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Methodology and Calculations for Clean Energy Cost Estimates in Proposed U.S. THRIVE Agenda and Related Policy Proposals

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This memo presents details on the underlying methodology and calculations for the March 2021 estimates Chakraborty, Wicks-Lim and I derived on employment creation through the THRIVE Agenda investment program in energy efficiency and clean renewable energy.[1] The material I present here supplements the methodological discussions on pp. 1 – 7 of this March 2021 report.

Specifically, this report presents estimates as to the level of investment spending required for the U.S. economy to reduce CO_2 emissions by 50 percent as of 2030 relative to the economy's 1990 emissions level. As of 1990, emissions totaled to 5.2 billion metric tons. Therefore, the goal is for the U.S. economy to reduce emissions to 2.6 billion metric tons as of 2030.

In the framework presented here, the economy's emissions reductions are achieved through reducing the consumption of all fossil fuel energy sources as well that of high-emissions bioenergy. The framework assumes that consumption from these energy sources falls by the following amounts relative to their 2019 levels: oil and natural gas by 40 percent; high-emissions bioenergy by 70 percent; and coal by 90 percent.

The framework also assumes that the U.S. economy grows at an average rate of 2.5 percent per year between 2019 – 2030. Within this growing economy, the major reduction in the demand for fossil fuel and high-emissions bioenergy will, of course, need to be compensated for through the expansion of alternative energy sources. This framework assumes that the reduction in fossil fuel energy is compensated for through investments to both 1) dramatically

1 https://www.peri.umass.edu/component/k2/item/1397-employment-impacts-of-proposed-u-s-economic-stimulus-programs

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increase energy efficiency and 2) equally dramatically expand the supply of clean renewable energy sources. The primary renewable energy sources will be solar and wind power, with smaller contributions by low-emissions bioenergy, geothermal, and small-scale hydro power.

This report includes 12 tables overall. Tables 1 – 7 provide background data and calculations for generating estimates of the costs of the overall clean energy investment program, including both the energy efficiency and clean renewable energy components of this overall investment program. Tables 8 and 9 then present those estimates themselves of the costs of investing to raise energy efficiency standards and to expand the supply of clean renewable energy to the level necessary. I define the necessary level of clean energy investment spending as being the amount that will be sufficient to enable the U.S. economy to succeed in reducing CO_2 emissions by 50 percent as of 2030 while the economy proceeds to grow at an average rate of 2.5 percent per year.

I provide two alternative estimates of this necessary level of clean energy investments. These alternative estimates are based on lower-cost and higher-cost assumptions respectively for producing a given amount of energy efficiency savings or a given increase in clean renewable energy supply. I measure the costs of both raising energy efficiency standards and expanding the supply of clean renewable energy as the ratio of billions of dollars per quadrillion BTUS (Q-BTUs) of either energy savings or expanded energy supply. The lower-cost estimates are reported in Table 8 and the higher-cost estimates in Table 9.

In Tables 10 – 12, I then show these alternative cost estimates in terms of both overall budget figures over 2021 – 2030, and also as average annual spending amounts over the 10-year period. Table 10 shows figures for the energy efficiency component of the overall clean energy program, Table 11 shows the comparable figures for the renewable energy component of the program, and Table 12 reports the overall cost estimates that include both energy efficiency and clean renewable energy investments.

In Tables 10 – 12, I also report figures on the public investment shares of the overall investment program. I assume two scenarios here—that public investment shares total, alternatively, to 50 percent and 25 percent of the overall investment budget.

Through providing this range of results based on alternative assumptions on investment costs and public investment shares of overall costs, we are able to observe, among other things, how the THRIVE Agenda established the budget figures for the various components of its overall program. For example, the THRIVE program assumes that the public investment share of clean renewable energy investments will need to average $114 billion per year over 2021 – 2030 in order for the U.S. economy to achieve the 50 percent reduction in CO_2 emissions. As Table 11 shows, this $114 billon figure is the amount that I have derived as the midpoint estimate for the public sector's share of the average annual renewable energy costs for 2021 – 2030, assuming that the public sector provides 25 percent of the overall renewable energy investment budget.

In estimating the impact of the overall THRIVE program on CO_2 emissions reduction, it is important to recognize that, in addition to the efficiency and clean renewable energy investments, other areas of the overall program will also contribution to reducing CO_2 emissions. In particular, THRIVE investments in the areas of agriculture and land restoration will serve both to reduce CO_2 emissions as well as absorb existing levels of CO_2 in the atmosphere.[2]

As a result, the overall THRIVE program will enable the U.S. to reduce its overall CO_2 emissions by more than 50 percent as of 2030. Reducing emissions in

2 See Noam Chomsky and Robert Pollin (2020) *Climate Crisis and the Global Green New Deal*, pp. 30 – 31 for a brief description of how organic/regenerative agriculture serves as a carbon sink, as opposed to industrial agriculture practices, which emit CO_2.

the U.S. by more than 50 percent as of 2030 would be consistent with the United States contributing a greater share to achieving the target set by the Intergovernmental Panel on Climate Change (IPCC) of a global emissions reduction of 50 percent as of 2030. It is appropriate that the U.S. should make greater than average contributions to reducing overall global emissions. This is because the U.S. is responsible to a much greater extent than other countries to having raised the stock of CO_2 and other greenhouse gases into the atmosphere, and thereby, contributed to producing the climate crisis faced by the entire globe.[3]

Overall Findings on Costs

- Under "Higher Cost Assumptions"
  - $6.9 trillion in total costs for 2021 – 2030
  - $690 billion per year for 2021 – 2030
  - Higher cost assumptions include:
    - $35 billion per Q-BTU average for energy efficiency gains
    - $200 billion per Q-BTU average to expand clean renewable energy supply
  - Higher cost assumptions were used in 3/21 PERI analysis of THRIVE Agenda: https://www.peri.umass.edu/component/k2/item/1397-employment-impacts-of-proposed-u-s-economic-stimulus-programs

- Under "Lower Cost Assumptions"
  - $5.3 trillion in total costs for 2021 – 2030
  - $530 billion per year for 2021 – 2030
  - Lower cost assumptions include:
    - $30 billion per Q-BTU average for energy efficiency gains (i.e. 14 percent lower than higher cost assumption).
    - $150 billion per Q-BTU average to expand clean renewable energy supply (i.e. 25 percent lower than higher cost assumption)

3 See Chomsky and Pollin op. cit,, pp. 91 – 92 for a discussion on the U.S. economy's contributions to global climate chang.e

Derivation of Cost Assumptions

Pollin et al. (2021), *Impact of the Reimagine Appalachia and Clean Energy Transition Programs for Pennsylvania*, pp. 33 – 34 for energy efficiency costs and pp. 36 – 37 for renewable energy costs. https://www.peri.umass.edu/economists/gregor123/item/1394-impacts-of-the-reimagine-appalachia-clean-energy-transition-programs-for-pennsylvania

Also, references cited in this 2021 study, including:

Pollin et al. (2014), *Green Growth: A U.S. Program for Controlling Climate Change and Expanding Job Opportunities*, https://www.americanprogress.org/issues/green/reports/2014/09/18/96404/green-growth/

Alternative Assumptions on Public Financing Share of Overall Costs

- Higher public financing share = 50 percent public funding
  - Assumption in 3/21 PERI analysis of THRIVE Agenda

- Lower public financing share = 25 percent public funding
  - Assumption in:
    - Pollin (2019): https://prospect.org/greennewdeal/how-to-pay-for-a-zero-emissions-economy/
    - Sattler et al. (2021): https://www.ucsusa.org/resources/federal-clean-energy-tax-credits#top
      - » Sattler et al. assumption is actually 26.4 percent. I have rounded to 25 percent.

Corroboration of Overall Modeling Results

1. Jim Williams and Ryan Jones (2020) "Technology Pathways to Zero Carbon,"

https://irp-cdn.multiscreensite.com/6f2c9f57/files/uploaded/zero-carbon-action-plan-ch-02.pdf

As shown in Pollin et al. (2020) (https://irp-cdn.multiscreensite.com/6f2c9f57/files/uploaded/zero-carbon-action-plan-ch-03.pdf , the Williams/Jones model estimates average annual costs of reaching zero emissions by 2030 through its "central case " as ~ $680 billion/year. This includes $551 billion per year within the central case net of the "reference case." The reference case reduces emissions by 23 percent. Thus, adding 23 percent to central case = $678 billion/year.

2. International Renewable Energy Agency (IRENA) global model:

Estimates global average clean energy investments to reach net zero emissions by 2050 = $4.4 trillion/year.
World Energy Transitions Outlook (2021)
https://irena.org/publications/2021/March/World-Energy-Transitions-Outlook

Pollin (2020) "An Industrial Policy Framework to Advance a Global Green New Deal,"
estimates average annual clean energy investments = $4.5 trillion/year to reach global zero emissions.
https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780198862420.001.0001/oxfordhb-9780198862420-e-16

Tables Presenting Background Data, Modeling Approach and Calculation of Results

TABLE 1
Projected Average Levelized Costs of Electricity: *U.S. Energy Information Agency Estimates for New Resources Entering Service in 2026*

Coal with carbon capture	7.3 cents
Advanced nuclear	6.9 cents
Solar PV	3.3 cents
Onshore wind	3.7 cents
Geothermal	3.6 cents
Hydro	5.5 cents
Bioenergy	8.9 cents

Sources: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

TABLE 2
Capital Expenditure Costs for Building Renewable Electricity Productive Equipment: Present Values of Total Lump-sum Capital Costs per Q-BTU of Electricity
U.S. Energy Information Agency Estimates for New Resources Entering Service in 2026

Solar PV	$97 billion
Onshore wind	$110 billion
Low-emissions bioenergy	$148 billion
Geothermal	$76 billion
Small-scale hydro	$138 billion
Weighted average costs *assuming: Investments are 50% solar; 20% wind; 15% bioenergy; 7.5% geothermal; 7.5% small-scale hydro*	**$109 billion**

Sources: EIA, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf. See Pollin et al. (2014) pp. 136 – 37 for methodology in converting levelized costs per Q-BTU into lump-sum capital costs.

TABLE 3

1990 U.S. Baseline CO_2 Emissions Level

	1) 1990 Energy consumption *(in Q-BTUs)*	2) 1990 CO_2 emissions *(in billions of metric tons)*	3) 1990 CO_2 emissions per Q-BTU *(= column 2/ (column 1/1000))*
Fossil Fuels			
Petroleum	33.5	2.2	65.7
Natural gas	19.6	1.0	51.0
Coal	19.2	1.8	93.8
Fossil fuel totals	72.3	5.0	---
Bioenergy	2.7	0.2	90 — *rough approximation*
Totals, including bioenergy estimate	**75.0**	**5.2**	---

Source:: https://www.eia.gov/environment/

TABLE 4

Sources of CO_2 Emissions for U.S.: *2019 Actuals and 2030 Projections*

CO_2 emissions target for 2030 = 2.6 billion metric tons/50 percent reduction relative to 1990 level

2030 Energy Consumption Levels relative to 2019: Oil = 60%; Natural Gas = 60%; Coal = 10%; Bioenergy = 30%

	2019 Actuals			2030 Projections	
	1) 2019 Energy consumption *(in Q-BTUs)*	2) 2019 CO_2 emissions *(in billions of metric tons)*	3) CO_2 emissions per Q-BTU *(= column 2/ (column 1/1000))*	4) 2030 Energy consumption *(in Q-BTUs)*	5) 2030 CO_2 emissions *(in millions of tons; = column 3 x column 4/1000)*
Fossil Fuels					
Petroleum	38.9	2.4	61.7	23.3	1.4
Natural gas	32.2	1.7	52.8	19.3	1.0
Coal	11.3	1.1	97.3	1.1	0.1
Fossil fuel totals	82.4	5.2	---	45.3	2.5
Bioenergy	4.9	0.4	90— *rough approximation*	1.4	0.1
Totals, including bioenergy estimate	**87.3**	**5.6**	---	**47.8**	**2.6**

Notes: Assumption made for the 2030 projected scenario is that consumption reduction levels are: 40 percent for oil and natural gas, 70 percent for high-emissions bioenergy and 90 percent for coal

Source: : https://www.eia.gov/environment/

TABLE 5

Determinants of Per Capita CO_2 Emissions Levels in U.S., India, and Various States, 2017

Level of development, energy intensity and emissions intensity

CO_2 emissions/population = (GDP/population) x (Q-BTUs/GDP trillion dollars) x (Emissions/Q-BTU)

	Per capita CO_2 emissions *(in metric tons)*	**Per capita GDP** *(in current U.S.$)*	**Energy intensity ratio:** *Q-BTUs/trillion dollars GDP*	**Emissions intensity ratio:** *CO_2 emissions/Q-BTU*
United States–2019	17.0	$65,240	4.7	55.9
United States–2017	17.2	$60,062	5.0	57.2
Comparisons–2017				
India	1.8	$2,104	13.4	66.8
California	9.8	$71,626	2.8	48.8
Ohio	18.6	$55,347	5.6	59.3
Kentucky	26.7	$45,082	8.3	71.6
New York	8.7	$81,887	2.3	46.5
Pennsylvania	18.0	$58,204	5.1	60.6
Texas	25.8	$58,866	8.1	54.4
Colorado	16.2	$62,368	4.2	62.1

Sources: EIA for emissions figures, U.S. Census for population figures, and Bureau of Economic Analysis for state-level GDP figures. Figures are inclusive of biomass emissions. India data from https://www.iea.org/countries/india.

TABLE 6

U.S. GDP Levels: *2019 Actual and Projections for 2022 – 2030*

Figures are in 2019 dollars

2019 GDP	$21.4 trillion
Projected average growth rate through 2030	2.5%
Projected 2022 GDP	$23.0 trillion
Projected 2030 GDP	$28.1 trillion
Projected midpoint GDP between 2022 – 2030 *(average of 2025 and 2026)*	$25.1 trillion

Source: BEA and authors' calculations.

TABLE 7
U.S. Energy Consumption and Emissions:
2019 Actuals and 2030 Alternative Projections

	1) 2019 actuals	2) 2030 with approximate Steady State Energy Infrastructure *(= categories grow at 2.5% average annual rate)*	3) 2030 through Clean Energy Investment Program
1) Real GDP *(in 2019 dollars)*	$21.4 trillion	$28.1 trillion	$28.1 trillion
2) Energy consumption *(Q-BTUs)*	100.6 Q-BTUs	132.1 Q-BTUs	84.3 Q-BTUs
3) Energy intensity ratio *(Q-BTUs / $1 trillion of GDP)*	4.7	4.7	3.0
Energy mix for in-state supply			
4) Non-renewables and bioenergy (Q-BTUs—rows 5-9)	*95.7*	*125.4*	*52.1*
5) Petroleum	38.9	51.0	23.3
6) Natural gas	32.2	42.2	19.3
7) Coal	11.3	14.8	1.1
8) High-emissions bioenergy	4.9	6.4	1.4
9) Nuclear	8.4	11.0	7.0
10) Clean renewables (T-BTUs = row 11 through row 15)	*6.4*	*8.4*	*32.2*
11) Solar	1.0	1.3	16.1
12) Wind	2.6	3.4	6.5
13) Low-emissions bioenergy	0	0	4.8
14) Geothermal	0.2	0.3	2.4
15) Hydro	2.6	3.4	2.4
Emissions			
16) Total CO_2 emissions *(billions metric tons)*	5.6	7.3	2.6
17) Emissions Intensity Ratio *(CO_2 Emissions per consumed Q-BTUs = row 16 / (row 2/1000)*	55.7	55.3	30.8

Source: Tables 3 and 5; EIA: https://www.eia.gov/totalenergy/data/monthly/pdf/sec1_7.pdf

TABLE 8

U.S. Clean Energy Investment Program for 2021 – 2030 / *1*:

***Lower Cost Assumptions** for Energy Efficiency and Clean Renewable Energy Investments*

A) Energy Efficiency Investments

1. 2030 Energy intensity ratio	3.0 Q-BTUs per $1 trillion GDP *(36% improvement over 4.7 Q-BTU per $1 trillion GDP steady state figure)*
2. Total energy consumption	84.3 Q-BTUs *(= 36% reduction relative to 132.1 Q-BTU steady state figure)*
3. Energy saving relative to steady state	47.8 Q-BTUs *(= 132.1 – 84.3 Q-BTUs)*
4. Average investment costs per Q-BTU in efficiency gains	$30 billion per Q-BTU
5. Costs of energy savings	$1.4 trillion *(= $30 billion x 47.8 Q-BTUs in savings)*
6. Average annual costs over 2021 – 2030	$140 billion *(= $1.4 trillion/10)*
7. Average annual costs of efficiency gains as % of midpoint GDP	0.6% *(= $159 billion/$25.1 trillion)*

B) Clean Renewable Energy Investments

1. Total renewable supply necessary	32.2 Q-BTUs *(= 84.3 Q-BTUs – 52.1 Q-BTUs supplied by non-renewables/biomass*
2. Expansion of renewable supply relative to 2018 level	25.8 Q-BTUs *(= 32.2 – 6.4 Q-BTUs)*
3. Average investment costs per Q-BTU for expanding renewable supply	$150 billion per Q-BTU
4. Costs of expanding renewable supply	$3.9 trillion *(=25.8 Q-BTUs x $150 billion)*
5. Average annual costs over 2021 – 2030	$390 billion *(= $3.9 trillion/10)*
6. Average annual costs of renewable supply expansion as % of midpoint GDP	1.6% *(= $390 billion/$25.1 trillion)*

C) Overall Clean Energy Investments: Efficiency + Clean Renewables

1. Total clean energy investments	$5.3 trillion *(= $1.4 trillion for energy efficiency + $3.9 trillion for renewables)*
2. Average annual investments	$530 billion *(= $5.3 trillion/10)*
3. Average annual investments as share of midpoint GDP	2.1% *(= $530 billion/$25.1 trillion)*
4. Total energy savings or clean renewable capacity expansion	73.6 Q-BTUs *(= 47.8 Q-BTUs in energy saving + 25.8 Q-BTUs in clean renewable supply expansion)*

Sources: Tables 5 and 6.

TABLE 9

U.S. Clean Energy Investment Program for 2021 – 2030 / 2:

***Higher Cost Assumptions** for Energy Efficiency and Clean Renewable Energy Investments*

A) Energy Efficiency Investments

1. 2030 Energy intensity ratio	3.0 Q-BTUs per $1 trillion GDP *(36% improvement over 4.7 Q-BTU per $1 trillion GDP steady state figure)*
2. Total energy consumption	84.3 Q-BTUs *(= 36% reduction relative to 132.1 Q-BTU steady state figure)*
3. Energy saving relative to steady state	47.8 Q-BTUs *(= 132.1 – 84.3 Q-BTUs)*
4. Average investment costs per Q-BTU in efficiency gains	$35 billion per Q-BTU
5. Costs of energy savings	$1.7 trillion *(= $35 billion x 47.8 Q-BTUs in savings)*
6. Average annual costs over 2021 – 2030	$170 billion *(= $1.7 trillion/10)*
7. Average annual costs of efficiency gains as % of midpoint GDP	0.7% *(= $189 billion/$25.1 trillion)*

B) Clean Renewable Energy Investments

1. Total renewable supply necessary	32.2 Q-BTUs *(= 84.3 Q-BTUs – 52.1 Q-BTUs supplied by non-renewables/ biomass*
2. Expansion of renewable supply relative to 2018 level	25.8 Q-BTUs *(= 32.2 – 6.4 Q-BTUs)*
3. Average investment costs per Q-BTU for expanding renewable supply	$200 billion per Q-BTU
4. Costs of expanding renewable supply	$5.2 trillion *(=25.8 Q-BTUs x $200 billion)*
5. Average annual costs over 2021 – 2030	$520 billion *(= $5.2 trillion/10)*
6. Average annual costs of renewable supply expansion as % of midpoint GDP	2.1% *(= $520 billion/$25.1 trillion)*

C) Overall Clean Energy Investments: Efficiency + Clean Renewables

1. Total clean energy investments	$6.9 trillion *(= $1.7 trillion for energy efficiency + $5.2 trillion for renewables)*
2. Average annual investments	$690 billion *(= $6.9 trillion/10)*
3. Average annual investments as share of midpoint GDP	2.7% *(= $767 billion/$25.1 trillion)*
4. Total energy savings or clean renewable capacity expansion	73.6 Q-BTUs *(= 47.8 Q-BTUs in energy saving + 25.8 Q-BTUs in clean renewable supply expansion)*

Sources: Tables 5 and 6.

TABLE 10
Alternative Models for Public and Private Financing of *Energy Efficiency* Investment Program

A) Overall Project Budget 2021 – 2031

	Lower cost investment assumptions	Higher cost investment assumptions	Midpoint between lower- and higher-cost investment assumptions
Total budget	$1.4 trillion	$1.7 trillion	$1.6 trillion
Public sector budget with 50% public funding	$700 billion	$850 billion	$800 billion
Public sector budget with 25%public funding	$350 billion	$425 billion	$400 billion

B) Average Annual Project Budget 2021 – 2030

	Lower cost investment assumptions	Higher cost investment assumptions	Midpoint between lower- and higher-cost investment assumptions
Overall average annual budget	$140 billion	$170 billion	$155 billion
Public sector average annual budget with 50% public funding	$70 billion	$85 billion	$78 billion
Public sector average annual budget with 25% public funding	$35 billion	$43 billion	$39 billion

Sources: Tables 8 and 9.

TABLE 11
Alternative Models for Public and Private Financing of *Clean Renewable Energy* Investment Program

A) Overall Project Budget 2021 – 2031

	Lower cost investment assumptions	Higher cost investment assumptions	Midpoint between lower- and higher-cost investment assumptions
Total budget	$3.9 trillion	$5.2 trillion	$4.6 trillion
Public sector budget with 50% public funding	$2.0 trillion	$2.6 trillion	$2.3 trillion
Public sector budget with 25%public funding	$1.0 trillion	$1.3 trillion	$1.1 trillion

B) Average Annual Project Budget 2021 – 2030

	Lower cost investment assumptions	Higher cost investment assumptions	Midpoint between lower- and higher-cost investment assumptions
Overall average annual budget	$390 billion	$520 billion	$455 billion
Public sector average annual budget with 50% public funding	$195 billion	$260 billion	$228 billion
Public sector average annual budget with 25% public funding	$98 billion	$130 billion	$114 billion

Sources: Tables 8 and 9.

TABLE 12
Alternative Models for Public and Private Financing of *Overall Clean Energy* Investment Program *(Efficiency + Renewables)*

A) Overall Project Budget 2021 – 2031

	Lower cost investment assumptions	Higher cost investment assumptions	Midpoint between lower- and higher-cost investment assumptions
Total budget	$5.3 trillion	$6.9 trillion	$6.1 trillion
Public sector budget with 50% public funding	$2.6 trillion	$3.5 trillion	$3.1 trillion
Public sector budget with 25%public funding	$1.3 trillion	$1.7 trillion	$1.5 trillion

B) Average Annual Project Budget 2021 – 2030

	Lower cost investment assumptions	Higher cost investment assumptions	Midpoint between lower- and higher-cost investment assumptions
Overall average annual budget	$530 billion	$690 billion	$610 billion
Public sector average annual budget with 50% public funding	$265 billion	$345 billion	$305 billion
Public sector average annual budget with 25% public funding	$133 billion	$173 billion	$153 billion

Sources: Tables 8 and 9.

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