency investments would be $136 billion, again, based on a 17-year spending cycle and a 3-year start-up period.

We then show the net effects of Case 2 in the bottom row of Table 10.4. That is, after 20 years, Indonesia would have created 2.2 Q-BTUs of clean renewable energy capacity. This would include a mix of clean renewable productive capacity that would, of course, be determined through examining a full range of options. As documented by Satyakti (2013) and elsewhere, Indonesia does have favorable prospects, in varying degrees, in all clean renewable areas. Indonesia would have also been able to save 12.4 Q-BTUs of energy consumption through having invested $136 billion in energy efficiency processes. We can then apply that 12.4 Q-BTUs of efficiency as energy savings relative to the government's 2030 BAU energy consumption level of 25.8 Q-BTUs.

Table 10.5 shows the impact of this clean energy investment project for Indonesia on its overall emission level in 20 years. We show this by comparing energy consumption figures under the government's 2030 BAU scenario with our more conservative Case 2 investment trajectory.

Table 10.5: Indonesia. Impact of clean energy investment relative to 2030 BAU scenario

	2030 BAU scenario	**20-year clean energy investment *(Case 2: 3-year start-up delay)***
Total energy consumption	25.8 Q-BTUs	13.4 Q-BTUs *(with 12.4 Q-BTUs of energy-efficiency savings)*
Total clean renewable energy supply	1.0 Q-BTUs	3.2 Q-BTUs *(with 2.2 Q-BTUs of additional clean renewables)*
Total nuclear power supply	0.0	0.0
Total fossil fuel + High-emissions renewables	24.8 Q-BTUs	10.2 Q-BTUs
Total CO_2 emissions	2,200 mmt	714 mmt *(Based on 70 mmt average emissions per Q-BTU for fossil fuels)*
Total CO_2 emissions per capita *(with population = 280 million)*	7.9 mt	2.6 mt

Source: Authors' calculations.

As we see, under the government's BAU assumptions, Indonesia's total energy consumption level in 2030 is, again, 25.8 Q-BTUs. This level now falls to 13.4 Q-BTUs due to the energy efficiency investments, which we estimate would generate 12.4 Q-BTUs of energy saving relative to the BAU scenario. Total clean renewable capacity in Indonesia now rises to a total of 3.2 Q-BTUs. This includes the 1 Q-BTU that was built into the government's BAU scenario, plus the 2.2 Q-BTUs that would be generated through investing 1 percent of GDP per year over a 17-year period, following the initial 3-year start-up phase.

The net effect of these energy efficiency and renewable investments can then be seen in terms of Indonesia's residual demand for fossil fuel energy sources. As we see, the demand for all fossil fuel sources falls from 24.8 Q-BTUs under the BAU scenario to 10.2 Q-BTUs under the clean energy investment scenario. This is a reduction of 14.6 Q-BTUs, or 58.9 percent, in the consumption of oil, coal and natural gas.

This decline in fossil fuel consumption in turn has a dramatic impact on Indonesia's overall CO_2 emissions within 20 years, as we see in the bottom two rows of Table 10.5. We assume an average emissions level for Indonesia's fossil fuel energy mix at 70 mmt per Q-BTU, which is approximately equal to the country's actual emissions levels per Q-BTU in 2010. Under this assumption, Indonesia's overall emissions fall from the BAU figure of 2,200 mmt to 714 mmt, a 68 percent decline. Emissions per capita are now 2.6 mt. This figure is only slightly above the 20-year global target level of 2.4 mt. But now, as a result of the 20-year clean energy investment project, Indonesia would have essentially stabilized its per capita emissions at the global target level while the economy would have also grown by 5 percent per year for 20 years, and population would have increased from 250 to 280 million people. This means that per capita income would have risen from its 2010 level of $3,600 to $8,200 - a 144 percent increase - while still maintaining a level of per capita emissions close to the global target level of 2.4 mt as of 2032.

Employment Generation through Clean Energy Investments

Table 10.6 presents our estimates of the effects on overall annual employment levels through an Indonesian clean energy investment project at the level of 1.5 percent of GDP. Of course, our results are derived from our employment estimates presented in Chapter 7 of numbers of jobs generated per $1 million in spending.

Table 10.6: Indonesia. Employment impact of clean energy investments vs. fossil fuel spending

Figures are jobs in Year 1 of 20-year clean energy investment strategy

Assumptions for clean energy investments:

- **Total investment = 1.5 percent of GDP**
  - 67 percent clean renewables;
  - 33 percent energy efficiency
- **"Domestic Content Declines" scenario**
- **70 percent of investment for capacity creation/production**
- **30 percent for financing costs**

Indonesia labor force in 2011 = 115.9 million

	Clean energy investments	Fossil fuel spending	Net employment effects of clean energy investments
Direct + indirect total employment in Year 1	953,900	203,300	750,600
Direct + indirect employment as share of total labor force in Year 1	0.8%	0.2%	0.6%

Source: See Chapter 7 and Appendix 3.

Working within that framework, we have calculated the effects of the 1.5 percent of GDP investment project given a spending breakdown at two-thirds renewables and one-third energy efficiency. We also make two other assumptions. First, we use the results from our “Domestic Content Declines” scenario. This provides a more conservative assessment as to the capacity of Indonesia to expand clean energy activities on the basis of their current proportions of domestic resource use. It assumes, in other words, that Indonesia will need to increase its imports while advancing its clean energy investment scenario. Indonesia is a rapidly growing economy, and anticipates sustaining an even faster growth trajectory over the coming 20 years. Still, building out clean energy sectors on a large scale will probably create significant strains on the country’s resources of technological capacity and skilled labor.

We then also assume that of the total amount of spending on the clean energy investment project, 30 percent is allocated to cover financing costs. This leaves 70 percent available for spending on creating capacity and producing, refining, transporting and marketing energy.

From these assumptions, we estimate that the total amount of direct plus indirect employment generated through the clean energy investment project at 1.5 percent of GDP would be about 950,000 jobs. This is, of course, a very large number of jobs. But, as we show, it is still only 0.8 percent of the overall Indonesian labor force of 115.9 million people as of 2011. The impact of the clean energy investment project would therefore be strongly positive in terms of employment, but its overall scope would be relatively small.

To gauge the net benefits of this level of job creation, we do also need to compare these figures with the job creation that would occur through maintaining spending in Indonesia’s existing fossil fuel industry, as opposed to shifting funds into clean energy. We see in Table 10.6 that the same level of spending in the coal, oil and natural gas sectors in Indonesia would create 203,000 jobs. As such, the net gain in employment through shifting funds out of fossil fuels and into clean energy at the level of 1.5 percent of Indonesia’s GDP would be 750,000 jobs, or 0.6 percent of Indonesia’s 2011 workforce.

In Table 10.7, we present our projections for employment creation in Year 20 of Indonesia’s 20-year clean energy investment project. These figures are based on two separate assumptions as to the average growth rate of labor productivity in Indonesia’s clean energy sectors over this 20-year period - a 1 percent low-end average annual labor productivity growth rate assumption and a 2.5 percent high-end assumption.

Table 10.7: Indonesia. Projected employment impacts of clean energy investments after 20 years under alternative labor productivity assumptions

Figures are jobs per year

Assumptions for 20-year employment projections

- Baseline year-one employment levels given in Table 10.6
- 20-year average annual GDP growth is 5 percent
- Average annual labor productivity growth ranges between 1 – 2.5 percent
- Population figure is projected 2035 population
- Labor force/population ratio at end of 20-year investment cycle equals 2011 ratio

Labor force at end of 20-year investment cycle = 145 million

	Scenario with 1 percent average annual labor productivity growth	**Scenario with 2.5 percent average annual labor productivity growth**	**Midpoint between 1 percent and 2.5 percent productivity growth scenarios**
Direct + indirect total employment	2.1 million	1.6 million	1.8 million
Year 20 direct + indirect employment relative to Year 1 employment	119.1%	63.9%	91.5%
Direct + indirect employment as share of total labor force	1.4%	1.1%	1.3%

Sources: See Chapter 7 and Appendix 3.

Notes: Labor force at end of 20-year investment cycle = 145 million. Assumptions for 20-year employment projections: a) Baseline year-one employment levels given in Table 10.6; b) 20-year average annual GDP growth is 5 percent; c) Average annual labor productivity growth ranges between 1–2.5 percent; d) Population figure is projected 2035 population; e) Labor force/population ratio at end of 20-year investment cycle equals 2011 ratio.

Working with these assumptions, as well as with the other assumptions on GDP growth, population and labor force participation listed above Table 10.7, we generate the following results:

1. Assuming labor productivity increases at 1 percent per year, total employment creation through clean energy investments will rise to about 2 million in Year 20. This is a nearly 120 percent increase relative to employment creation in Year 1. This strong gain in employment creation results through our assumption that GDP growth will average 5.0 percent per year over the 20-year clean energy investment cycle - a 4 percent faster rate than labor productivity in the clean energy sectors. GDP growth at 5 percent per year in turn means that clean energy investments will also be growing at 5 percent per year, to remain as a fixed 1.5 percent of GDP every year over the 20-year investment cycle.

2. Under this 1 percent labor productivity growth assumption, employment creation through clean energy investments will rise to about 1.4 percent of Indonesia's Year 20 labor force relative to the 0.8 percent figure as of Year 1.

3. Assuming average labor productivity in Indonesia's clean energy sectors increases at the higher-end rate of 2.5 percent over the 20-year investment cycle, employment

creation will still be rising significantly, given that we assume GDP growth will average 5.0 percent per year. Year 20 employment creation through clean energy investments then reaches 1.6 million. This is still a nearly 64 percent increase over the Year1 figure. Under this scenario, employment creation through clean energy investments rises as a share of Indonesia's overall labor force in Year 20, to around 1.1 percent, a 0.3 percent increase relative to the Year 1 figure of around 0.8 percent.

4. In the last column of Table 10.7, we report midpoint employment creation figures, that are based on averaging Year 20 employment levels derived from both the 1 percent and 2.5 percent labor productivity growth assumptions. As we see, the midpoint figure is 1.8 million jobs, which is about 1.3 percent of Indonesia's Year 20 labor force.

Overall, as we see, employment creation through Indonesia's clean energy investment project operating at 1.5 percent of GDP per year will expand significantly over time under a wide range of plausible assumptions as to the growth of labor productivity over the 20-year investment cycle. As such, we can conclude that the clean energy project for Indonesia, scaled at about 1.5 percent of GDP per year, will generate, first, huge reductions in CO_2 emissions while, concurrently, providing expanding employment opportunities throughout the country over the full 20-year investment cycle.

CHAPTER 11: SOUTH AFRICA - CLEAN ENERGY INVESTMENTS, EMISSIONS REDUCTIONS AND EMPLOYMENT EXPANSION

Growth Trajectory and Emissions

In Table 11.1, we review the basic statistics from Chapter 1 indicating South Africa's current level of development and the operations of their energy system. According to the World Bank Indicators, South Africa is at present an upper-middle income country, with, as we see in Table 11.1, average per capita GDP at $7,500 as of 2010. Overall energy consumption is at 5.6 Q-BTUs and overall CO_2 emissions are at 473.2 mmt. Emissions per capita are at 9.5 mt, which is more than twice the global average of 4.6 mt. It is also nearly four times greater than the targeted global average figure of 2.4 mt needed for achieving the 20-year global CO_2 emissions reduction target. In terms of both the energy intensity and emissions intensity ratios Table 11.1 shows that South Africa is both inefficient and dirty, relative to global averages, in its use of energy. These figures reflect the fact that South Africa relies heavily on its own abundant coal reserves to provide the economy with low-cost energy.

Table 11.1: South Africa. Basic energy indicators, 2010

	South Africa	World
Per capita GDP *(2005 $PPP)*	$7,500	$10,300
Total energy consumption *(Q-BTUs)*	5.6 Q-BTUs	510.5 Q-BTUs
Per capita energy consumption *(M-BTUs/population)*	111.8 Q-BTUs	74.0 M-BTUs
Total CO_2 emissions *(mmt)*	473.2 mmt	31,502 mmt
Per capita CO_2 emissions *(mt of emissions/population)*	9.5 mt	4.6 mt
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	14.6 Q-BTUs	7.1 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	84.5 mmt	65.9 mmt

Source: See Tables 1.1 and 1.4.

Between 2003 and 2012, the South African economy grew at an average annual rate of 3.5 percent. Projections by the government and other agencies, including the IMF and OECD, assume that this average growth rate will accelerate to at least around 4 percent over the next decade. This growth trajectory would generate a rough doubling of average GDP per capita in the country, from its current level of $7,500 to about $14,500. If such average income gains from growth are equitably distributed, the impact would be a large reduction in South Africa's poverty rate, which is presently at 23 percent of the population, according to the government's official measure. But for South Africa to sustain a healthy growth trajectory while maintaining its existing energy infrastructure more or less intact will also generate large increases in the country's per capita CO_2 emissions. These CO_2 increases would then be on top of a level, which is already twice the average global level.

In Table 11.2, we show the impact of South Africa's growth path under our rough estimate as compared to its BAU scenario for energy consumption through 2030. We are unaware of any official energy consumption projections for 2030. But the Department of Environmental Affairs does provide a range of projections for CO_2 emissions for various years. We present those projections in full later in this chapter. Based on assumptions we can make as to the ratio of CO_2 emissions per Q-BTU of energy, we were then able to provide energy consumption projections derived from these official emissions-level figures. As we have seen, under the actual figures from 2010, emissions per Q-BTU were 84.5 mmt. For the purposes of our estimate, we assume that ratio declines modestly to 80 mmt under the BAU scenario, reflecting a modest decline in the proportion of coal as a share of total consumption and a modest improvement in the efficiency in the country's fossil-fuel energy technologies.

Table 11.2: South Africa. Energy consumption and emissions: 2010 actuals and alternative official projections

	2010 actuals	2030 BAU Scenario	2030 "Low Carbon" Scenario
Total energy consumption	5.6 Q-BTUs	8.7 – 15.0 Q-BTUs[b] Midpoint = 11.9 Q-BTUs	5.3 – 8.2 Q-BTUs[c] Midpoint = 6.7 Q-BTUs
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)a*	14.6	15.0	8.4
Energy mix:			
Oil	19%	NA	NA
Coal	67%	NA	NA
Natural gas	2%	NA	NA
Nuclear	2%	NA	NA
High-emissions renewables	10%	NA	NA
Clean renewables			
• Hydro	< 1%	< 1%	< 1%
• All others	0	< 1%	< 1%
Total CO_2 emissions	473.2 mmt	952 mmt[d]	503 mmt[e]
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	84.5 mmt	80 mmt[f]	75 mmt[g]
CO_2 emissions per capita *(with population = 55 million)*	9.5 mt	17.3 mt	9.2 mt

Sources: Authors' calculations based on "South African Department of Environmental Affairs (2014); EIA (2013b), "International Energy Outlook 2013"; See Tables 1.1 and 1.4.

Note: a) Calculations based on average annual GDP growth of 4 percent; b-g) The energy consumption projections are derived from South Africa's Department of Environmental Affairs projections on CO2 emissions. In generating the energy consumption levels from the emissions estimates, we assume an average level of CO2 emissions at 80 mmt per Q-BTU under the BAU scenario and 75 mmt per Q-BTU under the "Low Carbon" scenario. This difference in emission levels per BTU reflects the assumption that, under the Low Carbon case, the share of coal in overall consumption declines relative to alternative sources.

Because the Environmental Affairs Department projects a range of emissions levels for various years as opposed to single data point, we show in Table 11.2 a range for energy consumption. As we see, that range is between 8-7 and 15 Q-BTUs. As a reference point, we then also report the midpoint within that range, which is 11.9 Q-BTUs. We work with this midpoint figure in considering our full set of emissions and employment scenarios for South Africa here. But, as is indicated in Table 11.2, we did not have enough detailed data to generate estimates of energy supply levels for the specific energy sources.

As Table 11.2 shows, working from this 11.9 Q-BTU level of overall energy consumption under South Africa's 2030 BAU case, the result is that CO_2 emissions would rise to 952 mmt. This amounts to 17.3 mt per person, assuming that South Africa's population is around 55 million as of 2030. This figure is 82 percent higher than South Africa's 2010 per capita emissions figure of 9.5 mt. It is also 7 times higher than the 2.4 mt average per capita level that the world needs to achieve as its 20-year emissions reduction target.

As we also see in Table 11.2, the Environmental Affairs Department has also developed alternative CO_2 emissions projections, including a "Low Carbon" scenario. Working with this alternative emissions projection, we then derived another set of energy consumption figures, following the same approach that we used for the BAU scenario. The one difference in the calculations with the Low Carbon scenario is that we assumed that the emissions intensity ratio is somewhat lower, at 75 mmt. This lower figure reflects both a relative decline in the country's reliance on coal as well as greater efficiencies in generating energy from coal and other fossil fuel sources. We show in the last column of Table 11.2 that our range for overall energy consumption under the Low Carbon scenario is 5.3-8.2 Q-BTUs. The midpoint estimate in this case is 6.7 Q-BTUs.

Based on this midpoint estimate, South Africa's overall emissions as of 2030 would then be 503 mmt and emissions per capita would be 9.2 mt. What these figures show is that, under South Africa's Low Carbon scenario, CO_2 emissions would remain flat through 2030, even as average incomes roughly double. This would certainly be a positive development. But it would also mean that South Africa's average per capita emissions would still be nearly four times the 20-year global target figure of 2.4 mt. It is therefore imperative to explore further possibilities for achieving dramatic reductions in South Africa's emissions levels over the next 20 years through a large-scale clean energy investment project.

Major Developments Supporting Clean Energy Investment Project

Overall Frameworks and Projections. According to South Africa's Department of Environmental Affairs:

> *South Africa is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), as well as the Kyoto Protocol. … Furthermore, South Africa has associated itself with the Copenhagen Accord, and was a Party to the decisions of the sixteenth Conference of the Parties (COP16) under the auspices of the UNFCCC in Cancun in 2010 (Marquard, Trollip and Winkler, 2011, p. 8).*

Within these stated commitments, South Africa's formal submission to the UNFCCC in a letter of January 29, 2010 proposes that the country "will take nationally appropriate mitigation action to enable a 34 percent decline from the BAU emissions growth trajectory by 2020 and a 42 percent decline by 2025" (Parramon-Gurney and Gilder, 2012). The baseline was not stated in this document, but has been widely assumed to be the BAU baseline presented as part of the country's 2011 Long Term Mitigation Scenario.[65] These baseline emissions are projected to be 760.5 mmt for 2020 and 901.5 for 2025. The declines from this baseline of 34 and 42 percent respectively imply national emissions target levels of 501.9 mmt as of 2020 and 522.9 mmt as of 2025.

Figure 11.1 below, reproduced from the Department of Environmental Affairs website page titled "South Africa's Position on Climate Change," shows further documentation on these alternative scenarios.[66] This figure shows the trajectory for the BAU case versus what it terms its "Peak, Plateau, Decline," scenario, which we have termed above the "Low Carbon" case.

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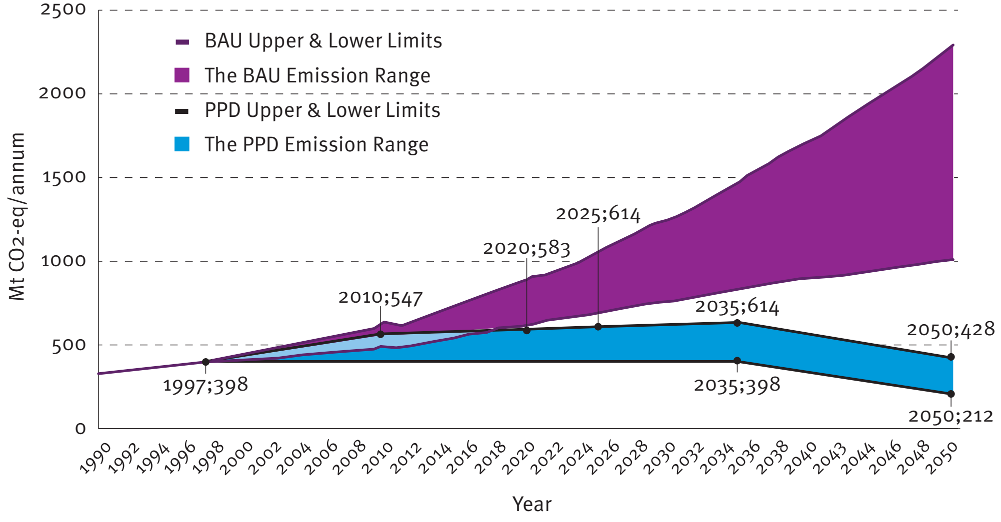
[65] Marquard, Trollip, and Winkler (2011).

[66] Figure 11.1 here is a replica of the image on the DEA's website, which was produced using data in Department of Environmental Affairs (2011a).

As we see in Figure 11.1, under the BAU case, emissions are expected to continue increasing, although the range for these projections is quite wide. The Peak, Plateau and Decline trajectory shows a possible range of emissions from 398 to 614 mmt as of 2030, or about 50 percent below the BAU projections Department of Environmental Affairs (2011a).

Figure 11.1: South Africa. Alternative greenhouse gas emissions trajectories through 2050: BAU vs "Peak, Plateau and Decline" (PPD)



Source: South Africa Department of Environmental Affairs, http://www.climateaction.org.za/cop17-cmp7/sa-government-position-on-climate-change.

In addition to these emissions reduction goals, South Africa's Department of Energy announced its Vision 2014 and Vision 2025 in its 2012 Revised Strategic Plan. The first goal aims to achieve universal access to modern energy carriers by 2014, while the second aims for clean energy sources, including nuclear power, to supply 30 percent of all energy by 2025.

As yet, there have been no official projections as to how much it would cost for South Africa to achieve these energy supply and clean energy targets. But broadly, the government projects the range as being between 1 and 2.5 percent of South African GDP. Our own working estimate for the clean energy investment project at 1.5 percent of GDP is therefore close to the mid-level within this range provisionally projected by the government.

Electricity Sector. The Department of Energy does provide more detailed projections for electricity supply specifically in its Integrated Resource Plan (IRP) 2010-2030 (Department of Energy, 2011). We show those figures in Table 11.3 below. As we see, in 2010, coal provided 90 percent of all energy used for generating electricity. Hydro and nuclear power each accounted for 5 percent. Under the 2030 BAU scenario, the share for coal rises slightly, to 91 percent, even while total electricity consumption rises from about 0.9 to 1.5 Q-BTUs. The shares for hydro and nuclear decline slightly under the BAU scenario, while there is a modest development of gas turbine capacity. Under the Low Carbon scenario, the share of total supply provided by coal declines sharply, to 65 percent. The big difference in this case is a large expansion of nuclear energy, to where it would provide 20 percent of all electricity generating power. Wind and solar energy are shown as beginning to also grow under the Low Carbon scenario, with wind accounting for 5 percent and solar for 4 percent of total electricity-generating supply as of 2030. It is notable also that, with this Low Carbon electricity scenario, there is no reduction in overall supply relative to the BAU case. That is, under both 2030 scenarios, electricity-based energy consumption is fixed at 1.5 Q-BTUs. We will therefore need to consider other references to obtain a sense of the prospects for energy efficiency investments in South Africa.

Table 11.3: South Africa. Electricity consumption levels and sources of supply under alternative scenarios, 2010-2030

Electricity source	2010 actuals		2030 BAU scenario		2030 Low Carbon scenario	
	Q-BTUs	*Share of total supply*	*Q-BTUs*	*Share of total supply*	*Q-BTUs*	*Share of total supply*
Coal	0.782	90%	1.36	91%	0.97	65%
Hydro	0.043	5%	0.06	4%	0.075	5%
Nuclear	0.043	5%	0.045	3%	0.3	20%
Gas turbines	0	0	0.03	2%	0.015	1%
Wind	0	0	0	0	0.075	5%
Solar	0	0	0	0	0.06	4%
Total	0.869	100%	1.49	100%	1.49	100%

Source: Department of Energy (2011); and authors' calculations.

Notes: Figures for gas turbines includes open- and combined-cycle turbines. Figures for solar power include solar PV and concentrated solar power (CSP).

Renewables. In considering renewables in South Africa, we must first recognize that fuel wood is the most commonly used source of renewable energy, though it is not used to produce electricity. Beyond this, we see that the Low Carbon scenario in the Integrated Resource Plan assumes that modern renewable capacity - hydro, wind, and solar - will grow to about 14 percent of total electricity generating supply as of 2030. But a broadly-held view in South Africa is that the potential for growth in renewables is much larger. These prospects include the following:

- The technical potential for solar energy is more than 6,000 times the country's current needs. Solar panels are already widely used in remote rural areas that are off the grid. But there is great potential for further expansions of solar power, both through supplying the grid and on off-grid distribution systems.

- Wind energy potential is estimated to exceed 30 gigawatts. This is three times greater than the capacity level as of 2011.

- The national bioenergy policy includes a 2 percent target for biofuels in transportation fuels as of 2030. This would mainly take the form of biodiesel liquid fuels, derived from soybeans, canola oil, sunflower oil, or ethanol from sugar cane and sugar beets. Ethanol from corn is excluded in the target.

- Biomass from waste resources is starting to be used in industrial co-generation, and biogas is produced from waste biomass. These are both relatively clean processes for utilizing biomass sources. According to South Africa's Second National Communication to the UNFCCC:

  > *The development of biomass energy is being highlighted in 'Working for Energy' (WfE), South Africa's national renewable energy programme. The purpose of the programme is to develop and apply practical approaches for sustainable, labour intensive, renewable energy and energy management type projects in rural areas.*[67]

In terms of more developed areas of the country, Ayogu (2013) describes major opportunities for advancing a solar sector in Gauteng, South Africa's economic hub. Gauteng accounts for 25 percent of South Africa's population and 35 percent of its GDP. Ayogu says that Gauteng enjoys excellent solar radiation levels. Solar PV systems could be placed widely on rooftops, mine dumps, dolomitic areas and other sites that are either not habitable or fit for agriculture. Ayogu describes an initial roll-out of solar PV technology over 8 million square meters of rooftops in Gauteng, providing 300 MW of solar capacity. The development of an economy-wide renewable investment strategy could build from such initial initiatives in Gauteng.[68]

Energy Efficiency. While the 2010 Integrated Resource Plan did not incorporate policies or projections regarding energy efficiency for the electricity sector, the South African government's 2011 National Energy Efficiency Strategy set targets, as of 2015, to reduce energy intensity by 10 percent for commercial and public buildings, 15 percent for the residential sector, 10 percent for the transport sector, 15 percent for industry and 15 percent for the mining sector, as part of its Green Economy Accord.[69]

In addition, a 2006 paper by Harald Winkler specifies efficiency strategies and potential energy savings in various sectors.[70] Winkler's major findings are as follows:

- The industrial sector has the potential of reducing energy demand by 12 percent compared to BAU scenario, the highest among all sectors. The strategies include greater use of variable speed drives, efficient motors, compressed air management, efficient lighting, heating, ventilation and cooling (HVAC) system efficiency and other thermal saving. Winkler covers these areas of energy saving potential in detail in his 2006 study (see pp. 112-13 in particular).

- The policy interventions proposed by Winkler to improve energy efficiency in the residential sector focused on the end uses. These include solar water heaters, geyser blankets[71], liquid petroleum gas for cooking, efficient housing shells, and compact fluorescent lights (CFLs) for lighting. But Winkler also emphasized that only urban higher-income electrified households could afford building retrofits to improve energy efficiency, while suggesting that geyser blankets should be generally used for poorer

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[67] Department of Environmental Affairs (2011b, p 19).

[68] Ayogu also cites the important work by the EnerKey project in Gauteng, which is a collaboration between South African and German researchers on developing and commercializing the most effective renewable energy and energy efficiency technologies. See, for example, the *EnerKey Technology Handbook* (IER, 2012).

[69] South African Government (2011).

[70] Ayogu (2013) provides a good overview of similar types of energy efficiency initiatives and prospects, especially as they are developing in Gauteng Province.

[71] A geyser blanket is an insulator that is wrapped around a geyser to reduce wasted heat loss.

households with electricity, due to their low costs.

- According to Winkler's modeling results, the commercial building sector has the potential for about 12 percent in energy savings. Strategies include new building thermal design, HVAC retrofit and for new buildings, installing variable speed drives for fans, efficient lighting systems, heat pumps for water heating, solar water heating and fuel switching.
- The transport sector accounts for roughly 25 percent final energy consumption in South Africa. It uses three-quarters of South Africa's petroleum products. The main areas for energy efficiency investments here would include the introduction of more energy efficient automobiles and the introduction of licensing differentials according to a car's engine efficiency, and roadworthy tests, with a targeted energy demand reduction of 9 percent by 2014. The transport sector also could achieve major gains in efficiency through the development of high-quality mass transit and rail systems.

Emissions Reductions through Clean Energy Investments

In Table 11.4, we begin to present the main features of our clean energy investment framework. In fact, this framework is closely aligned with the approach advanced by the various South African government agencies that we have reviewed above. This includes the government's broad view that the level of clean energy investments needed to achieve its Low Carbon ("Peak, Plateau, and Decline") scenario will be in the range of 1 to 2.5 percent of GDP on an annual basis for 20 years or more. Our framework attempts to provide further specificity to this approach. We begin with the assumption that South Africa's growth process incorporates clean energy investments at a rate of 1.5 percent of GDP annually over a full 20-year period. We define "clean energy investments" as including clean renewable energy sources and energy efficiency only. We do not include nuclear power or high-emissions renewables such as corn ethanol as clean energy sources. For purposes of our discussion, as with our other country-specific analyses, we assume that this 1.5 percent of GDP is allocated with 1 percent of GDP funding the expansion of clean renewables while 0.5 percent of GDP is channeled into energy efficiency investments. We are also assuming that South Africa's average annual GDP growth rate over 20 years will be 4 percent. This figure is in line with the long-term growth projections for South Africa developed by the IMF and OECD, and is also close to South Africa's actual growth experience from 2003-2012.

Table 11.4: South Africa. Clean energy 20-year investment growth

2012 GDP	$363 billion
Projected 20-year average annual GDP growth rate	4.0%
Projected 2032 GDP *(with 4 percent average annual GDP growth)*	$795 billion
Midrange GDP value for investment spending estimates *(= (2012 GDP + 2032 GDP)/2)*	$579 billion
Average annual clean renewable investments *(= 1 percent of midrange GDP)*	$5.8 billion
Average annual energy efficiency investments *(= 0.5 percent of midrange GDP)*	$2.9 billion

Source: Authors' calculations based on World Bank (2014), "World Development Indicators," GDP (current $US).

As Table 11.4 shows, when we assume a 4 percent average annual growth rate over 20 years, the result is that South Africa's GDP in 20 years would be $795 billion. To then estimate an average level of clean-energy investment spending over this 20-year period, we simply calculate the midrange GDP value between 2012 GDP at $363 billion and 2032 GDP at $795 billion. That midrange figure is $579 billion. This then means that the average level of annual spending on clean energy would be 1 percent of $579 billion per year for renewables, which is $5.8 billion, and 0.5 percent for energy efficiency, which is $2.9 billion.

Clean Energy Capacity and Emissions

In Table 11.5, we then estimate the levels of capacity expansion for both clean renewables and energy efficiency that will result through investing 1 percent of GDP annually in clean renewables and 0.5 percent of GDP in energy efficiency. Our estimates are derived from the assumptions that the costs of achieving gains in both efficiency and renewables are: $11 billion per Q-BTU for efficiency investments, as noted in Chapter 3; and $125 per Q-BTU for expanding clean renewable capacity. These are the same average cost figures we used for the case of Brazil. The reasoning for using these figures as rough benchmarks is the same as we presented for the Brazilian case in Chapter 8.

Table 11.5: South Africa. Cost assumptions and capacity expansion for clean renewables and energy efficiency investments

	Clean renewable energy	**Energy efficiency**
1) Cost assumptions	$125 billion per Q-BTU of capacity	$11 billion per Q-BTU of energy savings
2) Annual spending levels	$5.8 billion *(= 1% of midrange GDP)*	$2.9 billion *(= 0.5% of midrange GDP)*
CASE 1: No delay in implementing program: 20-year spending cycle		
3) Total spending with 20-year spending cycle[a]	$116 billion	$58 billion
4) Total capacity expansion or energy savings through 20-year spending cycle[b]	0.9 Q-BTUs of new capacity	5.3 Q-BTUs of energy savings
CASE 2: 3-year delay in implementing program: 17-year spending cycle		
5) Total spending with 17-year spending cycle[c]	$99 billion	$49.3 billion
6) Total capacity expansion or energy savings through 17-year spending cycle[d]	0.8 Q-BTUs of new capacity	4.5 Q-BTUs of energy savings

Source: Authors' calculations as developed in Chapter 11.

Notes: a) Calculated as row 2 multiplied by 20; b) Calculated as row 3 divided by row 1; c) Calculated as row 2 multiplied by 17; d) Calculated as row 5 divided by row 1.

Working with these assumptions, we then estimate the two alternative cases. Under Case 1, the clean energy investment project begins promptly, which means that South Africa begins accumulating a growing capital stock of renewable energy and energy efficiency processes over the full 20-year time period. Under Case 2, the more conservative scenario, we assume a 3-year delay from the time the investment project begins until the time when South Africa first sees renewable energy and energy efficiency capacity expand. Thus, under Case 2, the accumulation of new capacity proceeds for only 17 years of the full 20-year investment cycle. We are assuming that the second scenario is more realistic, and therefore we focus our discussion on this case.

We see under Case 2 that total investment spending on renewables would be $99 billion over 20 years, with a 17-year spending cycle after the 3-year start-up period. Energy efficiency investments would be $49 billion, again, based on a 17-year spending cycle and a 3-year start-up period.

We then show the net effects of Case 2 in the bottom row of Table 11.5. That is, after 20 years, South Africa would have created 0.8 Q-BTUs of new clean renewable capacity. This would include a mix of clean renewables that would be determined through examining the full range of options as described, for example, by Ayogu (2013). South Africa would have also been able to save 4.5 Q-BTUs of energy consumption through having invested roughly $50 billion in energy efficiency processes. We can then apply that 4.5 Q-BTU of efficiency as energy savings relative to the 2030 BAU scenario with our more conservative Case 2 investment trajectory.

We can then see the impact of these expanded levels of investment in renewables and efficiency in Table 11.6 below. As we see, under our rough estimate of the government's BAU assumptions, South Africa's total energy consumption level in 2030 is, again, 11.9 Q-BTUs. This level now falls to 7.4 Q-BTUs due to the energy efficiency investments, which we estimate would generate 4.5 Q-BTUs of energy saving relative to the BAU case. Total clean renewable capacity in South Africa now rises to a total of 0.9 Q-BTUs. This includes the 0.1 Q-BTUs that was built into the government's BAU scenario, plus the 0.8 Q-BTUs that would be generated through investing 1 percent of GDP per year over a 17-year period, following the initial 3-year start-up phase.

Table 11.6: South Africa. Impact of clean energy investments relative to 2030 BAU scenario

	2030 BAU Scenario	**20-year Clean Energy Investment scenario** ***(Case 2: 3-Year Start-Up Delay)***
Total energy consumption	11.9 Q-BTUs	7.4 Q-BTUS *(with 4.5 Q-BTUs of energy efficiency savings)*
Total clean renewable energy supply	0.1 Q-BTUs	0.9 Q-BTUs *(with 0.8 Q-BTUs of additional clean renewables)*
Total nuclear power supply	0.05 Q-BTUs	0.05 Q-BTUs
Total fossil fuel + High-emissions renewables	11.7 Q-BTUs	6.4 Q-BTUs
Total CO_2 emissions	936 mmt *(Based on 80 mmt average emissions per Q-BTU for fossil fuels)*	480 mmt *(Based on 75 mmt average emissions per Q-BTU for fossil fuels)*
Total CO_2 emissions per capita *(with population = 55 million)*	17.0 mt	8.7 mt

Source: Authors' calculations as developed in Chapter 11.

The net effect of these clean renewable and energy efficiency investments can then be seen in terms of South Africa's residual demand for fossil fuel energy sources. As we see, the demand for all fossil fuel sources falls from 11.7 Q-BTUs under the BAU scenario to 6.4 Q-BTUs in the clean energy investment scenario (after also taking account of nuclear energy supply at 0.05 Q-BTUs). This is a reduction of 5.3 Q-BTUs, or 45 percent, in the consumption of oil, coal and natural gas.

This decline in fossil fuel consumption in turn has a major impact on South Africa's overall CO_2 emissions within 20 years, as we see in the bottom two rows of Table 11.6. As noted earlier, we assume an average emissions level for South Africa's fossil fuel energy mix as 80 mmt per Q-BTU in the BAU case and 75 mmt per Q-BTU in the Clean Energy scenario. Under these assumptions, South Africa's overall emissions fall from the BAU figure of 936 mmt to 480 mmt, a 49 percent decline. Emissions per capita are now 8.7 mt. This figure is still 3.6 times greater than the global target figure of 2.4 mt within 20 years. But it also is an 8 percent absolute decline from the 2010 per capita emissions figure of 9.5 mt. This would occur while South Africa's population will have grown by 10 percent and per capita incomes would have roughly doubled.

Employment Generation through Clean Energy Investments

Table 11.7 presents our estimates of the effects on overall annual employment levels through a South African clean energy investment project at the level of 1.5 percent of annual GDP. Of course, our employment results are derived from our estimates presented in Chapter 7 of numbers of jobs generated per $1 million in spending.

Table 11.7: South Africa. Employment impact of clean energy investments vs. fossil fuel spending

Figures are jobs in Year 1 of 20-year clean energy investment strategy

Assumptions for clean energy investments:

- Total investment = 1.5 percent of GDP
  - 67 percent clean renewables;
  - 33 percent energy efficiency
- "Domestic Content Declines" scenario
- 70 percent of investment for capacity creation/production
- 30 percent for financing costs

South Africa labor force in 2011 = 18.6 million

	Clean energy investments	Fossil fuel spending	Net employment effects of clean energy investments
Direct + indirect total employment in Year 1	252,200	126,200	126,000
Direct + indirect employment as share of total labor force in Year 1	1.4%	0.7%	0.7%

Source: See Chapter 7 and Appendix 3.

Working within that framework, we have calculated the effects of the 1.5 percent of GDP investment project given a spending breakdown at two-thirds renewables and one-third energy efficiency. We also make two other assumptions. First, we use the results from our "Domestic Content Declines" scenario, which assumes that South Africa will need to increase its imports as a result of advancing its clean energy investment scenario. South Africa's economy has been growing at a healthy rate over roughly the past decade. It anticipates sustaining an even faster growth trajectory over the coming 20 years. Nevertheless, it is reasonable to anticipate that building out clean energy sectors on a large scale will probably create significant strains on the country's resources of technological capacity and skilled labor.

We then also assume that of the total amount of spending on the clean energy investment project, 30 percent is allocated to cover financing costs. This leaves 70 percent available for spending on creating capacity and producing, refining, transporting and marketing energy.

From these assumptions, we estimate the total number of direct plus indirect employment generated through the clean energy investment project at 1.5 percent of GDP is 250,000 jobs. That is a very large number of jobs in absolute terms. But it is also only 1.4 percent of the South African labor force of 18.6 million as of 2011. The impact of the clean energy investment project would therefore be strongly positive in terms of absolute employment, but its overall scope would be limited.

To gauge the net benefits of this level of job creation, we also need to compare these figures with the job creation that would occur through maintaining spending in South Africa's existing fossil fuel industry, as opposed to shifting funds into clean energy. We see in Table 11.7 that the same level of spending in South Africa's coal, oil and natural gas sectors would create about 126,000 jobs. That is, investing in clean energy in South Africa at a level of 1.5 percent of the economy would produce a net expansion of roughly 126,000 jobs in comparison with maintaining the country's existing fossil fuel energy infrastructure.

In Table 11.8, we present our projections for employment creation in Year 20 of South Africa's 20-year clean energy investment project. These figures are based on two separate assumptions as to the average growth rate of labor productivity in South Africa's clean energy sectors over this 20-year period - a 1 percent low-end average annual labor productivity growth rate assumption and a 2.5 percent high-end assumption.

Table 11.8: South Africa. Projected employment impacts of clean energy investments after 20 years under alternative labor productivity assumptions

Figures are jobs per year

Assumptions for 20-year employment projections
- Baseline Year 1 employment levels given in Table 11.7
- 20-year average annual GDP growth is 4 percent
- Average annual labor productivity growth ranges between 1-2.5 percent
- Population figure is projected 2035 population
- Labor force/population ratio at end of 20-year investment cycle equals 2011 ratio

Labor force at end of 20-year investment cycle = 21.4 million

	Scenario with 1 percent average annual labor productivity growth	**Scenario with 2.5 percent average annual labor productivity growth**	**Midpoint between 1 percent and 2.5 percent productivity growth scenarios**
Direct + indirect total employment	455,500	339,700	398,000
Year 20 direct + indirect employment as share of Year 1 employment	80.6%	34.7%	57.6%
Direct + indirect employment as share of total labor force	2.1%	1.6%	1.9%

Sources: See Chapter 7 and Appendix 3.

Working with these assumptions, as well as with the other assumptions on GDP growth, population and labor force participation listed above Table 11.8, we generate the following results:

1. Assuming labor productivity increases at 1 percent per year, total employment creation through clean energy investments will rise to about 450,000 in Year 20. This is about an 80 percent increase relative to employment creation in Year 1. This strong gain in employment creation results through our assumption that GDP growth will average 4.0 percent per year over the 20-year clean energy investment cycle - a 3 percent faster rate than labor productivity in the clean energy sectors. GDP growth at 4 percent per year in turn means that clean energy investments will also be growing at 4 percent per year, to remain as a fixed 1.5 percent of GDP every year over the 20-year investment cycle.

2. Under this 1 percent labor productivity growth assumption, employment creation through clean energy investments will rise to about 2.1 percent of South Africa's Year 20 labor force relative to the 1.4 percent figure as of Year 1.

3. Assuming average labor productivity in South Africa's clean energy sectors increases at the higher-end rate of 2.5 percent over the 20-year investment cycle, employment creation will still be rising significantly, given that we assume GDP growth will average 4.0 percent per year. Year 20 employment creation through clean energy investments then reaches nearly 340,000. This is still a nearly 35 percent increase over the Year1 figure. Under this scenario, employment creation through clean energy investments rises as a share of South Africa's overall labor force in Year 20, to around 1.9 percent, a 0.5 percent increase relative to the Year 1 figure of around 1.4 percent.

4. In the last column of Table 11.8, we report midpoint employment creation figures, that are based on averaging Year 20 employment levels derived from both the 1 percent and 2.5 percent labor productivity growth assumptions. As we see, the midpoint figure is nearly 400,000 jobs, which is about 1.9 percent of South Africa's Year 20 labor force.

Overall, as we see, employment creation through South Africa's clean energy investment project operating at 1.5 percent of GDP per year will expand significantly over time under a wide range of plausible assumptions as to the growth of labor productivity over the 20-year investment cycle. Moreover, this net gain in employment opportunities through clean energy investments will result in correspondence with the economy also making significant absolute declines in CO_2 emissions through the clean energy investment project over the next 20 years.

CHAPTER 12: THE REPUBLIC OF KOREA - CLEAN ENERGY INVESTMENTS, EMISSIONS REDUCTIONS AND EMPLOYMENT EXPANSION

Growth Trajectory and Emissions

In Table 12.1, we review the basic statistics from Chapter 1 indicating the ROK's current level of development and the operations of their energy system. According to the World Bank Indicators, the ROK is a high-income country, with, as we see in Table 12.1, average per capita GDP at $22,000 as of 2010. Overall energy consumption is at 10.8 Q-BTUs and overall CO_2 emissions are at 581 mmt. Emissions per capita are at 11.6 mt, which is 2.5 times the global average of 4.6 mt. It is also five times higher than the targeted global average figure of 2.4 mt needed for achieving the 20-year global CO_2 emissions reduction target. According to the energy intensity ratio - i.e. Q-BTUs/$1 trillion GDP – the ROK is operating an inefficient energy system. Its energy intensity ratio of 9.8 is nearly 40 percent higher than the global average of 7.1.

At the same time, its energy mix is relatively clean compared with the global average. Its emissions intensity ratio - CO_2 emissions/Q-BTUs - is 53.8. This is about 18 percent below the global average of 66. It is also a lower figure than either the U.S. or Germany. As we will see, the ROK can realistically reduce its per capita CO_2 emissions roughly in half over the next 20 years. It can achieve this while still maintaining a healthy GDP growth rate over this 20-year period and while expanding employment opportunities relative to maintaining its existing fossil fuel dominated energy infrastructure.

Table 12.1: Republic of Korea. Basic energy indicators, 2010

	ROK	World
Per capita GDP *(2005 $PPP)*	$22,000	$10,300
Total energy consumption *(Q-BTUs)*	10.8 Q-BTUs	510.5 Q-BTUs
Per capita energy consumption *(M-BTUs/population)*	218.2 M-BTUs	74.0 M-BTUs
Total CO_2 emissions *(mmt)*	581 mmt	31,502 mmt
Per capita CO_2 emissions *(mt of emissions/population)*	11.6 mt	4.6 mt
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	9.8 Q-BTUs	7.1 Q-BTUs
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	53.8 mmt	65.9 mmt

Source:See Tables 1.1 and 1.4.

Between 2003-2012, the economy of the ROK grew at an average annual rate of 3.9 percent. The average growth rate projection through 2040 that the EIA reports under a range of alternative assumptions - including its Reference case, as well as its high- and low-growth cases, and its high- and low-oil price cases - is between 3.2-3.3 percent. These are conservative growth projections given the ROK's past growth performance, but for the purposes of our discussion, it is better to work with relatively conservative assumptions. In generating our own estimates on clean energy investments and employment in this discussion, we will therefore assume that the ROK's average growth rate through 2030 will be 3.3 percent.

This growth trajectory would generate a near-doubling of average incomes in the country, from its current level of $22,000 per capita to $42,000, given that the projections are also that the ROK's population will remain roughly constant at around 50 million people through 2030.

In Table 12.2, we show the ROK's energy consumption and emissions levels for 2030 under the EIA's BAU scenario. As we see, the EIA estimates that the ROK's total energy consumption rises from 10.8 to 14.7 Q-BTUs between 2010-2030. This is a 36 percent increase in energy consumption over the 20-year period, which amounts to an average annual increase of 1.6 percent. As such, the EIA is projecting that the ROK will make significant gains in energy efficiency over the next 20 years, given that they project GDP to grow at an average of 3.3 percent. We see this directly through the change in the energy intensity ratio, which falls from 9.8 in 2010 to 7 by 2030, a 29 percent improvement, according to the EIA's BAU model.

Table 12.2: Republic of Korea. Energy consumption and emissions: 2010 actuals and alternative official projections

	2010 actuals	2030 EIA BAU scenario
Total energy consumption	10.8 Q-BTUs	14.7 Q-BTUs
Energy intensity ratio *(Q-BTUs/$1 trillion GDP)*	9.8 Q-BTUs	7.0 Q-BTUs
Energy mix:		
Oil	42%	36%
Coal	29%	22%
Natural gas	14.3%	14%
Nuclear	13%	8%
High-emissions renewables	NA	NA
Clean renewables	NA	NA
• Hydro	0.9%	2.0%
• All others	NA	NA
Total CO_2 emissions	581 mmt	666 mmt
Emissions intensity ratio *(CO_2 emissions/Q-BTUs)*	53.8 mmt	45.3 mmt
(CO_2 emissions per capita) *(with population = 50 million for 2010 and 2030)*	11.6 mt	13.3 mt

Source: Authors' calculations based on EIA (2013), "International Energy Outlook 2013."

In addition to these significant gains in energy efficiency, there are also changes in the ROK's energy mix under the BAU 2030 assumptions. The most important ones are that the level of coal consumption remains flat, and that most of the growth in overall energy consumption is absorbed by natural gas. The EIA estimates natural gas supply to more than double, from 1.8 to 4.7 Q-BTUs. Clean renewables is also projected to experience a major expansion. But it is operating from a very low base, so that, in absolute terms, its total supply as of 2030 would remain a modest 0.3 Q-BTUs, 2 percent of the ROK's overall 2030 energy supply.

The gains in energy efficiency, combined with a major coal-to-natural gas fuel switching transition does then mean that the ROK's energy mix becomes significantly cleaner, with its emissions intensity ratio falling from 53.8 to 45.3. Yet overall emissions do still rise, because energy consumption is still rising, albeit at a relatively slow rate. The overall effect is that emissions per capita do still rise, from 11.6 mt in 2010 to 13.3 mt in 2030. That is, even with the ROK achieving major gains in energy efficiency and undertaking a major coal-to-natural gas fuel switch, the net impact is that its emissions per capita ratio, at 13.3 is still 5.5 times greater than the Year 20 global target ratio of 2.4 mt.

It is therefore clear that it is necessary to explore the prospects for a still more ambitious clean energy transformation for the ROK over the next 20 years. The central premises of such a strategy would fully coincide with the commitment the government of the ROK to be a leader in pursuing an innovative Green Growth policy agenda moving forward.

Major Developments Supporting Clean Energy Investment Project

The Republic of Korea's Green Growth Strategy

Since the presentation of its first National Basic Energy Plan in 2008, the government of the ROK has begun a major project of defining and advancing what it has called a Green Growth strategy.[72] The statement of the first National Basic Energy Plan for 2008-2030 sets out its vision as follows:

> *The first Basic National Energy Plan suggests a society that realizes healthy growth while consuming less energy; a society that minimizes environmental pollution even when using energy; a society where energy industries create jobs and growth engines; and a strong energy self-reliant and welfare society despite energy crises as a long-term energy policy vision.*
>
> *As the implementation blueprint for the vision, the Basic National Energy plan also suggests realization of a 'low energy-consuming society' through improvement of energy intensity…independence from fossil energies in energy supply through a 4.6-fold expansion of the new and renewable energy ratio to 11 percent by 2030 from the present 2.4 percent while reducing the fossil energy ratio…including oil, to 61 percent by 2030 from 83 percent at present…*
>
> *The implementation plan also aims to raise the energy technology level, including 'green technology' compared with advanced countries to the world-class level by 2030 from the present 60 percent; nurture the energy industry into a growth engine; realize a self-reliant energy and welfare society by increasing self-development rates of oil and gas to the 30 percent level by 2030 from the present 4.2 percent, and addressing all energy-poor classes, which currently stand at the 7.8 percent level (Government of Korea, 2008, p. 5)*

As outlined by Kang (2013), six key features of the ROK's Green Growth strategy have been developed since the presentation of the National Energy Basic Plan. These are:

1. The formation of the Presidential Committee on Green Growth (2009).
2. The establishment of legislation of the Framework Act on Low Carbon, Green Growth (2010).
3. The establishment of the National Greenhouse Gas Reduction Target (2009). This set the 2020 target as a 30 percent reduction in all GHG emissions at 30 percent below BAU through 2020.
4. The establishment of a Green Budget for 2009-2013, with 2 percent of GDP devoted to Green Growth Policies.
5. Organizing the Green Technology Development project for 27 core areas of green technology.

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[72] See UNEP (2010) for a detailed overview of the Green Growth Strategy.

6. The establishment of the ROK as an international leader in fostering global green growth. The formation of the Global Green Growth Institute in 2010 was one major initiative within this international project.

Kang (2013) further writes that the ROK's Green Growth strategy consists of three key strategies, which incorporate 10 policy directions within the three strategies. These are:

Strategy 1: Measures for climate change and securing energy independence.

- Reducing carbon emissions;
- Decreasing energy dependence on oil and enhance energy sufficiency;
- Supporting adaptation to climate change impacts.

Strategy 2: Creation of a new growth engine.

- Developing green technologies as future growth engines;
- Greening of industry;
- Developing cutting-edge industries;
- Setting up a policy infrastructure for green growth.

Strategy 3: Contribution to international community

- Green city and green transport;
- Green revolution in lifestyle;
- Enhance national status as a global leader in green growth.

Table 12.3 below shows the Government of the ROK's overall fiscal expenditures on green growth, and the breakdown of spending according to strategic areas, as developed by Kang. As we see, total spending over the period 2009-2013 has been $122.8 billion (converted from current KRW to dollars at average annual exchange rates), for an average of $24.6 billion per year. As the table also shows, this figure is approximately 2.2 percent of the ROK's average annual GDP between 2009-2013.[73]

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[73] We estimated the ROK's 2013 GDP based on a growth rate for the year at 3.4 percent. This is taken from figures from the first three quarters of the year and projections for the rest of the year. See Jun (2013).

Table 12.3: Republic of Korea. Fiscal expenditure on green growth, 2009-2013

Current dollars at average annual KRW/Dollar exchange rate

		Shares of total spending		
	Total spending	**Mitigation of climate change & energy independence**	**Creating new engines for economic growth**	**Improvement in quality of life and enhanced international standing**
2009	$22.3 billion	49%	27%	24%
2010-11	$54.7 billion	60%	22%	18%
2012-13	$45.8 billion	46%	31%	23%
All years	$122.8 billion	52% annual average	27% annual average	21% annual average
	Average spending per year = $24.6 billion			
	2.2 percent of GDP			

Sources: Kang (2013) for spending figures, presented in KRW. Converted to dollars from IMF International Financial Statistics database.

Note: GDP figure for 2013.4 estimated on basis of 3.4 percent growth rate for 2013.

We also see from Table 12.3 that roughly half of the ROK's green growth budget has been devoted to mitigation of climate change and energy independence, while the other half has been divided between "creating new engines of economic growth," at 27 percent, and "improvement in quality of life and enhanced international standing," at 21 percent. The focus of our project is on the first strategy, mitigation of climate change and energy independence, which has received an average of about 1.1 percent of the ROK's GDP, or $12.8 billion per year.

This figure is basically in line with our working assumption that each of our five selected economies devotes 1.5 percent of GDP to investments in renewable energy and energy efficiency. However, to the best of our knowledge to date, there are two significant differences in comparing the Government of the ROK's budget allocation with the budgetary assumptions we use in this report. The first is that the ROK's budgetary figures includes funds to support the development of domestic oil and gas industries, following the goal expressed in the National Energy Basic Plan to increase "self-development rates of oil and gas to the 30 percent level by 2030 from the present 4.2 percent." Our funding allocation is targeted exclusively for investments in energy efficiency and clean renewable energy sources. The second is that the Government of the ROK's spending figure is, again, to the best of our knowledge to date, funds allocated by the public sector only. Our funding figures are inclusive of all public plus private spending within the economy of the ROK on clean renewable and energy efficiency investments. Nevertheless, our own clean energy investment figures are still in rough alignment with the large-scale funding commitments that the ROK's government has made since 2009 to clean energy.

Developments in Renewable Energy and Energy Efficiency

The impacts of these large-scale government green growth funding commitments are reflected in the recent advances as well as the prospects for renewable energy and energy efficiency investments. We review briefly some of the major developments in these two areas.

Clean Renewables

According to the most recent actual data, the levels of energy supplied from all clean renewable sources is negligible, less than 1 percent of the 10.8 Q-BTUs of total supply for 2010. This includes all hydro as well as clean bioenergy, wind, solar and geothermal energy sources. At the same time, major developments are underway, as described in the government's 2011 document *Low Carbon, Green Growth*.[74] These include the following.

Hydro. Hydro is currently the leading source of renewable energy supply in the ROK. Economically feasible hydro production is estimated at being around 19,000 GWh per year, including small-scale hydro. Current installations generate about 5 percent of this potential level of production.

Tidal. The ROK has built the largest tidal plant in the world at Sihwa Lake, which opened in 2011. It has the capacity to supply power for about 500,000 homes. According to Park (2007), it also should be able to play a major positive role in restoring the Lake Sihwa ecosystem and water quality through the continuing circulation of seawater. Because a dam has been operating at the lake, this led to a cut-off of tidal currents and the rapid increase of population and industrial waste loads from factories in the neighborhood. Other plants are also under development.

Biomass. This is considered a critical future resource in the ROK, which is a largely forested country. The government wants to promote production and use of wood pellets for electricity and heat. In 2007, biomass accounted for 6 percent of renewable production, but the Government of the ROK expects it to account for 30 percent by 2030, including both domestic production and imports.

Biofuels. The ROK is currently producing modest levels of biodiesel, as well as purchasing imports. There is potential for more biodiesel production from waste oils and algal sources. These can be harvested on bodies of water and thereby avoid some of the land-constraint problem facing other biofuels in the ROK.

Wind. Wind production has been increasing rapidly over the last decade, from about 5,900 MWh in 1999 to over 900,000 in 2012. Offshore wind projects are currently being developed, including one 500 turbine offshore project. Offshore wind is considered to have major untapped potential, in the range of 190 TWh per year - i.e. roughly 200 times the current level of generation. Onshore wind is considered to have less potential, because of terrain and siting issues.

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[74] This document is the Government of the ROK's Third Annual National Communication under the United Nations Framework Convention on Climate Change.

Solar. The use of solar panels has recently declined. However, the ROK aims to become one of the top five countries in the world in terms of solar panel usage by 2015. Among the specific short-term goals within this broader project is to install solar panels on 60 percent of all homes in the ROK.

Energy Efficiency

The IEA 2013 *Energy Efficiency Market Report* assesses developments to date in the ROK as follows:

> *Korea has a robust energy efficiency regime, founded on the Energy Use Rationalization Act, and strong related policies Label and Standard Program. Energy efficiency markets have grown remarkably due to strong government leadership, assertive regulations and industry-driven technical innovations in appliances and automobiles. Three important market sub-sectors stand out: appliances, transport, and energy service companies (IEA, 2013, p. 178).*

According to the 2013 IEA study as well as the government's 2011 *Low Carbon, Green Growth* report, the main areas for energy efficiency market expansion include the following:

> *Transportation*. Increasing the development and deployment of highly energy-efficient automobiles as well as the expansion in public transportation systems.
>
> *Residential and commercial buildings*. Improving home appliance and building energy efficiency standards through labeling programs, insulation standards and improved equipment.
>
> *Promotion of energy management systems (EMS)*. EMS allow entities to monitor, control and optimize the performance of their energy systems. The application of EMS will enable the ROK to draw on its competitive information and communications technology for energy-efficient related information for components such as sensors, software, hardware and controlling techniques. EMS can be applied to a variety of sectors, including factories, buildings and homes.

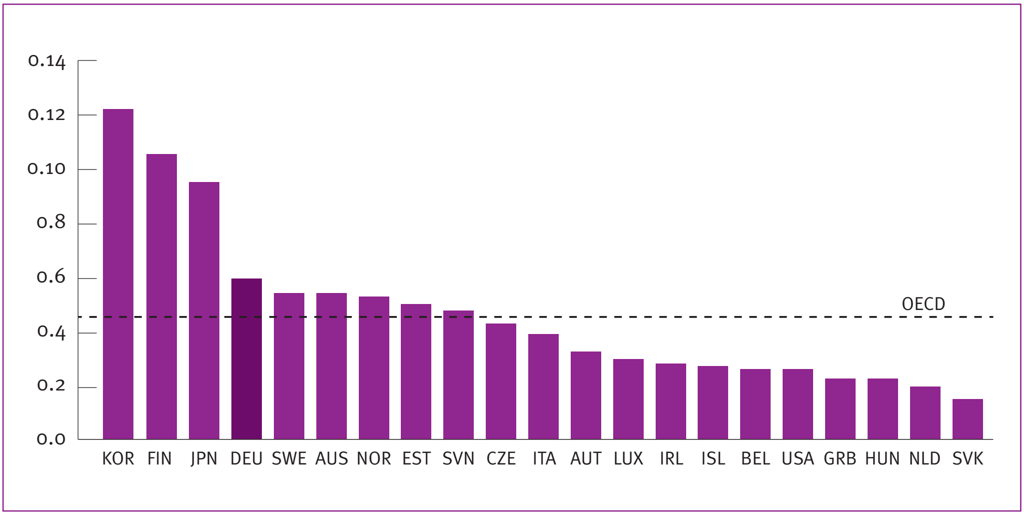
Government Spending on Environmental Research and Development

The prospects for the ROK to advance rapidly in both renewables and energy efficiency are being strengthened greatly by the high level of government commitment to R&D spending on environmental technologies. Figure 12.1 provides useful perspective on this, as it shows the ROK's environmental R&D spending levels compared with other OECD members. As we see, as a share of the economy's GDP, the ROK's R&D spending is the highest among OECD members - indeed, by a considerable margin compared with most other OECD countries. As Figure 12.1 shows, the ROK's R&D spending was about 0.13 percent of GDP as of 2012, equal to about $1.3 billion. By comparison, environmental R&D spending is about half that share of GDP in

Germany. In the U.S., the share of environmental R&D spending is about one-quarter the share of GDP as in the ROK.

Figure 12.1: Republic of Korea. Government R&D spending on environment and energy relative to other OECD countries

Percent of GDP, 2010 or latest



Source: OECD (2012) "OECD Economic Surveys: Germany 2012," OECD Publishing, Figure 9 (p. 31). http://dx.doi.org/10.1787/eco_surveys-deu-2012-en.

Emissions Reductions through Clean Energy Investments

In Table 12.4, we begin to present the main features of our 20-year clean energy investment framework for the ROK. As we have noted before, this framework is closely aligned with the government's Green Growth strategy. It is distinct in that our framework is more narrowly focused on investments in the areas of clean renewables and energy efficiency, in contrast with the broader agenda advanced under the Green Growth strategy. In addition, our annual budgetary allocation of 1.5 percent of GDP is a figure that is meant to apply to all public plus private spending. Our understanding of the funding levels we reported on Green Growth from 2009 to 2013 in Table 12.3 above, again, were public allocations only.

Table 12.4: Republic of Korea. Clean energy 20-year investment growth trajectory

2012 GDP	$1.1 trillion
Projected 20-year average annual GDP growth rate	3.3%
Projected 2032 GDP *(with 3.3 percent average annual GDP growth)*	$2.1 trillion
Midrange GDP value for investment spending estimates *(= (2012 GDP + 2032 GDP)/2)*	$1.6 trillion
Average annual clean renewable investments *(= 1 percent of midrange GDP)*	$16 billion
Average annual energy efficiency investments *(= 0.5 percent of midrange GDP)*	$8 billion

Source: Authors' calculations based on World Bank (2014), "World Development Indicators," GDP (current $US).

In our discussion, we assume that 1.5 percent of annual GDP is allocated with 1 percent of GDP funding the expansion of clean renewables while 0.5 percent is channeled into energy efficiency investments. We are also following the EIA in assuming that the ROK's average annual GDP growth rate over the next 20 years will be 3.3 percent.

As Table 12.4 shows, when we assume a 3.3 percent average annual growth rate over 20 years, the result is that the ROK's GDP in 20 years will be $2.1 trillion. To then estimate an average level of clean-energy investment spending over this 20-year period, we calculate the midrange GDP value between 2012 GDP at $1.1 trillion and 2032 GDP at $2.1 trillion. That midrange figure is $1.6 trillion. This then means that the average level of annual spending on clean energy would be $16 billion per year, equal to one percent of the midrange GDP figure, for renewables and $8 billion per year for energy efficiency, at 0.5 percent of the 20-year midrange GDP level.

Clean Energy Capacity and Emissions

In Table 12.5, we then estimate the levels of capacity expansion for both clean renewables and energy efficiency. The average cost assumptions that we work with are: 1) Expanding clean renewable capacity will cost $125 billion per Q-BTU, the same figure we have used for Brazil, Indonesia, and the ROK, following the reasoning we described for the Brazilian case in Chapter 8; and 2) Energy efficiency savings relative to the BAU case will cost $20 billion per Q-BTU. As we reported in Table 4.2, this $20 billion figure is at roughly the midpoint between the $11 billion per Q-BTU estimated in the 2010 McKinsey and Company study for projects throughout Africa, India, the Middle East, South East Asia, Eastern Europe and China and the $29 billion per Q-BTU estimated for the U.S. in the 2010 National Academy of Sciences study.

Table 12.5: Republic of Korea. Cost assumptions and capacity expansion for clean renewables and energy efficiency investments

	Clean renewable energy	**Energy efficiency**
1) Cost assumptions	$125 billion per Q-BTU of capacity	$20 billion per Q-BTU of energy savings
2) Annual spending levels	$16 billion *(= 1 percent of midrange GDP*)	$8 billion *(= 0.5 percent of midrange GDP)*
CASE 1: No delay in implementing program: 20-Year spending cycle		
3) Total spending with 20-Year spending cycle[a]	$320 billion	$160 billion
4) Total capacity expansion or energy savings through 20-Year spending cycle[b]	2.6 Q-BTUs of new capacity	8.0 Q-BTUs of energy savings
CASE 2: 3-Year delay in implementing program 17-Year spending cycle		
5) Total Spending with 17-Year Spending Cycle[c]	$272 billion	$136 billion
6) Total capacity expansion or energy savings through 17-Year spending cycle[d]	2.2 Q-BTUs of new capacity	6.8 Q-BTUs of energy savings

Notes: a) Calculated as row 2 multiplied by 20; b) Calculated as row 3 divided by row 1; c) Calculated as row 2 multiplied by 17; d) Calculated as row 5 divided by row 1.

Source: Authors' calculations as developed in Chapter 12.

Working with these cost assumptions, we then estimate the two alternative cases. Under Case 1, the clean energy investment project as we have defined it begins promptly - i.e. the increased levels of investments in clean renewables and efficiency build immediately off of the developments already underway through the Green Growth project. This means that the capital stock for clean renewable capacity and energy efficiency processes grows every year over the full 20-year cycle. Under Case 2, a more conservative scenario, we assume a 3-year delay in the implementation of this expanded focus on investments in renewables and energy efficiency. Thus, under Case 2, the accumulation of new capacity proceeds for only 17 years of the full 20-year investment cycle. Even though the ROK is already well underway in implementing its national Green Growth project, we are still assuming that the second scenario is more realistic. We therefore focus our attention on this case.

We see that under Case 2, total investment spending on clean renewables would be $272 billion over 20 years, with a 17-year spending cycle after the 3-year start-up period. Energy efficiency investments would be $136 billion, again, based on a 17-year spending cycle after a 3-year start-up period.

We then show the net effects of Case 2 in the bottom row of Table 12.5. That is, after 20 years, the ROK would have created 2.2 Q-BTUs of clean renewable capacity. This would of course incorporate a mix of clean renewables that would be determined through examining the full range of options as described, for example, in the government's 2011 *Low Carbon, Green Growth* report. The ROK would have also been able to save 6.8 Q-BTUs of energy consumption through having invested $136 billion in energy efficiency processes over 20 years. We can then apply those 6.8 Q-BTUs of saving relative to the EIA's 2030 BAU scenario.

We can then see the impact of these expanded levels of investment in renewables and efficiency in Table 12.6 below. We begin again, with the EIA's BAU assumption that total energy consumption in 2030 will be 14.7 Q-BTUs. This level now falls to 7.9 Q-BTUs due to energy efficiency investments, which we estimated would generate 6.8 Q-BTUs of energy saving relative to the BAU case. Total clean renewable capacity in the ROK now rises to a total of 2.5 Q-BTUs. This includes the 0.3 Q-BTUs that was built into the BAU scenario, plus the 2.2 Q-BTUs that would be generated through investing 1 percent of GDP per year over a 17-year period, following the initial 3-year start- up phase.

Table 12.6: Republic of Korea. Impact of clean energy investments relative to 2030 BAU scenario

	2030 BAU scenario	**20-year clean energy investment scenario** ***(Case 2: 3-year start-up delay)***
Total energy consumption	14.7 Q-BTUs	7.9 Q-BTUS *(with 6.8 Q-BTUs of energy efficiency savings)*
Total clean renewable energy supply	0.3 Q-BTUs	2.5 Q-BTUs *(with 2.2 Q-BTUs of additional clean renewables)*
Total nuclear power supply	1.2 Q-BTUs	1.2 Q-BTUs
Total fossil fuel + High-emissions renewables	13.2 Q-BTUs	4.2 Q-BTUs
Total CO_2 emissions	666 mmt	294 mmt
Total CO_2 emissions per capita *(with population = 50 million)*	13.3 mt	5.9 mt

Sources: EIA (2013b) for BAU Scenario; discussion in text for 20-year scenario.

We then factor in total energy supplied by nuclear power. We assume that this level will remain constant at 1.2 Q-BTUs relative to the BAU case.

The overall net effect of these clean renewable and energy efficiency investments can then be seen in terms of the ROK's residual demand for fossil fuel energy sources. As we see, according to this scenario, the demand for all fossil fuels falls to 4.2 Q-BTUs. Assuming an average emissions level of 70 mmt of CO_2 emissions per Q-BTU from the ROK's mix of oil, natural gas, and coal consumption in Year 20 of its clean energy investment cycle, this then means that the ROK's total CO_2 emissions would be at 294 mmt as of Year 20. This amounts to 5.9 mt of CO_2 emissions per capita - a 56 percent decline in per capita emissions relative to the ROK's 2030 BAU scenario of 13.3 mt of per capita CO_2 emissons, as well as a 50 percent decline relative to the ROK's actual emission level for 2010.

Employment Generation through Clean Energy Investments

Table 12.7 presents our estimates of the effects on overall annual employment levels through a ROK clean energy investment project at the level of 1.5 percent of annual GDP.

Table 12.7: Republic of Korea. Employment impact of clean energy investments vs. fossil fuel spending

Figures are jobs in Year 1 of 20-year clean energy investment strategy

Assumptions for clean energy investments:

- Total investment = 1.5 percent of GDP
  - 67 percent clean renewables;
  - 33 percent energy efficiency
- "Domestic Content Stable" scenario
- 70 percent of investment for capacity creation/production
- 30 percent for financing costs

Labor force in 2011 = 25.2 million

	Clean energy investments	Fossil fuel spending	Net employment effects of clean energy investments
Direct + indirect total employment at Year 1	174,800	157,100	17,700
Direct + indirect employment as share of total labor force at Year 1	0.7%	0.6%	0.1%

Source: See Chapter 7 and Appendix 3.

Our employment results are derived from our estimates presented in Chapter 7 as to the numbers of jobs generated per $1 million in spending through spending 1.5 percent of GDP per year on investments in clean renewables and energy efficiency. As such, our project should be seen as complimentary to, but distinct from, the important study by Kang, Oh, Lee, Jang, Hwang, Lee and Kim, *Green Growth: Green Industry and Green Jobs* (2011). The Kang et al. study is more broadly gauged. It attempts to estimate levels of employment for all green activities in the economy of the ROK, as defined within the economy's overall Green Growth project, as described above. In our case, we are estimating the number of jobs per year produced through investing 1.5 percent of the country's GDP per year in renewable energy and energy efficiency. We then compare the extent of job creation through these clean energy investments with the job creation generated by spending the same amount of money within the oil, coal and natural gas sectors.

Working within our own framework, we have calculated the effects of the 1.5 percent of GDP investment project given a spending breakdown at two-thirds renewables and one-third energy efficiency. We also make two other assumptions.

First, we focus for this analysis on the Domestic Content Stable scenario, as opposed to assuming the ROK's imports will have to rise to meet the resource demands of its clean energy investment strategy. This is because the ROK is an advanced economy, which has already been actively engaged in developing Green Growth initiatives throughout the economy. The ROK also has a long-term record of success as an economy capable of effective adaptation to new technologies. This basic strength of the economy of the ROK will only be enhanced with time through its major commitment to clean energy R&D spending.

In addition, we assume that, of the total amount of spending on the clean energy investment project, 30 percent is allocated to cover financing costs. This leaves 70 percent available for spending on creating capacity and producing, refining, transporting, and marketing energy.

From these assumptions, we estimate the total amount of direct plus indirect employment generated through the clean energy investment project at 1.5 percent of GDP is about 175,000 jobs. This is a very large number of jobs in absolute terms. But it is also only 0.7 percent of the ROK's total labor force of 25.2 million as of 2011. The impact of the clean energy investment project would therefore be strongly positive in terms of absolute employment, but its overall scope would be limited.

To gauge the net expansion in job opportunities, we also need to compare these figures with the job creation that would occur through maintaining spending in the ROK's existing fossil fuel industry, as opposed to shifting funds into clean energy. We see in Table 12.7 that the same level of spending in the ROK's coal, oil, and natural gas sectors would create close to the same number of jobs, at 157,000. That is, overall, there is a net gain of about 18,000 jobs through pursuing the clean energy investment agenda rather than standing pat with the fossil fuel-based infrastructure. We thus again see that, compared with maintaining the ROK's current fossil fuel based energy infrastructure, the clean energy investment project will be a net source of job creation, though this net gain in employment will be modest within the context of the ROK's overall labor market.

In Table 12.8, we present our projections for employment creation in Year 20 of the ROK's 20-year clean energy investment project. These figures are based on two separate assumptions as to the average growth rate of labor productivity in the ROK's clean energy sectors over this 20-year period - a 1 percent low-end average annual labor productivity growth rate assumption and a 2.5 percent high-end assumption.

Table 12.8: Republic of Korea. Projected employment impacts of clean energy investments after 20 years under alternative labor productivity assumptions

Figures are jobs per year

Assumptions for 20-year employment projections

- Baseline Year 1 employment levels given in Table 12.7
- 20-year average annual GDP growth is 3.3 percent
- Average annual labor productivity growth ranges between 1-2.5 percent
- Population figure is projected 2035 population
- Labor force/population ratio at end of 20-year investment cycle equals 2011 ratio

Labor force at end of 20-year investment cycle = 27.2 million

	Scenario with 1 percent average annual labor productivity growth	**Scenario with 2.5 percent average annual labor productivity growth**	**Midpoint between 1 percent and 2.5 percent productivity growth scenarios**
Direct + indirect total employment	315,700	235,400	276,000
Year 20 direct + indirect employment as relative to Year 1 employment	80.6%	34.7%	57.6%
Direct + indirect employment as share of total labor force	1.2%	0.9%	1.0%

Sources: See Chapter 7 and Appendix 3.

Working with these assumptions, as well as with the other assumptions on GDP growth, population and labor force participation listed above Table 12.8, we generate the following results:

1. Assuming labor productivity increases at 1 percent per year, total employment creation through clean energy investments will rise to about 316,000 in Year 20. This is about an 80 percent increase relative to employment creation in Year 1. This strong gain in employment creation results through our assumption that GDP growth will average 3.3 percent per year over the 20-year clean energy investment cycle - a 2.3 percent faster rate than labor productivity in the clean energy sectors. GDP growth at 3.3 percent per year in turn means that clean energy investments will also be growing at 3.3 percent per year, to remain as a fixed 1.5 percent of GDP every year over the 20-year investment cycle.

2. Under this 1 percent labor productivity growth assumption, employment creation through clean energy investments will rise to about 1.2 percent of the ROK's Year 20 labor force relative to the 0.7 percent figure as of Year 1.

3. Assuming average labor productivity in the ROK's clean energy sectors increases at the higher-end rate of 2.5 percent over the 20-year investment cycle, employment creation

will still be rising, though more modestly, given that we assume GDP growth will average 3.3 percent per year. Year 20 employment creation through clean energy investments then reaches 235,000. This is still a roughly 35 percent increase over the Year 1 figure. Under this scenario, employment creation through clean energy investments rises to around 0.9 percent as a share of the ROK's overall labor force in Year 20.

4. In the last column of Table 12.8, we report midpoint employment creation figures, that are based on averaging Year 20 employment levels derived from both the 1 percent and 2.5 percent labor productivity growth assumptions. As we see, the midpoint figure is 276,000 jobs, which is about 1 percent of the ROK's Year 20 labor force.

Overall, as we see, employment creation through the ROK's clean energy investment project operating at 1.5 percent of GDP per year will continue to expand over time under a wide range of plausible assumptions as to the growth of labor productivity over the 20-year investment cycle. As such, the overarching conclusion we reach here is that, through the clean energy investment project as we have described it, the ROK would be able to build on its major accomplishments to date in advancing a green growth policy framework. In fact, through this clean energy investment project at the level of 1.5 percent of GDP over the course of 20 years, the ROK could realistically reduce its absolute per capita emissions by 50 percent relative to actual 2010 emissions and by 56 percent relative to the EIA's 2030 BAU scenario for the ROK. Moreover, this dramatic level of emissions reduction can be accomplished without having to make any sacrifices overall in terms of creating job opportunities for its citizens.

CHAPTER 13: CONCLUSION

This report addresses the profound challenge now facing humanity to control climate change. According to the IPCC, to successfully control climate change over the next 35-40 years, we need to reduce total GHG emissions by 40 percent as of 2030 and 80 percent as of 2050 relative to current emissions levels.

The purpose of this report has been to show how the IPCC's intermediate emission reduction target can be achieved. We have been particularly focused on how it can be accomplished through a clean energy investment project that is also capable of expanding decent employment opportunities throughout all regions of the world. Any project to control climate change, which entails reducing decent job opportunities will also create major difficulties for all countries to raise average living standards and reduce poverty. These difficulties will be experienced most sharply in developing countries, where the imperative to fight poverty and raise average living standards is strongest. Limiting opportunities for countries to proceed on a healthy economic growth trajectory will also face formidable political resistance. This in turn will create unacceptable delays in proceeding with effective policies to control climate change.

Because of this report's sharp focus on achieving the IPCC's 20-year emission reduction targets while also expanding decent job opportunities, we do not compare the relative costs and benefits of investments that can reduce CO_2 emissions versus investments that can, for example, promote a successful high-tech sector. Correspondingly, it is only within the context of reducing CO_2 emissions that we explore the impact of a clean energy investment agenda on generating decent job opportunities. This is because it is only through investing in clean energy resources that we are able to deal with the challenge of achieving a country's emissions reduction targets. Within all country settings, there is, of course, a wide range of additional issues that need to be explored on behalf of the goals of promoting economic growth and employment opportunities. Many of these issues are not particularly concerned with a country's energy sector. It is of course critical that other researchers continue to explore this broader set of questions along with the energy- and environment-focused themes of this report.

Focusing on energy-based CO_2 emissions, which account for nearly 80 percent of all global GHG emissions, we present in Chapter 1 the IPCC's intermediate emission reduction target in terms of average emissions per capita for the entire global population. As of 2010, average annual global per capita CO_2 emissions were at 4.6 mt. This figure will need to fall to 2.4 mt within 20 years, after taking account of increasing population.

The basic idea of the strategy we have developed for achieving the IPCC's emission reduction target is simple. It proposes that most countries - including especially most large countries, in terms of either GDP or population levels - devote about 1.5 percent of GDP per year to investments in energy efficiency and clean renewable energy resources. In advancing this proposal, we have focused on the challenges faced by five countries - Brazil, Germany, Indonesia, South Africa, and the ROK. These are sharply distinct countries, in terms of their regions, levels of development, as well as their current energy infrastructures and emissions levels. But they are also all leading economies within their respective regions, and as such, represent important case studies. We conclude that the 1.5 percent of GDP clean energy investment project applies well to four of our five case study countries.

Brazil is the one exception, for two reasons. The first is that Brazil is already a very strong performer in both its reliance on renewable energy and its level of energy efficiency. As we saw in Chapter 1, per capita emissions in Brazil are presently at 2.3 mt - that is, at a level already slightly below the 2.4 mt global average level that is targeted for Year 20 based on the IPCC's emissions reduction goals. In addition, Brazil is unique among our five selected countries in that CO_2 emissions from energy-based sources account for less than 40 percent of the country's total GHG emissions. As such, for roughly the next decade, Brazil should devote a relatively large share of its resources to controlling methane and nitrous oxide emissions from non-energy sources. We saw that Brazil could reduce its CO_2 emissions to 2.0 mt per capita within 20 years through investing about 0.9 percent of GDP annually in clean renewable energy and energy efficiency, rather than the 1.5 percent that would apply to most other countries.

One of our starting points in developing the idea of a 1.5 percent of GDP clean energy investment strategy for most countries was that policymakers in our five selected countries have themselves proposed clean energy strategies at roughly along these lines - i.e. between 1-2 percent of their country's GDP. In addition, for all five of our selected countries and throughout the world more generally, there are no viable paths for achieving the IPCC's 20-year emissions reduction target through maintaining dependence on non-renewable energy sources at anything approximating current levels, much less through allowing consumption of non-renewables to increase. We reported in Chapter 1 the global emissions projections for 2030 of both the EIA and the IEA. Both the EIA and IEA project that, under their global energy consumption Reference cases for 2030, global CO_2 emissions will be more than twice as high as the IPCC's 20,000 mmt target level. Even under the IEA's "New Policies Case," for 2030, which incorporates "broad policy commitments…to address energy-related challenges," (IEA, 2013A, p. 645), the IEA still projects 2030 emissions at 36,493 mmt. This is 82 percent higher than the 20,000 mmt target. Increasing global fossil fuel consumption levels through any means - including utilizing existing resources and technologies; finding new reserves such as Brazil's pre-salt deposits; or deploying advanced technologies such as fracking - will, in all cases, only raise emission levels further.

Some analysts believe that CCS technologies and nuclear energy can effectively expand non-renewable energy supplies without producing emissions. But we conclude that neither CCS nor nuclear energy offer viable long-term solutions. CCS technologies aim to capture emitted carbon and transport it, usually through pipelines, to subsurface geological formations, where it would be stored permanently. Such technologies have not been proven at a commercial scale. The dangers of carbon leakages from flawed transportation and storage systems will, in any case, only increase to the extent that CCS technologies are commercialized. Nuclear power does generate electricity without producing CO_2 emissions. But it also creates major environmental and public safety concerns, which have only intensified since the March 2011 meltdown at the Fukushima Daiichi power plant in Japan.

In Chapters 3 and 4, we review the body of evidence from around the world as to the costs of building capacity in both clean renewable energy supply and energy efficiency. This body of evidence provides the critical basis supporting our conclusion that investments in these two areas can be the foundation for achieving the 20-year global emissions reduction target.

With respect to clean renewables, cost estimates from both IRENA and the EIA support the view that generating electricity from onshore wind, small-scale hydro, geothermal and clean bioenergy are all either at, or at least rapidly approaching, cost parity with non-renewables under average conditions. Solar is not yet approaching cost parity, but solar costs are diminishing rapidly. Through technical innovations and expanded market opportunities over the next two decades, solar promises to become the cleanest, safest, and most abundant renewable energy source. The range of costs are still generally greater for all clean renewables, given differences in, among other things, the amounts of sun, wind, and fast-flowing rivers between regions and specific locations. But this wider range can be controlled through policies that utilize the most cost-effective combination of renewable sources within any given setting.

In addition, these cost comparisons between clean renewables and non-renewables do not factor in any impact of carbon cap or carbon tax policies that would raise the relative prices of oil, coal, and natural gas. As we review in Chapter 3, renewables would become still more competitive if the market prices of fossil fuels incorporated some reasonable measure of the environmental costs generated by burning oil, coal, and natural gas. Using a simple mark-up approach to estimating such price effects, we show in Chapter 3 that, with a $75 per ton carbon price utilized in the EIA's energy forecasting models, price mark ups for fossil fuels would range between about 20 percent for crude oil, 64 percent for natural gas, and 250 percent for coal. The price increases would of course be higher still with a higher carbon price, such as the $125 per ton figure used by the IEA in its policy modeling exercises.

With respect to energy efficiency costs, we reported in Chapter 4 on the wide range of cost estimates presented by alternative studies. For example, a 2008 World Bank study by Taylor et al. of 455 projects in 11 industrialized and developing economies estimated the average costs of achieving one Q-BTU of energy savings at $1.9 billion. A 2010 study by McKinsey and Company of a range of non-OECD economies estimated average energy efficiency energy costs at $11 per Q-BTU. The U.S. National Academy of Sciences estimates average costs within the U.S. at roughly $30 billion per Q-BTU.

These alternative studies do not provide sufficiently detailed methodological discussions that would enable us to identify the main factors generating these major differences in cost estimates. But it is at least reasonable to conclude from these figures that there are likely to be large variations in costs on a project-by-project basis. At the same time, for the purposes of our estimates in this report, we needed to proceed with some general rules-of-thumb for estimating the level of savings that are attainable through a typical set of efficiency projects in our five selected countries, as well as in other settings.

Our approach has been to assume relatively high-end average costs both for expanding clean renewable productive capacity and achieving major gains in energy efficiency. Specifically, we derived our clean energy investment cost assumptions as follows: 1) With clean renewables, we worked from both IRENA's region- and country-specific figures on costs per kWh of electricity and the EIA's U.S.-based figures on capital expenditures for building renewable capacity; and 2) For energy efficiency, we utilized the three studies described in Chapter 4 - from the World Bank, McKinsey and Company, and the U.S. National Academy of Sciences respectively - on investment costs per Q-BTU of energy savings. Working with these various studies, for the cases of Brazil, Indonesia, and South Africa, we assumed the average costs of expanding clean renewable capacity at $125 billion per Q-BTU and the costs for efficiency investments at $11 billion per Q-BTU of savings. For the ROK, we assume the same $125 billion average figure for clean renewable investments but a higher figure, $20 billion per Q-BTU, for efficiency gains. With Germany, we directly incorporated the government's own cost estimates for their 2030 Low Carbon Scenario.

The key here is not that these cost assumptions are necessarily accurate in any of the countries, and certainly not on an individual project-by-project basis, but rather that they err, if anything, on the high side. This is because we need to assess whether investing 1.5 percent of GDP in clean renewables and energy efficiency can bring down CO_2 emissions sufficiently within a framework of relatively high-end cost assumptions in all cases. Our support for a 1.5 percent of GDP clean energy investment project would not be robust if we could demonstrate its viability only on the basis of highly aggressive low-end assumptions on costs, including an assumption of rapid cost reductions through technological learning.

In working with these cost figures, we should also emphasize again that, in all cases, the payback period for such energy efficiency investments are generally estimated to be relatively short - in most cases, less than three years for full payback. The 2011 survey research by UNIDO that we discussed in Chapter 4 provided more careful evidence on mean internal rates of return for the 119 energy efficiency projects they analyzed. UNIDO found that mean IRRs ranged between 25 percent for projects with a three-year lifespan to 50 percent for 10-year projects.

We do also consider in Chapter 4 the prospect that large-scale efficiency investments may not have their intended effect, as a result of the rebound effect. However, we concluded that any rebound effect that may emerge as a by-product of an economy-wide energy efficiency investment project will not be large enough to counteract the emissions and cost reductions these efficiency investments can achieve. Still, the most effective way to limit rebound effects is to combine efficiency investments with complementary measures to expand renewable energy capacity and to establish a price on carbon emissions.

Assessing the likely employment effects of clean energy investments in Brazil, Germany, Indonesia, South Africa, and the ROK required us to first estimate the numbers of jobs generated by a given amount of spending in each country's various clean energy sectors. We estimated these employment effects on the basis of the I-O modeling approach we developed in Chapter 6 as well as the assumptions we described in Chapter 5 on each country's domestic content proportions as demand increases along the clean energy sectors' supply chain. Overall, we find here that, per $1 million in spending in each country (converted at current exchange rates), clean energy investments generate, on average, about 37 jobs in Brazil, 10 jobs in Germany, 100 jobs in Indonesia, 70 jobs in South Africa, and 15 jobs in the ROK. Critically, as mentioned above, we also find that the clean energy investments create more jobs in all five countries than spending the same amount of funds within each country's fossil fuel sectors. In the cases of Brazil, Indonesia, and South Africa, the net employment gains for clean energy investments are substantial. They are more modest in Germany and especially the ROK. Still, in all cases, we find that investing in building a clean energy economy will also be a net positive source of job creation.

In Chapter 7, we also provide disaggregated statistics showing the types of jobs that would be created through an expansion of clean energy investments. We look at four criteria - gender balance; the proportions in self-employment and working in micro-enterprises; and the educational attainment levels of people employed in energy-linked activities. Not surprisingly, these disaggregated employment results varied significantly by country, and sectors. We observe, for example, a high proportion of employment in informal sectors in Brazil, Indonesia, and South Africa, and, to a somewhat lesser extent, the ROK, as indicated by our figures on both self-employment and micro-enterprise employment. This pattern is tied, first, to the large proportion of agricultural employment that will be generated by the growth of clean bioenergy production. It is also associated with the large increase in construction work that would result through the expansion of energy efficiency building retrofit projects. The major increase in investment funds flowing into construction and agriculture should provide opportunities to raise the level of formalization for these sectors.

In its current composition, employment in clean energy areas is heavily male dominated in all five countries. This is due to the significant role played by both manufacturing and construction in overall clean energy investments. Advancing major clean energy initiatives in all five countries (and elsewhere) could therefore be seen as an opportunity to open up decent job opportunities for women in these heretofore male employment strongholds. In general terms, the levels of educational attainment in the clean energy areas are not especially high. This suggests that, at least at the level of general educational levels, there should not be major challenges in finding qualified workers to cover the rising employment needs for expanding clean energy activities. At the same time, some of these new employment activities will entail new activities and skills. Countries advancing clean energy investment projects will therefore need to make provisions for new types of training and related skill acquisition initiatives.

In Chapters 8 -12, we then presented the overall effects on emissions reductions and employment expansion through clean energy projects in each of our five selected countries. For Brazil in Chapter 8, we estimated that clean energy investments will need to be at about 0.9 percent of GDP on average over the 20-year investment cycle to achieve the IEA's Low Carbon Scenario, through which Brazil's per capita emissions would fall to 2.0 mt as of 2030. For Germany, Indonesia, South Africa, and the ROK in Chapters 9-12, we assume clean energy investments at 1.5 percent of GDP every year over the 20-year cycle. We were able to generate these estimates of emission reductions and employment expansion on the basis of: 1) our cost estimates for investments in clean energy and energy efficiency; 2) our estimates of employment creation per dollar of expenditure in each of the five countries; and 3) our assumptions for average GDP growth in each country over the 20-year cycle. We deliberately work with conservative GDP growth assumptions, derived from projections by the IEA, IMF and the countries' own forecasting models. Once again, our point in working with these conservative GDP growth forecasts is not that they should necessarily be accurate but that, if anything, they err on the low side. If our five selected countries experience faster GDP growth than we assume, this then also means that they have more resources to channel towards clean energy investments, since our clean energy investment levels for all countries are a fixed ratio of each country's GDP (1.5 percent of GDP in all cases but Brazil, with Brazil at 0.9 percent of GDP).

In Table 13.1, for each of our five selected countries, we summarize the impact of our 20-year clean energy investment project on emissions levels and employment creation as of Year 20. Panel A of Table 13.1 shows the main results of our estimates for all countries, and Panel B presents the main underlying assumptions underlying our estimates.

Table 13.1: Summary of emissions reduction and employment expansion effects through 20-year country-specific clean energy investment projects

a) Main results from estimates

	Brazil	Germany	Indonesia	South Africa	ROK
Emissions reductions					
Year 20 per capita emissions	2.0 mt	5.5 mt	2.6 mt	8.7 mt	5.9 mt
Year 20 per capita emissions relative to 2010	-13.0%	-43.3%	+52.9%	-8.4%	-49.1%
Year 20 per capita emissions relative to 2030 BAU	-37.5%	-28.6%	-66.7%	-49.7%	-55.6%
Employment expansion					
Clean energy jobs per $1 million	37.4 jobs	9.5 jobs	103.3 jobs	66.2 jobs	15.1 jobs
Clean energy *minus* fossil fuel jobs per $1 million	16.2 jobs	1.9 jobs	81.3 jobs	33.1 jobs	1.5 jobs
Midpoint Year 20 employment through clean energy investments	806,000	352,000	1.8 million	398,000	276,000
Midpoint Year 20 employment as share of labor force	0.7%	0.9%	1.3%	1.9%	1.0%

Sources: For emissions figures, Tables 1.4, 8.4 9.3, 10.5, 11.6, and 12.6. For employment figures, Tables 7.1, 7.5, 7.9, 7.13, 7.17, 8.7, 9.5, 10.7, 11.8, 12.8.

b) Main assumptions underlying estimates

	Brazil	Germany	Indonesia	South Africa	ROK
20-Year GDP growth trend	3.7%	2.0%	5.0%	4.0%	3.3%
Clean energy investments as share of GDP	0.9%	1.5%	1.5%	1.5%	1.5%
Costs of clean renewable capacity expansion per Q-BTU	$125 billion	Direct government estimates	$125 billion	$125 billion	$125 billion
Costs of energy efficiency improvements per Q-BTU	$11 billion	Direct government estimates	$11 billion	$11 billion	$20 billion

Sources: Tables 8.5, 9.3, 10.3, 10.4, 11.4, 11.5, 12.4.

As the table shows, in all cases, the clean energy investment project generates major gains in emissions reductions relative to both 2010 levels and BAU assumptions as of Year 20. Brazil is at 2.0 mt per capita emissions under the clean energy strategy. This is a 38 percent improvement over the BAU model, even while Brazil is devoting only 0.9 percent of GDP to the project. We assume that Brazil is also channeling major resources toward controlling other GHG emissions from non-energy sources. Germany is at 5.5 mt per capita emissions through our clean energy investment project. This is a 43 percent improvement relative to 2010 and a 29 percent improvement relative to Germany's 2030 BAU scenario. Indonesia is at 2.6 mt within 20 years under our investment project. This figure is 53 percent higher than Indonesia's actual 2010 level. But, critically, it is also 67 percent lower lower than Indonesia's BAU framework for 2030, and it is still only slightly higher than the 20-year target figure of 2.4 mt per capita of CO_2 emissions. This result for Indonesia underscores how Indonesia can proceed on a rapid GDP growth trajectory (our assumption being 5.0 percent for the 20-year period) without generating major increases in its per capita emissions. The Indonesian case thus suggests a workable approach for other low- and lower-middle income countries to follow, enabling them to grow rapidly while still keeping emissions levels within close range of, if not below, the 20-year 2.4 mt target. The situation is similar for South Africa, even while the South African economy is at a much higher per capita GDP level than Indonesia. Nevertheless, we show that South Africa can support a 4.0 percent GDP growth trajectory while still lowering its emissions within 20 years by nearly 50 percent relative to its 2030 BAU scenario. Similarly, with the ROK, we show that investing 1.5 percent of GDP per year over the 20-year investment cycle can lower the country's per capita CO_2 emissions by fully 56 percent relative to the 2030 BAU Scenario.

In conjunction with these major across-the-board gains in emissions reductions, we also see in Table 13.1 that clean energy investments will be a positive source of net job creation for all five countries. As we have discussed, these positive job effects are proportionally larger for South Africa, Indonesia, and, operating on a somewhat smaller scale project, Brazil. They are relatively modest in Germany and the ROK, because the levels of employment creation per dollar of expenditure are more similar to those in the fossil fuel sectors in these countries. Therefore, for Germany and the ROK, the job increases generated by clean energy investments will be more closely matched by the job losses produced by retrenchments in the oil, coal and natural gas sectors.

The most critical point of our report nevertheless remains valid for all five selected countries. In all five cases, our research finds that the clean energy investment project is capable of achieving dramatic reductions in CO_2 emissions while overall job opportunities are expanding and GDP growth proceeds along a healthy long-run growth trajectory.

Effective industrial policies, for all countries at all levels of development, will certainly be necessary to advance these emission reduction and employment expansion outcomes. In Chapter 5, we reviewed some of the main considerations with respect to advancing effective industrial policies. This begins with governments playing a leading role in adapting clean energy technology. As the UNIDO 2013 *Industrial Development Report* usefully summarized specifically with respect to uptakes of green technologies in manufacturing, "technological change rarely takes place in a vacuum, and often requires incentives. Success stories of new energy technologies are the product of forward-thinking ambitious government policies," (2013, p. 124). Governments will also need to play a leading role in delivering affordable and flexible financing arrangements for clean energy investments to be sustained on a large-scale basis.

Ambitious government policies will also be needed to effectively manage the unavoidable major retrenchments in the oil, coal and natural gas industries. As we review in Chapter 5, all owners of fossil fuel assets, including public sector entities as well as private oil, coal and natural gas corporations, will, by necessity, experience a major decline in the value of their holdings. Along with this, workers tied to the oil, coal, and natural gas industries will inevitably face job losses as a consequence. Economic policies are needed in all countries to assist these workers, as well as their families and communities, with transitional support into new areas of economic activity, where decent job opportunities are expanding. In most countries, the energy efficiency and clean renewable energy sectors will be among the most important new areas of expanding job opportunities.

Overall again, the overarching conclusions that emerge from this report are straightforward. We conclude that there is a clear path for the global economy to achieve the 20-year CO_2 emissions target from energy-based sources of 20,000 mmt, or, on a per capita basis, 2.4 mt of emissions. We show that the large-scale investments necessary to build a clean energy economy over the next 20 years will also promote expanded job opportunities, even while the fossil fuel sectors will be contracting. Further, pursuing these clean energy investments will not act as an obstacle to countries sustaining healthy long-term growth trajectories. In large measure, this is due to the fact that costs of generating energy from clean renewable sources are approaching parity with non-renewables. Equally important is that investments in energy efficiency are highly cost effective over time.

In short, this report has advanced a realistic framework for dramatically reducing CO_2 emissions and thereby taking major strides towards controlling climate change over the next 20 years. It is also a project that can expand job opportunities and does not depend on slowing down GDP growth in any country or regional setting. This, indeed, is what makes the project *realistic*. It is a unified framework for controlling climate change and improving living standards in all country and regional settings.

TECHNICAL APPENDICES

APPENDIX 1: CALCULATIONS AND CONVERSIONS FOR ESTIMATING THE EFFECTS ON FOSSIL FUEL PRICES OF A CARBON PRICE

We present here the calculations through which we estimate the impact on the prices of oil, coal and natural gas of a $75 per ton carbon price, operating in 2035. As described in the main text in Chapter 3, we work within a simple price mark-up framework. That is, we assume that the cost and price increases on fossil fuels from the carbon price policy follow proportionally from both the stipulated level of the given carbon price policy - in this case the $75 per ton carbon price - and the amount of CO_2 emissions generated by burning oil, coal, and natural gas to produce energy. Our figures on emissions are those that we present in Table 2.2, and show again in Table 3.8. These are expressed in terms of emissions per Q-BTU of energy: oil is approximately 69 mmt per Q-BTU, coal is at 100 mmt per Q-BTU, and natural gas is at 56 mmt per Q-BTU.

Calculations for Oil

1. Converting CO_2 emissions figures from millions of tons to tons.

- ◆ 1 Q-BTU of energy emits 69 mmt of CO_2, then:
  - 1 billion BTUs of energy emit 69 mt of CO_2. Therefore:
  - 1 ton of CO_2 is produced by ~14.5 M-BTUs of oil
    - » (i.e. 1 billion BTUs/69 mmt of Co_2)
  - The cost of the $75 per ton carbon price would therefore be $75 per 14.5 M-BTUs of oil

2. Converting oil units from BTUs to barrels of oil

- ◆ 1 barrel of oil = 5.6 M-BTUs of energy; therefore
- ◆ 2.6 barrels of oil = 14.5 M-BTUs of oil

3. Carbon price in barrels of oil

- ◆ If 2.6 barrels of oil = 14.5 M-BTUs of oil, it follows that 2.6 barrels of oil will generate 1 ton of CO_2 emissions; and that
- ◆ 1 barrel of oil will generate ~ 0.4 tons of emissions (i.e. = 1 ton CO_2/2.6 barrels of oil)
- ◆ If carbon price is $75 per ton, that means the price of barrel of oil will go up by about $30 per barrel of oil (i.e. $75 * .4 = $30).

4. Scaling carbon price increase for oil

- The EIA reference case for the price of oil in 2035 is ~ $140 per barrel.
- Thus, the impact of a cost mark-up through the carbon price would be a price increase of 21.4 percent (= $30/$140).

Calculations for Coal

1. Converting CO2 emissions figures from millions of tons to tons.

- 100 mmt of CO_2 emissions are generated per 1 Q-BTU of coal-fired energy; therefore:
  - 1 billion BTUs of energy emit 100 mt of CO_2; therefore
  - 1 ton of CO_2 is produced along with 10 M-BTUs of coal-fired energy; and
  - 0.1 tons of CO_2 are produced by 1 M-BTUs of coal-fired energy.

2. Carbon price per 1 M-BTUs of coal energy

- 1 M-BTUs of coal-fired energy will carry a carbon price of $7.50 (i.e. $75 per ton/0.1 tons).

- The EIA's reference price for coal in 2035 is ~ $3.00 per 1 M-BTUs.
  - The market price of coal would therefore rise from $3.00 to $10.50 per 1 M-BTUs.
  - This means the carbon price would raise the overall price of coal in 2035 by 250 percent - an increase of $7.50, from $3.00 to $10.50.

Calculations for Natural Gas

1. Converting CO2 emissions figures from millions of tons to tons.

- 56 mmt of CO_2 are generated per 1 Q-BTU of natural gas-fired energy; therefore:
  - 1 billion BTUs of energy emit 56 mt of CO_2; and
  - 1 ton of CO_2 is produced with 18 M-BTUs of natural gas-fired energy; and
  - 0.06 tons of CO_2 are produced by 1 M-BTUs of natural gas-fired energy

2.Carbon Price per 1 M-BTUs of natural gas energy

- 1 million BTUs of natural gas-fired energy will bear a carbon price of $4.50 (i.e. $75 per ton/0.06 tons).
  - The EIA's reference price for natural gas in 2035 is ~ $7.00 per 1 M-BTUs.
  - The market price of natural gas would therefore rise from $7.00 to $11.50 per 1 M-BTUs.
  - The carbon price would therefore raise the overall price of natural gas in 2035 by 64.3 percent - an increase of $4.50, from $7.00 to $11.50.

APPENDIX 2: ESTIMATING DOMESTIC CONTENT OF CLEAN ENERGY INVESTMENTS

Domestic content is defined as the proportion of a good or service that is produced in domestically as opposed to being imported. For each country in our report, we use country-specific data on imports and domestic production from the I-O tables in order to calculate domestic content in each industry. For the constructed renewable energy sectors, as defined in Appendix 3, we calculate weighted average domestic content figures for each energy category.

The domestic content percentage of each industry (DC_i) is calculated as

$$\mathrm{DC_i} = \frac{Domestic\ Production_i}{Domestic\ Production_i + Imports_i}$$

The weighted domestic content for each energy category is the sum of the domestic content of each component industrial sector multiplied by the weight of that industry in the category (see Appendix 3 for weights and industries):

$\mathrm{DC_c} = \sum_{i=1}^{n}(DC_i * w_i)$ where w_i is the weight of industry *i* within category *c*.

The domestic content of each energy category will be affected both by what the industry composition is, and what the domestic content is in each industry. For example, weatherization has a very high domestic content since it is comprised of the construction industry, which tends to have domestic content close to 100 percent. Categories with more manufactured goods, such as solar and wind, will generally have lower domestic content, since a larger share of manufactured goods are imported.

It is important to note here that since we calculate employment based on the I-O model, and we proxy clean energy industries using the industrial sectors as defined in the I-O tables, it is quite possible that the actual domestic content values for industries such as wind or solar could differ from those presented in this report. The results presented in this report show what the domestic content *could be* if these proxy industries were producing clean energy goods, given the relationships captured by the I-O model.

Two Cases of Domestic Content: Baseline and Reduced Domestic Content

We present two different scenarios – one in which the domestic content of all industries remains the same even as production scales up. This we consider the “aggressive industrial policy scenario” since it implies that all industries will scale up production as more investments are made in clean energy, and one in which domestic content in “tradable” industries is reduced by 20 percent. This we call the more conservative scenario, since it implies that not all industries will be able to scale up production and that some increase in imports will be necessary in order to meet increased demands for clean energy.

We identify all industries in the I-O models of each country as either “non-tradable” or “tradable.” Non-tradable industries are those that have a domestic content of 90 percent or above. The country is nearly or completely self-sufficient in meeting demands for the goods or services of these industries, and they are often location-specific industries such as construction or education. Industries with less than 90 percent domestic content are considered “tradable” since there is already more than 10 percent of imported good or services in these industries.

We generate weighted-average domestic content and employment estimates for both the original domestic content and the reduced domestic content scenarios. In the reduced scenario, we reduce the domestic content of “tradable” industries by 20 percent from their current level. Thus, an industry that is currently meeting its demands with 85 percent domestic production and 15 percent imports, we reduce the domestic content from 85 percent to 68 percent. This enables us to calculate domestic content and employment in a scenario in which industries are not able to adequately scale up to meet increased demands. For calculating weighted average domestic content in this “reduced” scenario, the procedure is the same as above. In order to calculate employment, we reduce employment levels by 20 percent in each of the “tradable” industries contained throughout the supply chain of each energy category and then recalculate our employment multipliers as described in Appendix 3.

APPENDIX 3: METHODOLOGY AND DATA SOURCES FOR AGGREGATE EMPLOYMENT ESTIMATES

Input-Output Methodology

The employment impacts of investments in renewable energy or energy efficiency are estimated using an I-O model. I-O tables are national accounting systems that show linkages between industries and are used to analyze how changes in final demand affects industrial output and employment. I-O models are constructed from country-specific data, including firm-level information. I-O models have been widely used to estimate employment since they were first developed by Wassily Leontief in the 1930s, and have recently been used by economists to study the impacts of clean energy investments.[75]

Miller and Blair (2009) note that the two main assumptions in I-O tables are those of fixed technical coefficients and fixed input proportions. Fixed technical coefficients means that the inter-industry flows from industry *i* to industry *j* depend entirely on the output of industry *j*. In other words, if the output of industry *j* doubles, its input from industry *i* will also double i.e. the models assume that the production technology exhibits constant returns to scale. Fixed proportions implies that industry *j* will use the same mix of inputs from all industries even as demand increases for industry *j*'s output – the basic I-O model does not allow input substitution.

Given these assumptions, I-O tables are best suited to studying the current state of the economy and making short-term projections. We should therefore exercise caution when using I-O models to conduct long-range forecasts. The assumption of constant returns to scale is relevant only for relatively small changes in levels of output. If an industry increases output by, say, 5 or 10 percent, we might be able to assume constant returns to scale. But a doubling of the size of the industry, such as we might expect to occur with renewable energy, may lead to changes in the returns to scale. Furthermore, because I-O data is captured at a point in time (such as through an annual census), the resulting I-O tables themselves are static. Thus, we must be aware of not only homogeneity and proportionality, but also of fixed prices. If, over time, input prices change, then we would expect industries to substitute cheaper inputs for the more expensive inputs.

The limitations of the I-O model lie in these three assumptions (homogeneity, proportionality, and fixed prices), which are made to simplify the analysis. Its strength, however, lies in the transparency of the model and the relatively limited number of assumptions in comparison to more complex general equilibrium models that typically rely on a far greater number of assumptions.[76] Richardson (1972) says that part of the appeal of the I-O model is that it is

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[75] For a detailed discussion of the I-O method, including data collection and the mathematical underpinnings, see the Horowitz and Planting (2009).

[76] For example, typical assumptions in CGE include profit-maximization, perfect competition, market-clearing conditions, production at full capacity, and full employment.

"value-free" and "neutral" and thus is useful for economic impact studies in a wide variety of settings – from capitalist to planned economies.

I-O tables can essentially be used in one of three ways: To determine the current state of economic interactions (static); to change assumptions regarding production functions or prices, or to change final demand (comparative static); or to incorporate technological change or permit expansion of the economy by introducing capital accumulation into the framework (dynamic). In this report, we use the I-O model for comparative static analysis. Namely, we will study the employment effects of an increase in final demand for renewable energy and energy efficiency.

The industrial categories in the economic censuses and I-O tables of the featured countries in this report currently do not explicitly identify 'Renewable Energy' or 'Energy Efficiency' industries. While traditional energy industries such as oil/gas extraction, coal mining, support services for these extraction activities, power generation and distribution, and various petroleum- or coal-based manufacturing activities are identified within the accounts, renewable energy sectors such as wind, solar, biomass, geothermal, and so on, are not defined as distinct sectors. Similarly, energy efficiency industries such as building weatherization, industrial energy efficiency, and so on are not included as distinct sectors. Nonetheless, the component activities of these industries are captured within the explicitly defined industrial sectors that comprise the I-O model.

For example, the manufacture of hardware and electrical equipment used for solar panels are categorized respectively in the hardware and electrical equipment industries. If we can thus identify the various components and their weights that make up the REEE industry, we can study the impact of increased demand for REEE products and services. The methodology for this strategy is presented in Miller and Blair (2009). PERI economists have employed this methodology in a variety of studies[77] and in consulting work for the U.S. Department of Energy. The estimates produced by PERI have been corroborated through survey work as well as through data collected by the U.S. Department of Energy as part of the energy provisions of the American Recovery and Reinvestment Act of 2009.

In this report, we construct employment requirements tables for each of the five featured countries using their national I-O tables and industry-specific employment/output (E/O) ratios. Multiplying the Leontief Inverse Coefficient Matrix by the industry-specific E/O ratios yields the employment requirements table, from which the number of jobs (both direct plus indirect) associated with a given amount of expenditure on the final demand for the products or services of a given industry or set of industries.

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[77] See, for example, (Pollin, Heintz and Garrett-Peltier, 2009)

Incorporating Variable Coefficients and Labor Productivity into Employment Estimates

Estimates of output multipliers. The data used to estimate the change in output multipliers over time were taken from the World Input-Output Database (WIOD), a project of the European Commission. The WIOD produces annual I-O tables for select countries. I-O tables exist for four out of the five countries in this report: Brazil, Germany, Indonesia, and the ROK. The WIOD tables are more aggregated than the ones used to produce the employment estimates presented in this report. The sectors in the WIOD are standardized across countries. There are 34 industrial sectors in the I-O tables for Brazil, Germany, and the ROK and 33 sectors for Indonesia. The missing sector in the Indonesian tables is "sale, maintenance, and repair of motor vehicles and motorcycles". This industrial category does not feature in the estimates of output multipliers for the various energy sectors considered in the report and its absence should not affect the results.

Output multipliers are calculated from the Leontief inverse for each of the four countries. The Leontief inverse matrix is given by $L=(I-A)^{-1}$ in which L is the Leontief inverse matrix, I is the identify matrix, and A is the matrix of I-O coefficients derived from the WIOD tables. The energy sectors analyzed in this report are synthetic sectors – in that they represent weighted averages of the sectors that actually appear in the I-O tables. The weights for determining the output multipliers of these sectors correspond to the weights used in the employment estimates presented in the report. Since the WIOD tables are more aggregated than the I-O tables used in the primary analytics of this report, the weights had to be adjusted to match the 34 (or, in the case of Indonesia, the 33) sectors of the WIOD tables.

Estimates of labor productivity growth rates. The data used to calculate labor productivity growth rates were taken from the World Bank's World Development indicators. Labor productivity was defined as value-added per worker and as estimated for three broad sectors: agriculture, industry, and services. Total employment in these broad sectors was estimated from the size of the working age population, the employment to working age population ratio, and the share of total employment in agriculture, industry, and services. Total value added was expressed in constant local currency units – i.e. labor productivity was measured in real terms. Note that the data used to calculate labor productivity was only available for South Africa beginning in 2000.

Annual growth rates in labor productivity were estimated by calculating the percent change in labor productivity over the relevant time period and then converting these total percent changes into annualized values. The change in labor productivity for each of the energy sectors was then calculated as a weighted average of the change in labor productivity in agriculture, industry, and services. The weights correspond to the weights used elsewhere in the report.

Modeling Clean Energy

The national I-O accounts in this report do not explicitly identify clean energy industries as such. We therefore created "synthetic" industries that are proxies for various renewable energy (RE) and energy efficiency (EE) industries. Based on past modeling experience by PERI as well as various publications on the components and costs of renewable energy and energy efficiency installations[78], we construct renewable energy and energy efficiency categories that are similar across countries but based on the specifics of each country's I-O tables. The weighting scheme for each country is presented in Table A3.1.

Table A3.1: Industries and weights for renewable energy, energy efficiency and fossil fuels in the I-O models

Brazil

Category	I-O industry	Weight
Bioenergy	Agriculture, forestry, logging	50%
	Construction	25%
	Petroleum refining and coking	12.5%
	Other services	12.5%
Solar	Construction	30%
	Manufacture of steel and steel products	5%
	Machinery and equipment, including maintenance and repairs	6%
	Machinery, equipment and material	7%
	Electronic material and communication equipment	35%
	Information services	18%
Wind	Appliances	4%
	Electronic material and communication equipment	14%
	Machinery and equipment, including maintenance and repairs	11%
	Manufacture of steel and steel products	14%
	Transport, storage and mail (belong to the service sector, for example, transport here could mean using transportation to deliver goods, etc.)	14%
	Construction	22%
	Cement	15%
	Information services	8%
Geothermal	Information services	30%
	Oil and natural gas (drilling)	15%
	Construction	45%
	Machinery, equipment and material	10%

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[78] See, for example, IRENA (2012) and various other studies in the "Renewable Energy Cost Analysis" studiesseries produced in 2012 by Agency IRENA.

Hydro	Information services	43%
	Cement	18%
	Construction	18%
	Machinery and equipment, including maintenance and repairs	7%
	Appliances	14%
Weatherization	Construction	100%
Grid upgrades	Construction	25%
	Machinery and equipment, including maintenance and repairs	25%
	Electronic material and communication equipment	50%
Industrial energy efficiency	Machinery and equipment, including maintenance and repairs	50%
	Information services (includes R&D)	30%
	Construction	20%
Coal	Other mining	50%
	Petroleum refining and coking	50%
Oil/gas	Oil and natural gas	70%
	Transportation	30%
“Renewable energy”	Bioenergy, hydro, wind, solar, geothermal	20% each
“Energy efficiency”	Weatherization	50%
	Industrial energy efficiency	25%
	Grid upgrades	25%
“Fossil fuels”	Coal, oil/gas	50% each

Germany

Category	**I-O industry**	**Weight**
Bioenergy	Products of agriculture, hunting	25%
	Forestry and DL	25%
	Bauinstallations and other construction work	25%
	Coke, refined petroleum products and nuclear materials	13%
	Research and development services	13%
Solar	Prep site work, civil engineering work	30%
	Foundry products	18%
	Electrical machinery and apparatus, nec-	18%
	Nachrtechn, Rundf. -. Televisions and electron. Components	18%
	Research and development services	18%

Wind	Prep site work, civil engineering work	26%
	Plastic products	12%
	Foundry products	12%
	Machinery	37%
	Electrical machinery and apparatus, nec-	3%
	Nachrtechn, Rundf. -. Televisions and electron. Components	3%
	Research and development services	7%
Geothermal	Research and development services	30%
	Oil, gas, DL for petroleum, natural gas extraction (Drilling)	15%
	Bauinstallations and other construction work	45%
	Machinery	10%
Hydro	Research and development services	43%
	Pig iron, steel, pipes and products thereof	18%
	Prep site work, civil engineering work	18%
	Machinery	7%
	Electrical machinery and 3apparatus, nec-	14%
Weatherization	Prep site work, civil engineering work	50%
	Bauinstallations and other construction work	50%
Industrial energy efficiency	Machinery	20%
	Electrical machinery and apparatus, nec-	30%
	Bauinstallations and other construction work	20%
	Research and Development Services	30%
Grid upgrades	Prep site work, civil engineering work	25%
	Machinery	25%
	Electrical machinery and apparatus, nec-	25%
	Nachrtechn, Rundf. -. Televisions and electron. Components	25%
Coal	Mining and quarrying Other mining and quarrying products	50%
	Coal and peat	50%
Oil/gas	Oil, gas, DL for petroleum, natural gas extraction	50%
	Coke, refined petroleum products and nuclear materials	20%
	Otherwise. Landv.leistungen, transportation via pipelines	30%
“Renewable energy”	Bioenergy, hydro, wind, solar, geothermal	20% each
“Energy efficiency”	Weatherization	50%
	Industrial energy efficiency	25%
	Grid upgrades	25%
“Fossil fuels”	Coal, oil/gas	50% each

Indonesia

Category	I-O industry	Weight
Bioenergy	Rice	12.5%
	Maize	12.5%
	Wood	25%
	Refining	12.5%
	Construction	25%
	Other services	12.5%
Solar	Construction	30%
	Manufacture of fabricated metal products	17.5%
	Manufacture of machine, electrical machinery and apparatus	35%
	Other services	17.5%
Wind	Manufacture of rubber and plastic wares	12%
	Manufacture of fabricated metal products	12%
	Manufacture of machine, electrical machinery and apparatus	43%
	Construction	26%
	Other services	7%
Geothermal	Crude oil, natural gas and geothermal mining (drilling)	15%
	Manufacture of machine, electrical machinery and apparatus	10%
	Construction	45%
	Other services	30%
Hydro	Manufacture of non metallic mineral products	18.2%
	Manufacture of machine, electrical machinery and apparatus	21%
	Construction	18.20%
	Other services	42.90%
Weatherization	Construction	100%
Industrial energy efficiency	Manufacture of machine, electrical machinery and apparatus	50%
	Other services	30%
	Construction	20%
Grid Upgrades	Construction	25%
	Manufacture of machine, electrical machinery and apparatus	75%
Coal	Coal and metal ore mining	50%
	Manufacture of chemicals	50%
Oil/gas	Crude oil	50%
	Petroleum refinery products	50%
“Renewable energy”	Bioenergy, hydro, wind, solar, geothermal	20% each

"Energy efficiency"	Weatherization	50%
	Industrial energy efficiency	25%
	Grid upgrades	25%
"Fossil fuels"	Coal, oil/gas	50% each

South Africa

Category	**I-O industry**	**Weight**
Bioenergy	Agriculture (Including live animals)	25%
	Forestry	25%
	Construction	12.5%
	Construction services	12.5%
	Petroleum products	12.5%
	Research and development	12.5%
Solar	Electrical machinery	48%
	Glass products	5%
	Non-ferrous metals	5%
	Structural metal products	7%
	Engines, turbines	4%
	Construction	16%
	Research and development	15%
Wind	Construction	13%
	Construction services	13%
	Plastic products	12%
	Other fabricated metal	12%
	General machinery	37%
	Lifting equipment	3%
	Electrical machinery	3%
	Research and development	7%
Geothermal	Research and development	30%
	Petroleum products (Drilling)	15%
	Construction	45%
	Pumps, compressors	10%

Hydro	Research and development	42.9%
	Plaster, cement	18.2%
	Construction	18.2%
	Engines, turbines	7%
	Electrical machinery	14%
Weatherization	Construction	50%
	Construction services	50%
Industrial energy efficiency	Special machinery	30%
	General machinery	10%
	Engines, turbines	10%
	Research and development	30%
	Construction	10%
	Construction services	10%
Grid upgrades	Construction	12.5%
	Construction services	12.5%
	General machinery	25%
	Electrical machinery	37.5%
	Electricity and Gas	12.5%
Coal	Coal and lignite	50%
	Petroleum products	50%
Oil/gas	Other minerals	50%
	Petroleum products	10%
	Coal and lignite	10%
	Transport	30%
“Renewable energy”	Bioenergy, hydro, wind, solar, geothermal	20% each
“Energy efficiency”	Weatherization	50%
	Industrial energy efficiency	25%
	Grid upgrades	25%
“Fossil fuels”	Coal, oil/gas	50% each

Republic of Korea

Category	**I-O industry**	**Weight**
Bioenergy	Cropping	25%
	Forestry	25%
	Building construction and repair	25%
	Refined petroleum	12.5%
	Research and development	12.5%
Solar	Electrical equipment, and supplies	44%
	Glass products	5%
	Nonferrous metal ingots and primary nonferrous metal products	5%
	Fabricated metal products except machinery and funiture	8%
	Electrical equipment, and supplies	7%
	Building construction and repair	16%
	Research and development	15%
Wind	Building construction and repair	26%
	Plastic products	12%
	Fabricated metal products except machinery and funiture	12%
	Machinery and equipment of general purpose	37%
	Other transportation equipment	3%
	Electronic components and accessories	3%
	Research and development	7%
Geothermal	Research and development	30%
	Mining of coal, crude petroleum and natural gas (drilling)	15%
	Building construction and repair	45%
	Machinery and equipment of general purpose	10%
Hydro	Research and development	42.9%
	Cement and concrete products	18.2%
	Civil engineering construction	18.2%
	Machinery and equipment of general purpose	6.9%
	Electrical equipment, and supplies	14%
Weatherization	Construction	100%
Industrial energy efficiency	Machinery and equipment of general purpose	10%
	Machinery and equipment of special purpose	30%
	Electrical equipment, and supplies	10%
	Building construction and repair	20%
	Research and development	30%

Grid upgrades	Building construction and repair	25%
	Machinery and equipment of general purpose	25%
	Electronic components and accessories	25%
	Household electrical appliances	12.5%
	Electrical equipment, and supplies	12.5%
Coal	Coal mining + support activity	52%
	Coke and hard-coal	48%
Oil/Gas	Mining of coal, crude petroleum and natural gas	50%
	Refined petroleum products	20%
	Gas and water supply	30%
“Renewable energy”	Bioenergy, hydro, wind, solar, geothermal	20% each
“Energy efficiency”	Weatherization	50%
	Industrial energy efficiency	25%
	Grid upgrades	25%
“Fossil fuels”	Coal, oil/gas	50% each

Source: Authors’ own estimates.

Data Sources

Brazil

We obtain the 55-sector level I-O Leontief Inverse Coefficient Matrix for year 2005 from the National Statistic Office of Brazil, the IBGE (Instituto Brasilerio de Geografia e Estatistica). These I-O tables are the most updated and most detailed available as of 2013.[79] We use the 2005 PNAD (Pesquisa Nacional por Amostra de Domicílios) household survey data and adjust the results by the relevant population weights to estimate national-level employment by sectors.[80]

Germany

The German I-O data are extracted from the database of the Federal Statistical Office of Germany.[81] There are 71 sectors in the model, with 2007 as the latest available information at such a detailed level. The labor force data used to construct the E/O ratios is extracted from the 2007 Microcensus data for Germany.[82] Adjustments are made, as described above, to match the industrial sectors in the survey data with those of the I-O model.

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[79] IBGE (2013).

[80] IBGE (2005).

[81] Federal Statistical Office (2011).

[82] Federal Statistical Office (2014).

Indonesia

The Indonesian I-O tables are based on 2008 data and include 66 industrial sectors. Employment estimates for Indonesia are derived from the 2008 National Labor Force Survey. Both the I-O tables and the labor force survey data are from Statistics Indonesia (Badan Pusat Statistik).[83]

The Republic of Korea

The I-O table for the ROK case comes from the Bank of Korea.[84] The I-O model used is based on 2008 data and contains 77 industrial sectors. Employment estimates are based on 2008 data from the Household Survey on Employment Established by Region. This data set was chosen to provide employment estimates that would correspond to the industrial sectors in the I-O model for the same year and which would allow us to generate disaggregated employment estimates on the basis of such categories as sex of the employed and employment status.

South Africa

The I-O table we used for the calculations in this report is derived from supply- and use- tables developed by Statistics South Africa (as detailed in the 2010 publication, *Final Supply and Use Table, 2005*).[85] The I-O matrix based on the supply- and use- tables is comprised of 95 distinct sectors. Data from the 2005 South Africa Labor Force Survey (September) were used to produce the employment estimates.[86]

General discussion of differences in employment multipliers

The employment impacts of energy investments are largely determined by the labor intensity of the production process. The labor intensity of an industry can be measured by the employment/output ratio, which is the number of workers per $1 million of output (in this report we have converted the output of each country in its local currency to output per $1 million). Industries such as agriculture and education tend to have high E/O ratios while those such as manufacturing have lower ratios. The employment multipliers derived through the I-O model are not, however, just the E/O ratio of a given industry, but rather are the result of the E/O ratios of all the industries in a supply chain. Thus the employment multiplier for wind power, for example, is a function of the labor intensities of steel, hardware, construction, and all the industries directly and indirectly involved in wind power production.

Across the countries in this report, we note the trend that the bioenergy industry tends to have high employment multipliers (due mainly to the agricultural component) while renewable energy industries with manufactured components tend to have lower employment multipliers. Each country will have its unique set of employment multipliers. This is due both to the fact that production processes differ across countries (so for example manufacturing metal products is more labor intensive in Brazil than in Germany), and also that the size and presence of various industries differ across countries.

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[83] Statistics Indonesia (2013) for I-O tables and (2008) for labor force survey.

[84] Bank of Korea (2010).

[85] Statistics South Africa (2010).

[86] Statistics South Africa (2006).

APPENDIX 4: EMPLOYMENT DECOMPOSITIONS BASED ON LABOR FORCE SURVEY DATA

Data and Methodology for Employment Decompositions

Aggregate employment numbers were disaggregated into specific subcategories using data from household and labor force surveys. The surveys used for each of the five countries are listed in Table A4.1. In each case, the survey year was chosen to match the year of the I-O model used in the employment analysis. The subcategories of employment included employment by sex, employment status (self-employment and wage employment), employment by educational attainment, and employment by enterprise size (micro and non-micro enterprises).

Table A4.1: Data sources for employment decomposition estimates

Country	Survey
Brazil	Pesquisa National por Amostra dos Domicílios (National Household Survey), 2005
Germany	Microcensus, 2007
ROK	Household Survey on Employment Established by Region, 2008
Indonesia	National Labor Force Survey, 2008
South Africa	Labour Force Survey, September 2005

The industrial sectors used to classify employment in the labor force and household surveys do not always correspond to the industrial categories of the corresponding I-O models. Therefore, the first step in the analysis is to map the industrial categories in each of the surveys to the relevant I-O model. Once this is done, aggregate employment estimates for each of the I-O industrial sectors are generated using the labor force or household survey data and the relevant population weights to produce national-level estimates. In each case, the employment estimates are based on the working age population only (i.e. estimates of child labor and those individuals below the bottom age threshold of the working age population are not included).

The aggregate population numbers are disaggregated into the relevant subcategories using the relevant variables contained in the household surveys. These subcategories are expressed as percentages of the total employment numbers. The definitions of each of the subcategories are as follows:

Employment by Sex – total employment of men and women in each of the I-O model's industrial sectors is estimated.

Employment Status – total wage employment and total self-employment in each of the I-O model's industrial sectors is estimated. Wage employment consists of all paid employees.

Self-employment consists of own-account workers, employers, and unpaid contributing family workers. In the case of Indonesia, employment in more detailed categories is estimated: wage employment, unpaid contributing family workers, employers with regular paid workers, employers with nonregular/unpaid workers, and own-account workers.

Enterprise Size - Enterprise size estimates are available for Brazil, Germany, and South Africa. Micro-enterprises are defined as those with fewer than 5 paid employees (South Africa and Germany) or 5 or fewer paid employees (Brazil).

Educational Attainment – Educational attainment is measured as a highest level of education completed, based on each country's own education system. For Brazil, the ROK, Indonesia, and South Africa, educational attainment is classified as "less than primary", "primary", "secondary", and "tertiary" (i.e. post-secondary). For Germany, categories based on official ISCED (International Standard Classification of Education, version of 1997) are used.[87]

Within the ISCED, education is broken down into seven educational levels:

Level 0: Pre-primary education: nursery school

Level 1: Primary education: primary school

Level 2: Lower secondary education, including secondary general school, intermediate school, grammar school, vocational extension school and pre-vocational training year.

Level 3: Upper secondary education, including vocational training.

Level 4: Post-secondary non-tertiary education.

Level 5: Undergraduate/masters level tertiary education

Level 6: Advanced tertiary education: doctor's degree and post-doctoral lecturing qualifications

The educational attainment estimates for Germany use the following three categories:

Low educational attainment: ISCED levels 0, 1 and 2

Medium educational attainment: ISCED levels 3 and 4

High educational attainment: ISCED levels 5 and 6

Once the estimates for each of the subcategories are developed, the proportions that each category represents of total employment are used to disaggregate the I-O employment estimates into the relevant labor market categories. This is done at the level of each of the I-O industrial sectors. For instance, the proportion of men and women employed is determined for each of the individual industrial sectors in the I-O model. This allows an I-O analysis to be performed

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[87] ISCED tables produced by UNESCO (n.d.).

for each of the employment subcategories. In effect, this involves calculating employment to output ratios for the I-O sectors in which employment refers to a specific subcategory. The employment estimates for the composite sectors used in the energy analysis (e.g. wind or biofuels) in this report are simply the weighted sum of the employment effects of each of the component industrial sectors – disaggregated by the relevant subcategory of employment (e.g. employment status, enterprise size, sex, and educational attainment).

Comparing Energy-related Employment Characteristics to National Averages

The five countries in this report differ in terms of the average earnings from employment. Table A4.2 shows average monthly earnings (2012) for the five countries in local currency units. Earnings were converted into U.S. dollar equivalents using market exchange rates and a purchasing power parity (PPP) conversion factor. The dollar earnings calculated using market exchange rates are useful for comparing labor costs internationally (e.g. to compare levels of competitiveness). Earnings adjusted for PPP are better for comparing average living standards. The PPP adjustment is meant to show how much a given level of earnings can purchase if prices were equivalent to those in the U.S. economy. Since domestic prices of goods and services are often lower than their equivalent in the U.S., PPP-adjusted earnings tend to be higher than dollar earnings calculated using market exchange rates.

Table A4.2: Average monthly earnings in local currency units, 2012

Country	Local currency	Dollars (market exchange rate)	PPP dollars
Brazil	1,342.7	687.0	882.0
Germany	3,749.0	4,952.0	4,964.0
Indonesia	1,580,882.0	168.0	427.0
ROK	2,566,585.0	2,278.0	3,027.0
South Africa	6,744.0	821.0	1,363.0

Sources: ILOStat: “Mean Nominal Monthly Earnings of Employees,” (Accessed July 2014); The World Bank: World Development Indicators “PPP conversion factor, GDP (LCU per international $),” (Accessed July 2014).

To get a sense of the relative earnings of jobs in different sectors within a country, we identified the industrial sectors that would experience the largest employment gains for a given level of spending on clean energy technologies and spending on nuclear, coal, natural gas, and petroleum. The average characteristics of workers, jobs, and firms were then determined – wage versus self-employment, micro-enterprises versus larger enterprises, and the level of educational attainment. Each of the industrial sectors was then compared to the national average to determine whether the sector had above- or below-average educational attainment, self-employment, or share of microenterprises. We expect wages to be lower in micro-enterprises, in many forms of self-employment, and for workers with lower educational attainment. Wages increase with educational attainment, size of the firm, and, often, with the prevalence of wage employment. Given these broad trends, we can estimate whether we would expect wages to be lower than average, average, or higher than average in each of the sectors associated with the largest employment effects. This analysis is summarized in Table A4.3.

Table A4.3: Comparison of energy-related employment characteristics to national averages

Brazil

	Self-employment	**Microenterprise**	**Education**	**Estimated earnings**
Clean energy investments				
Agriculture & forestry	Above average	Above average	Below average	Lower
Construction	Above average	Above average	Below average	Lower
Machinery	Below average	Below average	Above average	Higher
Metal products	Below average	Below average	Above average	Higher
Cement	Below average	Below average	Below average	Average
Non-metallic mineral products	Below average	Below average	Below average	Average
Trade	Above average	Above average	Above average	Lower-Average
Transport services	Below average	Average	Average	Average
Business/prof services	Below average	Below average	Above average	Higher
Nuclear, coal, petroleum, and natural gas				
Mining	Below average	Average	Below average	Lower-Average
Utilities	Below average	Below average	Above average	Higher
Transport services	Below average	Average	Average	Average
Trade	Above average	Above average	Above average	Lower-Average
Business/prof services	Below average	Below average	Above average	Higher

Germany

	Self-Employment	**Microenterprise**	**Education**	**Estimated Earnings**
Clean energy investments				
Agriculture & forestry	Above average	Above average	Below average	Lower
Construction	Above average	Above average	Below average	Lower
Machinery	Below average	Below average	Average	Average-Higher
Metal products	Below average	Below average	Below average	Lower-Average
Non-metallic mineral products	Below average	Below average	Below average	Lower-Average
Electrical machinery	Below average	Below average	Average	Average-Higher
Research and development	Below average	Below average	Above average	Higher
Business services	Above average	Above average	Above average	Average-Higher
Nuclear, coal, petroleum, and natural gas				
Coal mining	Below average	Below average	Average	Average-Higher
Utilities	Below average	Below average	Above average	Higher
Auxiliary transportation	Below average	Below average	Average	Average-Higher
Business services	Above average	Above average	Above average	Average-Higher

Indonesia

	Self-employment	**Microenterprise**	**Education**	**Estimated earnings**
Clean energy investments				
Paddy	Above average	n.a.	Below average	Lower
Maize	Above average	n.a.	Below average	Lower
Other agriculture	Above average	n.a.	Below average	Lower
Wood	Average	n.a.	Below average	Lower
Construction	Below average	n.a.	Average	Average
Other mining	Above average	n.a.	Below average	Lower
Rubber	Above average	n.a.	Below average	Lower
Machinery	Below average	n.a.	Above average	Higher
Non-metallic mineral products	Below average	n.a.	Below average	Lower
Road transportation	Below average	n.a.	Average	Average
Trade	Average	n.a.	Above average	Ave-higher
Nuclear, coal, petroleum, and natural gas				
Coal and metal ore mining	Below average	NA	Above average	Higher
Crude oil and natural gas extraction	Below average	NA	Above average	Higher
Utilities	Below average	NA	Above average	Higher
Chemical products	Below average	NA	Above average	Higher
Road transportation	Below average	NA	Average	Average
Auxiliary transportation	Below average	NA	Average	Average

Republic of Korea

	Self-Employment	**Microenterprise**	**Education**	**Estimated Earnings**
Clean energy investments				
Crops	Above average	NA	Below average	Lower
Forestry	Above average	NA	Below average	Lower
Construction	Below average	NA	Average	Average
Mining (energy)	Below average	NA	Average	Average
Machinery	Below average	NA	Above average	Higher
Metal products	Below average	NA	Average	Average
Electrical equipment	Below average	NA	Above average	Higher
Wholesale trade	Above average	NA	Average	Average
Research and development	Below average	NA	Above average	Higher

Business services	Below average	NA	Above average	Higher
Nuclear, coal, petroleum, and natural gas				
Mining (energy)	Below average	NA	Average	Average
Electric utilities	Below average	NA	Above average	Higher
Gas & water	Below average	NA	Above average	Higher
Wholesale trade	Above average	NA	Average	Average
Land transport	Above average	NA	Average	Average
Other business services	Below average	NA	Below average	Lower

South Africa

	Self-employment	**Microenterprise**	**Education**	**Estimated earnings**
Clean energy investments				
Agriculture	Above average	Above average	Below average	Lower
Forestry	Below average	Below average	Below average	Lower-Average
Construction	Below average	Below average	Below average	Lower-Average
Cement	Below average	Below average	Below average	Lower-Average
Structural metal products	Below average	Below average	Average	Average
General machinery	Below average	Below average	Above average	Higher
Specialized machinery	Below average	Below average	Above average	Higher
Electrical equipment	Below average	Below average	Above average	Higher
Trade	Above average	Above average	Average	Lower-Average
Other business services	Below average	Below average	Average	Average
Nuclear, coal, petroleum, and natural gas				
Coal mining	Below average	Below average	Average	Average
Other mining	Below average	Below average	Below average	Lower-Average
Petroleum manufacturing	Below average	Below average	Above average	Higher
Electricity and gas	Below average	Below average	Above average	Higher
Construction	Below average	Below average	Below average	Lower-Average
Other business services	Below average	Below average	Average	Average

Source: See Tables A4.1 and A4.2.

In general, the employment associated with clean energy investments spans a wider range of jobs than that associated with nuclear, coal, natural gas, and petroleum. The clean energy jobs include relatively low earnings/low credential employment (e.g. in agriculture), average jobs (e.g. trade), and higher-end jobs (machinery manufacturing). In contrast, the jobs associated with fossil fuel energy sectors tend to be somewhat higher in earnings and credentials, but there is a smaller range of jobs created by spending in these areas. Countries differ somewhat in these patterns, as can be seen in Table A4.3.

APPENDIX 5:
SCALED EMPLOYMENT EFFECTS

Tables A5.1-A5.7 present our employment estimates for Brazil, Germany, Indonesia, South Africa, and the ROK scaled according to two sets of calculations. Our first set of calculations is our estimates of jobs created per $1 million - the figures on which we focus in our Chapter 6 methodology discussions as well as the actual figures we report in Chapter 7. We then adjust these jobs per $1 million figures through scalars based on each country's average domestic wage level relative to U.S. average wage levels.

More specifically, in the estimates presented in the main text of this report, the job creation effects are measured on the basis of number of jobs per $1 million of in spending in the various energy-sector activities. This allows for comparison between industries within a country, but makes it difficult to draw comparisons across countries. In order to make some cross-country comparisons, we scale the results of each country.

The most straightforward way to scale the results for each country based on their own domestic wage levels would be to use average wages in each country and index them to one country (in this case, we index to the U.S. = 1). However, we were unable to find adequate data on average wages for all five countries in our report. We therefore created a scalar that is an average of three types of data:

1. Total compensation/All employed persons in labor force. For this, we use World Bank World Development Indicator data on total compensation in the economy, as well as the unemployment rate and the size of the labor force (to calculate total number employed). This produces the index in column 1 of Table 1.

2. Average wages in manufacturing. For this, we use the BLS International Labor Statistics "Average Hourly Compensation Costs In Manufacturing, U.S. Dollars, 2011."[88] This produces the index in column 2 of Table 1.

3. GDP (in 2005 PPP) per employed person. From the Penn World Table.[89] This produces the index in column 3 Table 1.

Finally, we average the three indexes and scale our employment results. The results of these calculations are then presented in Tables A5.1-A5.7 below.

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[88] BLS (2012).

[89] Heston, Summers, and Atten (2012).

Table A5.1: Indexes to employment estimates scaled by domestic wage levels

	(1) Total compensation/ employed persons	(2) Average manufacturing wages	(3) GDP per employed person	(4) Average
Brazil	0.30	0.12	0.18	0.20
Germany	0.42	0.99	0.74	0.72
Indonesia	0.05	0.14	0.10	0.10
South Africa	0.35	0.23	0.21	0.27
ROK	0.28	0.40	0.59	0.43
U.S.	1.00	1.00	1.00	1.00

Source: Authors’ own estimates.

Table A5.2: Brazil. Employment effects of alternative energy investments scaled by domestic wage levels

	Jobs per $1 million			Scaled by domestic wage levels		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	73.1	8.7	81.8	14.6	1.7	16.4
Hydro	13.9	11.7	25.5	2.8	2.3	5.1
Wind	18.9	10.3	29.2	3.8	2.1	5.8
Solar	14.0	11.7	25.7	2.8	2.3	5.1
Geothermal	17.7	11.1	28.7	3.5	2.2	5.7
Weighted average for renewables	27.5	10.7	38.2	5.5	2.1	7.6
Energy efficiency						
Building retrofits	34.2	12.0	46.2	6.8	2.4	9.2
Industrial efficiency	13.6	11.6	25.1	2.7	2.3	5.0
Grid upgrades	13.0	13.2	26.2	2.6	2.6	5.2
Weighted average for efficiency	23.7	12.2	35.9	4.7	2.4	7.2
Fossil fuels						
Coal	10.0	12.3	22.4	2.0	2.5	4.5

Oil/natural gas	10.6	9.3	20.0	2.1	1.9	4.0
Weighted average for fossil fuels	10.3	10.8	21.2	2.1	2.2	4.2

Source: Authors' own estimates and Table 7.1.

Table A5.3: Germany. Employment effects of alternative energy investments scaled by domestic wage levels

	Jobs per $1 million			**Scaled by domestic wage levels**		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	8.3	2.7	11.0	6.0	1.9	7.9
Hydro	5.3	3.5	8.8	3.8	2.5	6.3
Wind	5.5	2.9	8.4	4.0	2.1	6.0
Solar	5.7	3.1	8.8	4.1	2.2	6.3
Geothermal	6.3	3.4	9.7	4.5	2.4	7.0
Weighted average for renewables	6.2	3.1	9.3	4.5	2.2	6.7
Energy efficiency						
Building retrofits	8.7	3.1	11.8	6.3	2.2	8.5
Industrial efficiency	5.5	3.2	8.6	4.0	2.3	6.2
Grid upgrades	5.3	2.8	8.1	3.8	2.0	5.8
Weighted average for efficiency	7.0	3.1	10.1	5.0	2.2	7.3
Fossil fuels						
Coal	6.1	3.8	10.0	4.4	2.7	7.2
Oil/natural gas	2.8	2.5	5.3	2.0	1.8	3.8
Weighted average for fossil fuels	4.5	3.2	7.6	3.2	2.3	5.5

Source: Authors' own estimates and Table 7.5.

Table A5.4: Indonesia. Employment effects of alternative energy investments scaled by domestic wage levels

	Jobs per $1 million			Scaled by domestic wage levels		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	237.0	73.5	310.5	23.7	7.4	31.1
Hydro	29.4	46.5	75.9	2.9	4.7	7.6
Wind	19.6	60.1	79.7	2.0	6.0	8.0
Solar	18.9	44.5	63.4	1.9	4.5	6.3
Geothermal	18.4	46.2	64.7	1.8	4.6	6.5
Weighted average for renewables	64.7	54.2	118.8	6.5	5.4	11.9
Energy efficiency						
Building retrofits	36.3	61.7	97.9	3.6	6.2	9.8
Industrial efficiency	12.8	46.8	59.6	1.3	4.7	6.0
Grid upgrades	17.0	45.2	62.2	1.7	4.5	6.2
Weighted average for efficiency	25.6	53.8	79.4	2.6	5.4	7.9
Fossil fuels						
Coal	7.1	33.5	40.6	0.7	3.4	4.1
Oil/natural gas	2.7	0.8	3.5	0.3	0.1	0.4
Weighted average for fossil fuels	4.9	17.1	22.0	0.5	1.7	2.2

Source: Authors' own estimates and Table 7.9.

Table A5.5: South Africa: Employment Effects of Alternative Energy Investments Scaled by Domestic Wage Levels

	Jobs per $1 million			Scaled by domestic wage levels		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	50.1	28.1	78.2	13.5	7.6	21.1
Hydro	25.4	36.2	61.6	6.9	9.8	16.6
Wind	29.9	30.6	60.5	8.1	8.3	16.3
Solar	19.6	35.9	55.6	5.3	9.7	15.0
Geothermal	31.2	38.2	69.5	8.4	10.3	18.8
Weighted average for Renewables	31.3	33.8	65.1	8.5	9.1	17.6
Energy efficiency						
Building retrofits	56.5	37.5	94.0	15.3	10.1	25.4
Industrial efficiency	24.6	35.9	60.5	6.6	9.7	16.3
Grid upgrades	24.3	31.6	55.9	6.6	8.5	15.1
Weighted average for efficiency	40.5	35.6	76.1	10.9	9.6	20.5
Fossil fuels						
Coal	5.3	24.1	29.4	1.4	6.5	7.9
Oil/natural gas	11.7	25.1	36.8	3.2	6.8	9.9
Weighted average for fossil fuels	8.5	24.6	33.1	2.3	6.6	8.9

Source: Authors' own estimates and Table 7.13.

Table A5.6: Republic of Korea: Employment effects of alternative energy investments scaled by domestic wage levels

	Jobs per $1 million			Scaled by domestic wage levels		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Renewables						
Bioenergy	23.1	4.8	27.9	9.9	2.1	12.0
Hydro	7.5	7.8	15.2	3.2	3.4	6.5
Wind	5.9	6.5	12.4	2.5	2.8	5.3
Solar	4.7	6.3	11.0	2.0	2.7	4.7
Geothermal	7.2	7.2	14.3	3.1	3.1	6.1
Weighted average for renewables	9.6	6.5	16.2	4.1	2.8	7.0
Energy efficiency						
Building retrofits	5.9	8.0	13.9	2.5	3.4	6.0
Industrial efficiency	5.3	7.1	12.3	2.3	3.1	5.3
Grid upgrades	5.2	6.7	12.0	2.2	2.9	5.2
Weighted average for efficiency	5.6	7.5	13.0	2.4	3.2	5.6
Fossil fuels						
Coal	10.1	4.0	14.1	4.3	1.7	6.1
Oil/natural gas	9.9	3.3	13.1	4.3	1.4	5.6
Weighted average for fossil fuels	10.0	3.6	13.6	4.3	1.5	5.8

Source: Authors' own estimates and Table 7.17.

Table A5.7: Summary of aggregate job creation estimates by country, scaled to domestic wage levels

	Renewable energy (weighted average)			**Energy efficiency** (weighted average)		
	Direct jobs	*Indirect jobs*	*Direct + indirect jobs*	*Direct jobs*	*Indirect jobs*	*Direct + indirect jobs*
Brazil	5.5	2.1	7.6	4.7	2.4	7.2
Germany	4.5	2.2	6.7	5.0	2.2	7.3
Indonesia	6.5	5.4	11.9	2.6	5.4	7.9
South Africa	8.5	9.1	17.6	10.9	9.6	20.5
ROK	4.1	2.8	7.0	2.4	3.2	5.6

Source: Authors' own estimates.

APPENDIX 6: ALTERNATIVE WEIGHTING PROPORTIONS FOR AGGREGATE CLEAN ENERGY INVESTMENTS: ROBUSTNESS TESTS OF CLEAN ENERGY EMPLOYMENT ESTIMATES

As noted in Chapter 7 of the main text, we use the following weighting scheme in aggregating the specific sectors within each energy-producing industry: With renewable energy, all sectors - bioenergy, hydro, wind, solar, and geothermal - are weighted equally. With energy efficiency, we have assigned a 50 percent weight to building retrofits, to reflect the centrality of this area of energy efficiency. We then weighted the other two energy efficiency sectors, building efficiency and electrical grid upgrades, at 25 percent each. Finally, in aggregating investment proportions for a "clean energy" sector overall, we then assigned a 67 percent weight to renewable energy and a 33 percent weight to energy efficiency.

We recognize that, in any given country setting, the actual size of any given sector in all energy-producing areas, will depend on the specific conditions in each country. But we assigned this one basic weighting scheme in the interests of simplicity and clarity across all of our selected countries here. In this appendix, we examine what would be the impact on our employment estimates that would result through altering the weights of the five renewable technologies. Altering these relative weights imply a change in the country's investment allocation between the various clean energy sectors. We present the results of these exercises in Tables A6.1 and A6.2.

Altering Renewable Energy Sector Proportions

In Table A6.1, we first present figures with the original weights used in the main text of the report, then present three alternative scenarios. The first alternative prioritizes bioenergy, the second prioritizes wind and solar, and the third removes geothermal and gives equal weights to the other four renewables. We calculate the total employment (direct plus indirect jobs) per $1 million and then calculate the percentage difference from the original estimates presented in Chapter 7.

Table A6.1: Alternative weighting proportions for aggregate renewable energy investment

First set of Robustness Tests for Clean Energy Employment Impacts

a) Proportions of total renewable energy investment (percentage)

Energy Type	Equal weights	Bioenergy prioritized	Wind and solar prioritized	No geothermal
Bioenergy	20%	40%	10%	25%
Hydro	20%	15%	10%	25%
Wind	20%	15%	35%	25%
Solar	20%	15%	35%	25%
Geothermal	20%	15%	10%	0%

b) Weighted average of direct + indirect jobs per $1 million

Country	Equal weights	Bioenergy prioritized	Wind and solar prioritized	No geothermal
Brazil	38.2	49.1	32.8	40.6
Germany	9.3	9.8	9.0	9.3
Indonesia	118.8	166.8	95.2	132.4
South Africa	65.1	68.4	61.6	64.0
ROK	16.2	19.1	13.9	16.6

c) Percentage difference relative to equal weighting for all renewables

Country	Equal weights	Bioenergy prioritized	Wind and solar prioritized	No geothermal
Brazil	-	+28.6%	-14.1%	+6.2%
Germany	-	+4.4%	-4.0%	-1.0%
Indonesia	-	+40.3%	-19.9%	+11.4%
South Africa	-	+5.0%	-5.4%	-1.7%
ROK	-	+18.2%	-13.8%	+2.9%

Sources: See Appendix 2.

Note: Employment multipliers in report are presented in tables 7.1, 7.5, 7.9, 7.13, and 7.17. Estimates presented in this research were calculated using equal weights.

As we see in Table A6.1, the effects of the alternative weighting schemes are minimal in some countries and significant in others. In Germany and South Africa, employment estimate changes by no more than about 5 percent. The biggest difference in all cases results from increasing the bioenergy industry in Indonesia, which results in a 40 percent increase in the employment multiplier for renewable energy. This highlights the fact that bioenergy is highly labor-intensive in Indonesia. There are significant differences in the overall renewable energy employment multipliers in Brazil and the ROK as well when bioenergy is prioritized.

The second scenario, prioritizing wind and solar, again results in a small change in employment for Germany and South Africa, but a 14-20 percent reduction in employment for Brazil, Indonesia, and the ROK relative to equal weighting framework. Since employment multipliers are actually fairly similar for wind, solar, and hydro in most countries (see Tables 7.1, 7.5, 7.9, 7.13, and 7.17), the difference in the weighted average renewable estimate is less a function of increasing wind and solar and more a function of decreasing bioenergy, which has an outsized impact in most countries because of the current level of labor intensity in agricultural production.

Removing geothermal has the least impact, mainly because the geothermal multiplier is quite similar to the hydro, wind, and solar multipliers in most cases. However it is useful to observe these differences particularly since in some countries, such as Brazil, there are limited geothermal resources that are economically feasible to develop.

The results of these alternative specifications show us that our estimates are in fact quite robust to changes in the investment allocation for renewable energy, with the exception of changing the importance of bioenergy. The other four renewable industries have fairly similar multipliers, and thus if a country chose to change the investment allocation among any of these four technologies, the employment results would be similar to those we present in the main text of the report.

Weighting Energy Efficiency and Renewables Equally

In Table A6.2 we show the results of altering the investment allocation between renewable energy and energy efficiency. That is, we allocate total clean energy investments in equal proportions between renewables and energy efficiency in our alternative framework, as opposed to the 67 percent for renewables/33 percent weighting that we utilize in the main text of the report.

Table A6.2: Alternative weighting proportions for aggregate clean energy investments between renewables and energy efficiency

Second set of robustness tests for clean energy employment impacts

	Clean energy investment allocation		
	67 percent renewable energy; 33 percent energy efficiency *(Assumptions for main text)*	**50 percent renewable energy; 50 percent energy efficiency**	**Percentage difference**
	Direct + indirect jobs per $1 million		
Brazil	37.4	37.1	-1.0%
Germany	9.6	9.7	1.4%
Indonesia	105.7	99.1	-6.2%
South Africa	68.8	70.6	2.7%
ROK	15.1	14.6	-3.5%

Sources: See Appendix 2.

Note: Employment multipliers in report are presented in tables 7.1, 7.5, 7.9, 7.13, and 7.17.

As we see in Table A6.2, the results do not vary significantly, ranging from a 6.2 percent lower level of total employment in Indonesia to a 7.2 percent higher level in South Africa. As with the case of adjusting within renewables, these results on efficiency and renewables investments combined show the robustness of the estimates to changes in the clean energy investment allocation.

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