Effects of Renewable Energy Provisions of the Inflation Reduction Act on Technology Costs, Materials Demand, and Labor

Yohan Min[1], Maarten Brinkerink[1], Jesse Jenkins[2*], Erin Mayfield[1*]

1 Dartmouth College, Thayer School of Engineering, Sustainable Transitions Lab, Hanover, New Hampshire

2 Princeton University, Department Mechanical and Aerospace Engineering and Andlinger Center for Energy and the Environment, ZERO Lab, Princeton, New Jersey

*Corresponding authors' contact information: mayfield@dartmouth.edu and jessejenkins@princeton.edu

Summary of Findings

- The clean electricity production and investment tax credits (PTC and ITC) expanded and extended by the Inflation Reduction Act (IRA) substantially reduce the levelized cost of utility-scale solar and wind projects deployed in the United States (U.S.), making renewable energy projects economically viable across much wider extents of the country.
- Additional project costs associated with meeting labor requirements to qualify for the PTC and ITC *bonus* rates are potentially more than compensated by the increased tax credit rates. We estimate that the levelized cost of utility-scale solar and land-based wind projects receiving the PTC *bonus* rate will be approximately 60% lower than a comparable project receiving the *base* rate. Similarly, offshore wind projects receiving the *bonus* tax rate have the potential to be approximately 20% less expensive than comparable projects receiving the *base* tax rate.
- With the 45X Advanced Manufacturing Production Tax Credit, components manufactured in the U.S. are now likely to be less expensive than imports across the entire solar supply chain (i.e., polysilicon ingots, wafers, cells, and module assembly as well as inverters). Before the IRA, domestic production was more expensive than imports for each component. We estimate the cost of solar modules assembled in the U.S. and made from 100% domestically-manufactured components will now be more than 30% less expensive to produce than imported modules (before accounting for any applicable tariffs, which further advantage domestic production).
- The 45X manufacturing tax credit will also make U.S. manufactured onshore and offshore wind components (i.e., towers, blades, nacelles) less expensive to produce than imported products.
- The degree to which lower domestic production *costs* pass through to *prices* for solar or wind components or installed projects is uncertain and depends on competitive market dynamics not assessed in this study.
- Considering the competitive cost of domestic components after accounting for 45X as well as the 10% tax credit adder to the PTC and ITC for renewable energy projects employing domestic content, the IRA has the potential to induce significant demand for solar and wind components manufactured in the U.S. This demand will outstrip current U.S. solar and wind component manufacturing capacity, prompting investment to expand U.S. supply chains.
- The IRA could induce demand for approximately 1.3 million *additional* jobs related to utility-scale solar and 250,000 wind related jobs in 2035, relative to the level of employment in these sectors

without passage of IRA (and assuming no change in domestic content shares for wind and solar components absent IRA). This includes domestic demand for an additional 800,000 jobs in solar manufacturing and 55,000 additional jobs in wind manufacturing by 2035.

- The induced demand for solar and wind employment under the IRA is the result of both accelerated renewable power capacity additions associated with PTC/ITC tax credit incentives as well as increases in domestic manufacturing associated with the 45X manufacturing tax credit and the PTC/ITC *domestic content* adder. Domestic demand for solar and wind manufacturing employment in 2035 would be about 800,000 jobs lower if solar and wind deployment expanded at modeled rates but domestic content shares remained at current levels.
- With the IRA, the wind and solar PV sectors could induce demand for 1.7 million total utility-scale solar related jobs by 2035 (800,000 in construction and operations of utility-scale solar projects and 850,000 in solar component manufacturing) and total wind employment could reach 520,000 jobs (450,000 in construction and operations and 70,000 in manufacturing). That compares to roughly 300,000 utility-scale solar related jobs and 200,000 wind related jobs in the U.S. today.
- Due to expanded employment alone, the IRA could increase total wages earned by solar and wind workers in 2035 by about $70 billion and $15 billion, respectively, relative to the wages earned without passage of the law. This estimate assumes the workforce earns median real wages and does not account for wage increases that may be induced by the labor requirements to qualify for the *bonus* rate or any increases in compensation that may be required to satisfy high demand for labor in the expanding wind and solar sectors. Prior research found that a 20% increase in installation and construction labor costs would increase the installed cost of utility-scale solar PV and wind projects by only 3% and 1%, respectively.
- Under the IRA, aluminum, cement, and steel demand for construction of solar and wind projects is projected to increase by an order of magnitude between 2023 and 2035, although there is high uncertainty regarding the material intensity of renewable projects. By 2035, mid-range estimates of aluminum and steel demand induced by the growth of wind and solar under IRA amounts to 131% and 37% of 2022 U.S. consumption, respectively, and 156% and 42% of 2022 U.S. production. For aluminum and to a lesser extent steel, a large and rapid expansion of total supply is required to meet demand, while the 10% *domestic content* tax credit adder suggests that some of this demand will be satisfied by increased U.S. materials production.

Acknowledgments

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Introduction

In 2021, the Biden administration issued multiple executive orders which commit the U.S. to reduce economy-wide greenhouse gas emissions to half of peak levels by 2030 and reach net-zero emissions by mid-century[1,2]. In 2022, the U.S. Congress passed the Inflation Reduction Act (IRA), which appropriates $110 billion in direct spending on climate-related programs over ten years and includes a package of tax incentives for clean energy sources, electrification of vehicles and buildings, and energy efficiency[3]. The Congressional Budget Office (CBO) and Joint Committee on Taxation (JCT) estimate these tax credit programs will decrease government revenues by $269 billion over ten years (2022-2031)[4]. However, outlays for IRA tax credits could be materially larger than CBO's estimates, given that the actual spending is not constrained by a fixed budget nor subject to further appropriations, and in many cases, provisions persist beyond 2031. Multiple independent projects to model the impacts of IRA on the U.S. energy economy and emissions conclude that accelerated deployment of wind and solar power spurred by the law is likely to be the largest driver of emissions reductions over the next decade[5–7].

The IRA extends and increases the value of the production tax credit (PTC) and investment tax credit (ITC) incentives for renewable projects (including sections 45, 45Y, 48, and 48E). The IRA extends full credit eligibility to projects commencing construction before the end of 2033 or the year after U.S. power sector emissions fall to 25% of 2022 levels, whichever comes *later,* providing long-term investment certainty for clean energy investors. The IRA makes it easier for project owners to monetize the tax credits, by making direct payments available to non-taxable entities and allowing taxable entities to transfer some or all of the tax credit in any year to any other entity with business tax liability—an important provision given that renewable energy project owners rarely have sufficient tax appetite to fully absorb the large tax credits directly and non-taxable entities could previously not benefit at all from the credit.

New and existing renewable energy projects can qualify for either a *base* rate (i.e., $0.0055/kWh PTC and 6% ITC)[i], or a *bonus* rate that is equivalent to five times the *base* rate ($0.0275/kWh PTC and 30% ITC). For a project to qualify for the bonus rate, the following labor requirements must be met: 1) laborers and mechanics must be paid prevailing wage rates for construction, alteration, or repair work, and 2) a certain percentage of construction work must be performed by qualified apprentices. In addition to the bonus and base rates for the PTC and ITC, a tax credit adder of 10% can be applied if renewable projects meet *domestic content* requirements or qualify as an *energy community*. To qualify for the domestic content adder, developers are required to utilize U.S. steel and iron and procure manufactured products meeting a minimum domestic content share. To qualify for the energy community adder, a project must be located in an energy community which is defined as a 1) brownfield site, 2) census tract (or an adjoining tract) where a coal-fired power plant or coal mine has recently closed, or 3) metropolitan or non-metropolitan statistical area where a significant portion of employment or local tax revenues is linked to coal, oil, or natural gas activities and unemployment rates meet or exceed the national average in the preceding year.

[i] Dollar values are in 2022 USD. All cost estimates for utility-scale solar are in units of $/MWh-ac, unless otherwise noted.

For more detailed information regarding policy provisions, refer to Supplemental Information (SI) Section 1.1.

In addition to incentives for developers, the IRA establishes the advanced manufacturing production tax credit (AMPC, section 45X) for domestic producers of wind, solar, and battery components and critical minerals. Incentives are available for individual components across the wind and solar supply chains, such as polysilicon ingots, solar photovoltaic (PV) wafers, cells and modules, solar tracking equipment, inverters, wind turbine blades, nacelles and towers, offshore wind foundations, and vessels for offshore wind installation (refer to SI Table S6 for details). In addition, the advanced energy project credit (section 48C) establishes a 30% investment tax credit to defray capital expenditures at qualified clean energy manufacturing facilities, although funding for this tax credit is limited to $10 billion from 2023-2032. At least $4 billion of the 48X credit value must be reserved for projects in *energy communities* that historically hosted coal mines or power plants.

The incentives in the IRA are likely to drive substantial investment in not only wind and solar generation capacity, but also domestic manufacturing of wind and solar components. In turn, this will induce demand for labor in the solar and wind sectors and materials such as steel, aluminum, and cement. Here, we assess the potential impact of provisions that will directly affect renewable costs, including the PTC/ITC (sections 45, 45Y, 48, and 48E) and the advanced manufacturing production credit (section 45X). We do not account for all provisions within the IRA that can indirectly impact renewable costs (e.g., section 48C advanced energy project credit, loan guarantee programs). Specifically, we model the cost of domestically-produced and imported renewable components as well as the levelized cost of land-based wind, offshore wind, and utility-scale solar. In addition, we estimate the impacts of renewable manufacturing and installation on demand for labor as well as materials such as aluminum, steel, and concrete. Refer to SI Section 1 for additional details regarding methods.

Solar and wind component costs

Figure 1 depicts estimated production costs for globally- and domestically-produced solar and wind components, in addition to the implications of the 45X manufacturing tax credit. We do not account for the 48C investment tax credit for clean energy manufacturing facilities, which may further decrease the price of domestically-produced components. We estimate the average costs of production across countries, taking into account factors such as labor, raw material, and transportation costs (but excluding tariffs). Note that final component *prices* can differ from *production costs* and will reflect competitive market dynamics (e.g. relative product pricing, producer margins, and pass-through of lower costs to purchasers) not assessed in this study.

Excluding the impact of 45X tax credit, we estimate that the cost of domestically-produced components across the solar supply chain are higher than imported component costs. This domestic production cost premium (in part) accounts for the low domestic production shares in 2021, including 16% for module assembly and effectively 0% for all other components[8]. The estimated cost of a solar PV module assembled in the U.S. and made from 100% domestically-manufactured components was $0.38/W[9] in 2021, while the global average cost for PV modules (excluding shipping and tariff costs) was 32% lower at $0.26/W[9]. Shipments of PV modules to the U.S. in 2021 were dominated by China, Singapore, Taiwan, and Vietnam (49%), followed by Malaysia (14%), and South Korea, Thailand, and the United Arab Emirates (22%), with the remaining 15% coming from the rest of the world[8]. After accounting for the impact of the 45X tax credit, the cost of domestically manufactured solar PV components is likely less than imported costs across the solar supply chain (including polysilicon ingots, wafers, cells, and module assembly as well as inverters). We estimate the 45X tax credit reduces the cost of modules assembled in the U.S. and made from 100% domestically-manufactured components to \$0.20/W, or more than 30% less expensive than imported modules (before accounting for tariffs).

We estimate the global average production cost for onshore wind turbines in 2021 was \$921 per kilowatt (kW), which accounts for turbine costs and market shares for the leading wind turbine manufacturers such as GE Wind (\$962/kW, 47%), Vestas (\$962/kW, 26%), SGRE (\$773/kW, 13%), and Nordex (\$846/kW, 13%)[10]. U.S. onshore wind manufacturing currently holds a market share of 15-25% for blades, 55-70% for nacelles, and 0-10% for towers[10], indicating a potential cost advantage for imported products. However, there are no publicly-available data to estimate the domestic and global cost spreads for wind turbine components, and correspondence with wind turbine manufacturers indicated that there is little notable cost difference after accounting for shipping. Given the nascent state of the U.S. offshore wind industry, there are no publicly-available data, but costs of globally and domestically-produced offshore wind components are likely to be approximately comparable[11]. Given approximately comparable costs for domestically- and globally-manufactured wind turbine components, the 45X tax credits will likely make U.S. manufactured onshore and offshore wind components less expensive to produce than imported products.

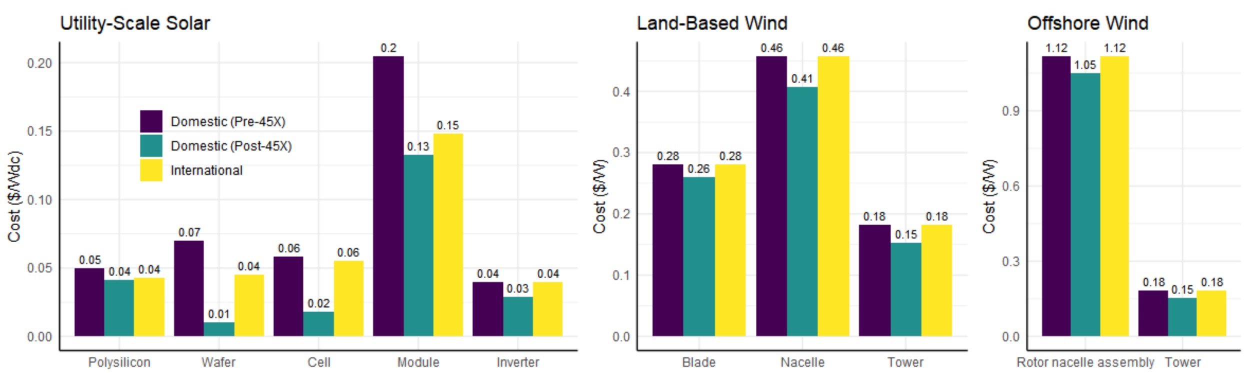

Figure 1. Estimated production costs for solar and wind components that are globally- and domestically-produced. Costs for domestically-produced components are reported prior to and after receiving the 45X tax credit. Production costs may differ from final product pricing. Refer to SI Table S17 for details.

Impacts of IRA incentives on levelized cost of electricity from wind and solar

We estimate the levelized cost of electricity (LCOE) – a measure of the net present value of capital and operations and maintenance (O&M) costs of electricity generation over the life of a project. For details of the LCOE formulation and parameterization, refer to SI Sections 1.2 and 1.3. We model technology costs for the following five policy scenarios: 1) no tax credits (baseline), 2) *base* rate PTC or ITC tax credit (labeled PTC/ITC), 3) *bonus* rate PTC or ITC tax credit (+PTC/+ITC), 4) *bonus* rate PTC or ITC tax credit and the adder for meeting either the *domestic content* or *energy community* requirement (+PTC1/+ITC1), or 5) *bonus* rate PTC or ITC tax credit and the adder for meeting both the *domestic content* and *energy community* requirements (+PTC2/+ITC2). For all policy scenarios, we assume that the value of 45X manufacturing tax credits for domestic manufactured content are transferred through to installed renewable project costs, which may be optimistic, as domestic manufacturers may retain some portion of the tax credit value. Reported LCOE thus reflects a lower-bound estimate on installed project costs. We further assume the effective pre-tax value of the ITC and PTC are adjusted to take into account an average marginal business tax rate of 21% and credit transfer overhead of 7.5%; this latter adjustment is included under the assumption that not all projects will have sufficient tax basis to make use of direct tax credits and hence are dependent on transferability of credits, which is likely to incur transaction costs. In addition, we model costs under alternative domestic content shares assumptions, including current (as of 2021) and 100% domestic shares. To estimate LCOE, we derive capacity factors for 2030, using the U.S. average capacity factors for 2021, (i.e., utility-scale solar 0.24, land-based wind 0.43, fixed offshore wind 0.49, and floating offshore wind 0.38) and inflating over time to reflect technological improvements (see SI Table S12 and SI Figures S2, S3, and S4).

Figure 2 depicts U.S. average LCOEs for each policy scenario and technology in 2030. For each technology, we present results for the either the ITC or PTC tax credit, depending on which incentive provides the lowest LCOE; based on U.S. average capacity factors, the PTC is preferable for utility-scale solar and land-based wind, and the ITC is preferable for offshore wind. We find that the PTC, ITC, and 45X manufacturing tax credit substantially reduce the LCOEs across all technologies. The 10% *domestic content* adder to the PTC and ITC has the potential to induce significant demand for solar and wind components manufactured in the U.S. and associated expansion of domestic manufacturing capacity.

We find that the LCOEs for utility-scale solar and land-based wind projects receiving the *bonus* tax rate have the potential to be approximately 60% lower than comparable projects receiving the *base* tax rate. Similarly, the LCOEs of offshore wind projects receiving the *bonus* tax rate have the potential to be approximately 20% lower than comparable projects receiving the *base* tax rate. Demonstrating compliance with the labor requirements to qualify for the *bonus* tax rate may add legal and compliance costs for project developers that are not estimated in this study. Additionally, since we assume median wages to estimate the labor cost component of LCOEs, we do not assume prevailing wage requirements increase median project costs. While meeting prevailing wage requirements may lead to small increases in LCOE for projects that currently pay below the median wage rate, we found in prior work that a 20% increase in installation and construction labor costs would increase the installed cost of solar and wind projects by only 3% and 1%, respectively[12]. Thus, additional project costs associated with meeting labor requirements to qualify for the *bonus* tax rate are likely more than compensated by the increase in the tax credit.

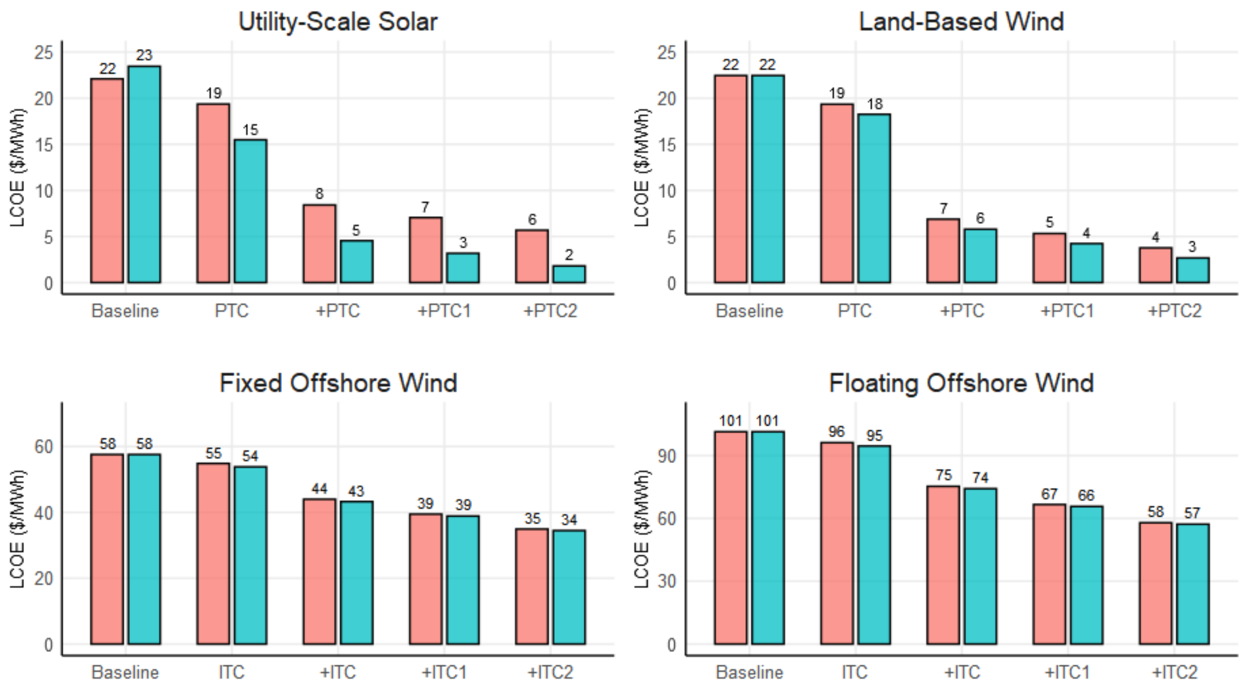

Figure 2. U.S. average levelized cost of electricity (LCOE) in 2030 for each policy scenario. Pink and turquoise bars indicate current (as of 2021) and 100% domestic content shares, respectively.

Figure 3 illustrates the impact of solar and wind capacity factors on LCOE. We find that the preferred policy incentive (i.e., ITC versus PTC) may depend on the capacity factor for each technology, as higher capacity factor leads to greater value from the PTC. The PTC generally is more cost-effective than the ITC for utility-scale solar and land-based wind technologies, regardless of the capacity factor. For floating offshore wind, the ITC is always more cost-effective than the PTC, regardless of capacity factor. For fixed offshore wind, the differential in LCOE with the ITC and PTC incentives are very similar, and the most cost-effective incentive varies based on capacity factor.

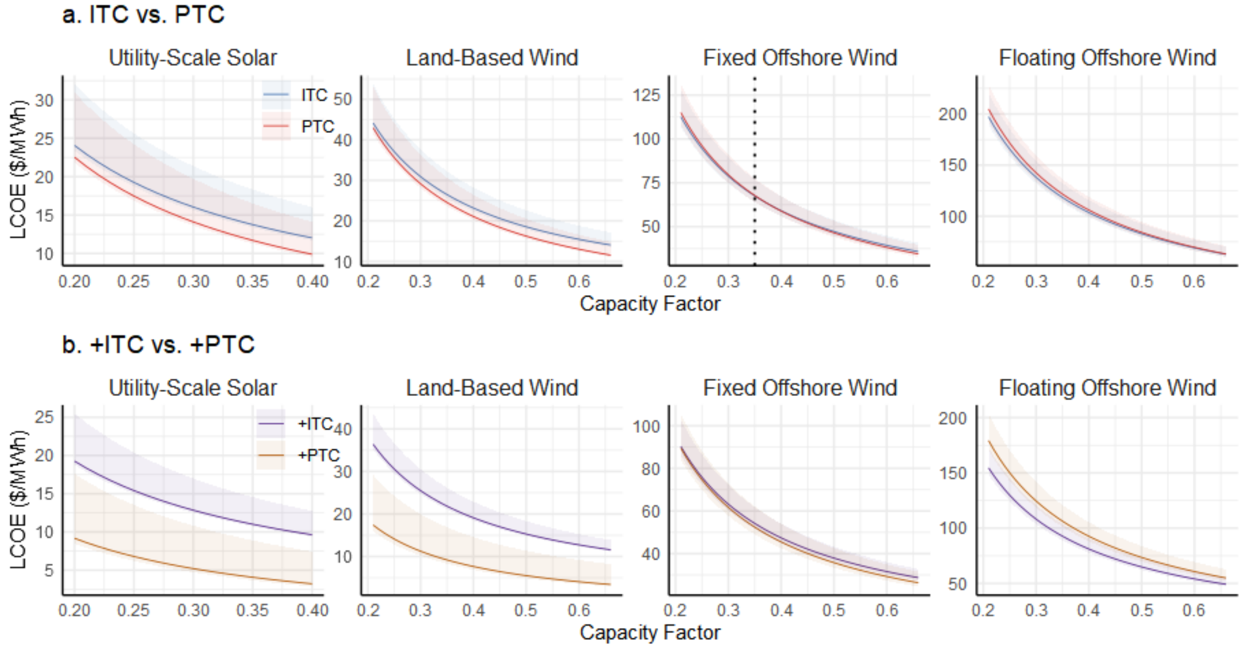

Figure 3. Levelized cost of electricity (LCOE) for each technology with respect to capacity factor. The impact of capacity factors is evaluated for the *base* (a) and *bonus* (b) tax credit rates. The LCOE for 2030 is depicted by solid lines, while the shaded regions represent the potential range of LCOE values from 2023 to 2050. The vertical dotted lines represent capacity factors, where the minimum LCOE shift occurs between policy scenarios.

Figure 4 depicts the LCOE projections for projects that enter service between 2022 and 2032 assuming average capacity factors (see SI Figure S7 for LCOE projections out to 2050). These LCOE projections reflect declining renewable technology costs and increasing capacity factors over time. Note that IRA specifies that incentives will phase down over a four-year period (at 100%, 75%, 50% and 0% of full value) beginning the year after 2032 *or* the year after the power sector reduces greenhouse gas emissions to 25% of 2022 levels, whichever comes later.

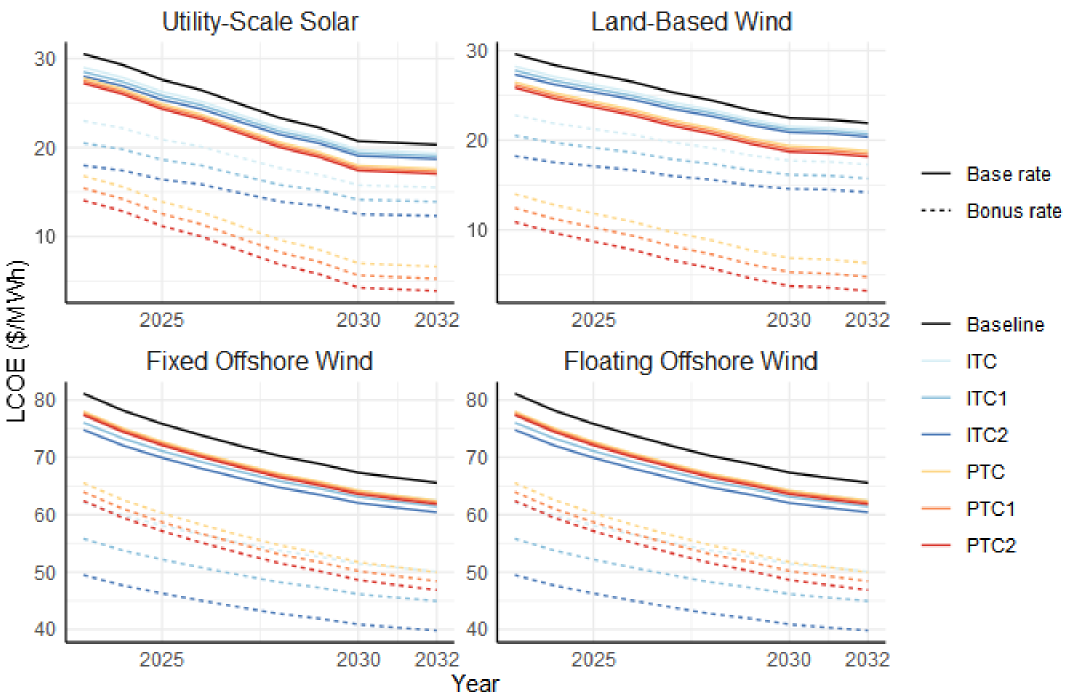

Figure 4. Levelized cost of electricity (LCOE) for alternative policy scenarios from 2022 to 2032. Current domestic content shares are assumed.

Figure 5 depicts spatially-explicit LCOE estimates for alternative policy scenarios for 2030. Spatial variation in LCOE estimates reflect heterogeneous capacity factors, estimated transmission interconnection costs, and the *energy community* tax credit adder. These incentives make many regions economically feasible to develop. For utility-scale solar, the West, Southwest, and South of Rocky Mountain regions have the lowest LCOE due to high solar irradiation levels. In contrast, the Midwest and Texas are the most cost-effective regions for developing wind projects.

The LCOE differential of the *bonus* rate incentives (relative to the baseline) are greatest in regions with higher LCOEs (refer to SI Figure S9). Solar projects experience the highest cost reduction in the West, Southwest, and Northwest regions with the bonus ITC, and in the South Texas and Southeast regions with the bonus PTC. The largest LCOE differentials for land-based wind projects are in the West and Southeast regions.

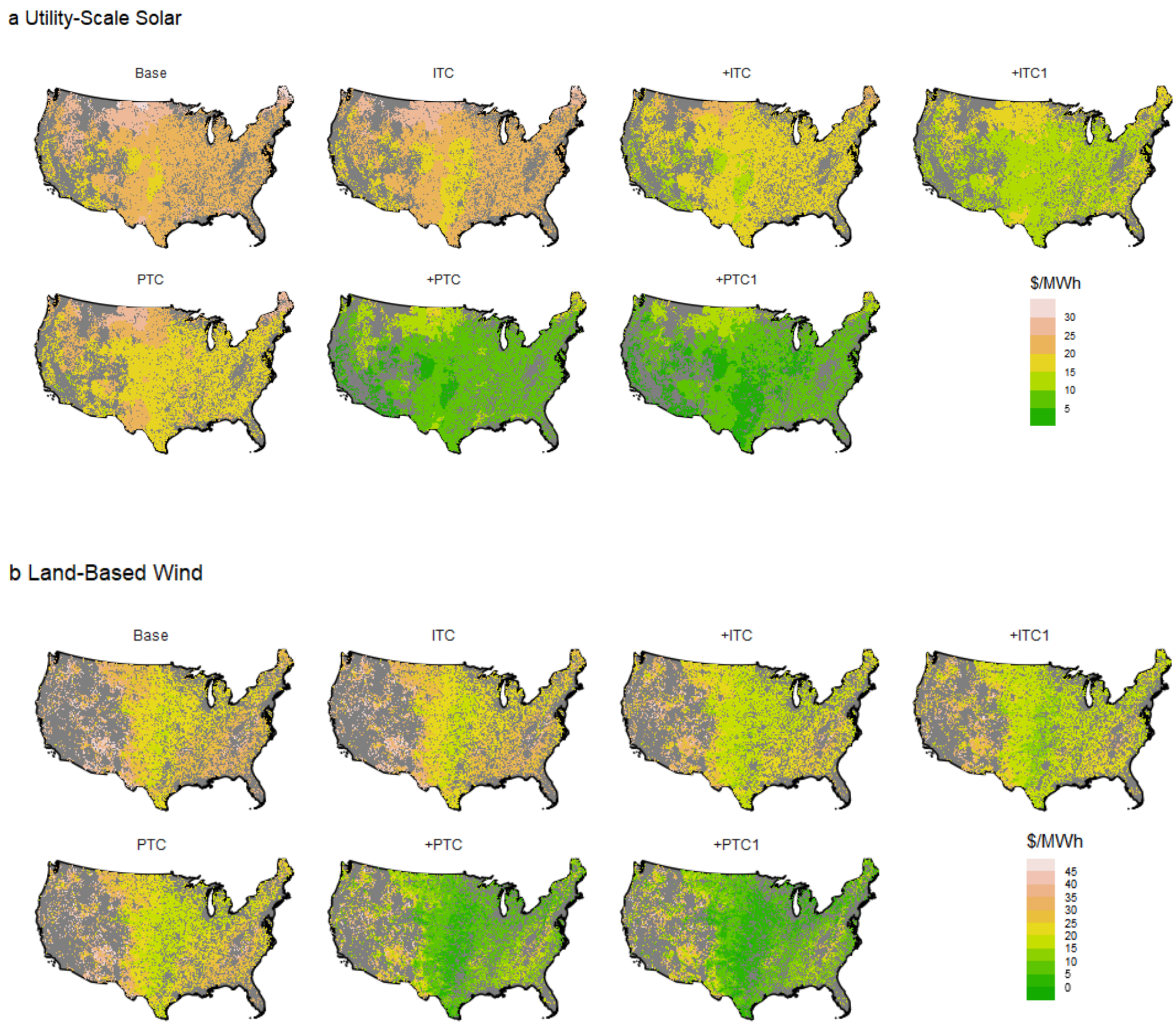

Figure 5. Spatially-explicit levelized cost of electricity (LCOE) for alternative policy scenarios for 2030, including site-specific estimated transmission interconnection costs. Gray shaded regions indicate areas that are unsuitable for project development based on site suitability screening[13]. In addition to the site suitability screening, areas with an LCOE over $50/MWh for wind were also considered unsuitable.

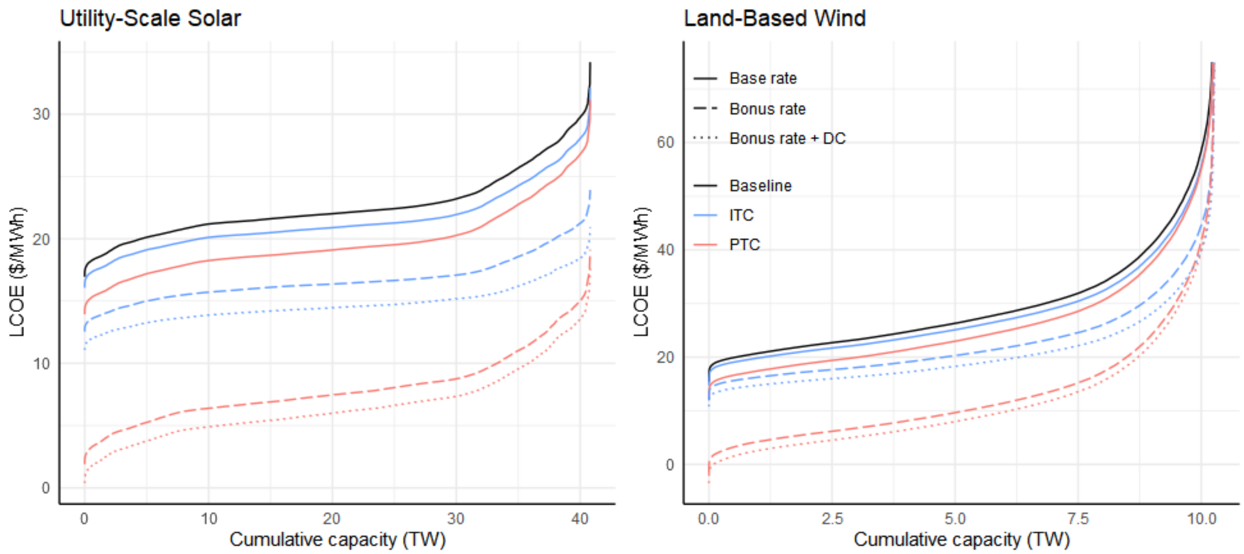

Figure 6. Utility-scale solar and wind supply curves for alternative policy scenarios for 2030. These curves are a transposition of the maps in Figure 5.

Demand for materials from utility-scale solar and wind deployment associated with IRA

We simulate aluminum, cement, and steel demand induced by the modeled expansion of utility-scale solar, land-based wind, and offshore wind capacity. We leverage the techno-economic modeling framework used in the Rapid Energy Policy Evaluation and Analysis Toolkit (REPEAT) project to determine cost-optimized energy supply pathways associated with the implementation of the IRA and the Infrastructure Investment and Jobs Act of 2021 (IIJA).

Figure 7 shows that demand for materials for wind and solar projects substantially increases from 2022 to 2035, with aluminum demand largely driven by solar capacity expansion and cement demand driven by land-based wind capacity expansion. Mid-range estimates of total aluminum, cement, and steel demand for solar and wind are projected to increase from 0.2, 0.6, and 1.7 Mt per year in 2022 to 7.8, 6.5, and 39.6 Mt in 2035, respectively. Absent the IRA, annual aluminum, cement, and steel demand from the wind and solar is projected to be 2.2, 1.8, and 18.5 Mt in 2035, respectively. Note that there is uncertainty regarding material intensity values for wind and solar projects, resulting in a substantial range in projected material demand (refer to SI Figures S11-S12); for example, projected aluminum demand ranges from 2.8 to 12.7 Mt, depending on the assumed material intensity.

In Figure 8, we contextualize material demand projections relative to U.S. production and consumption in 2022. Mid-range estimates of aluminum and steel demand induced by the implementation of the IRA in 2035 are 131% and 37% of U.S. consumption in 2022, respectively (156% and 42% of production). For aluminum and to a lesser extent steel, a large and rapid expansion of total supply is required to meet demand, which can be met through increased domestic production or imports. Notably, the 10% *domestic content* adder to the PTC and ITC requires 100% of steel and iron be sourced from the U.S. and a substantial share of the value-added content in manufactured goods be produced domestically, suggesting that much of the increased materials demand may be satisfied by increased domestic production.

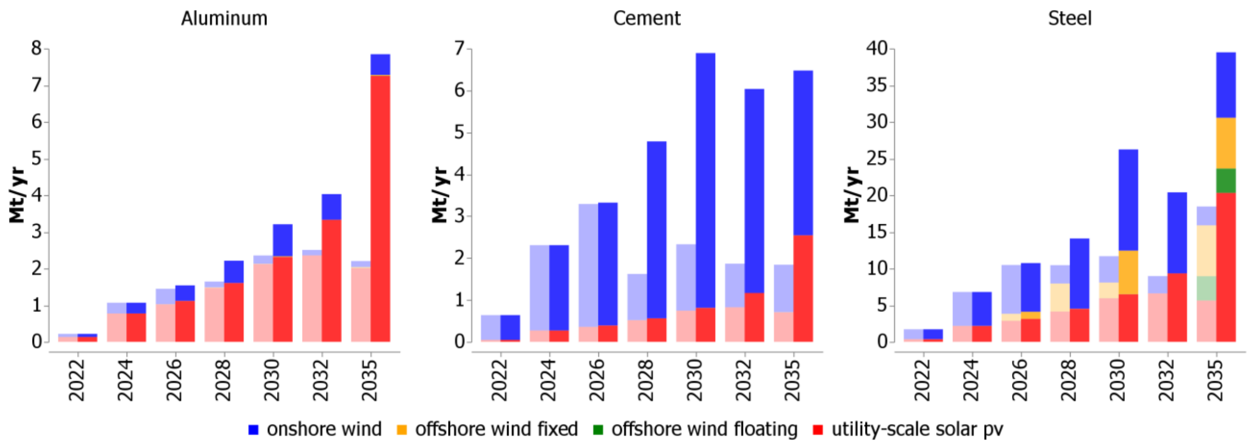

Figure 7. Material demand for each technology from 2022 to 2035 with (dark bars) and without (light bars) the implementation of the IRA.

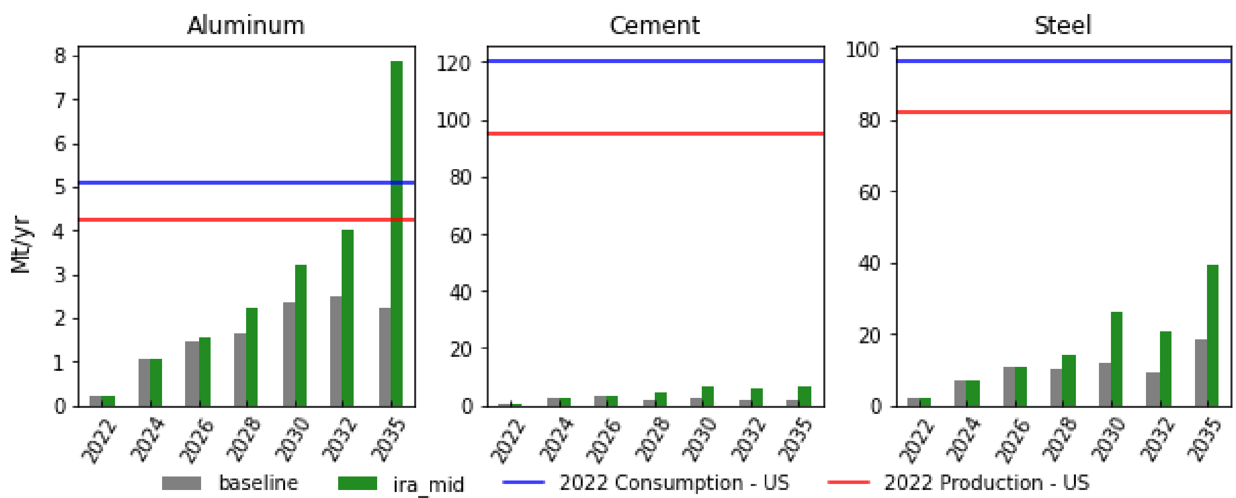

Figure 8. Material demand from 2022 to 2035 without (gray bars) and with (green bars) the implementation of the IRA compared to 2022 consumption (blue lines) and production (red lines).

Labor demand from utility-scale solar and wind deployment associated with IRA

We evaluate the labor implications of wind and utility-scale solar PV deployment under the IRA. We use the Decarbonization Employment and Energy Systems (DEERS) model to assess the labor implications of the cost optimal techno-economic pathways described in the previous section as input. We model demand for direct employment and wages associated with solar and wind manufacturing, installation, and operations and maintenance (O&M) under alternative domestic manufacturing share and wage rate assumptions. Note that reported estimates reflect *demand* for labor, and domestic labor *supply* constraints may influence real world employment outcomes.

As shown in Figure 9, we estimate the IRA could induce demand for about 1.3 million additional jobs related to utility-scale solar PV and 250,000 additional wind related jobs in 2035 (Figure 9c-d), relative to the level of employment in these sectors without passage of IRA and at current domestic content shares for wind and solar components. This includes demand for approximately 800,000 additional jobs in solar manufacturing and 55,000 additional jobs in wind manufacturing by 2035.

The induced demand for solar and wind employment under IRA is the result of both accelerated renewable power capacity additions associated with PTC/ITC tax credit incentives as well as increases in domestic manufacturing associated with the 45X manufacturing credit and the PTC/ITC *domestic content* adder. Figures 9a-b depict total demand for utility-scale solar and wind labor over time assuming domestic content shares gradually increase at rates consistent with a plausible expansion of the domestic manufacturing base shown in Figure 9e. Figures 10a-b depict employment in 2035 under different policies (with and without the IRA) and illustrate the impact of different domestic content share assumptions on manufacturing employment. As illustrated by Figure 10, we estimate that demand for domestic solar and wind manufacturing labor in 2035 would be about 800,000 jobs lower if solar and wind deployment expanded at modeled rates but domestic content shares remained at current (as of 2021) levels.

With the IRA and assuming the gradual increase in domestic content shares in Figure 9e, the wind and solar PV sectors could induce demand for a total of approximately 800,000 utility-scale solar-related jobs and 520,000 wind-related jobs by 2030. While wind employment remains somewhat constant, total solar employment grows substantially more to a total of roughly 1.7 million solar jobs by 2035, including 800,000 million in construction and operations of utility-scale solar projects and 850,000 million in solar component manufacturing. These figures compare to approximately 300,000 utility-scale solar-related jobs and 200,000 wind-related jobs in U.S. in 2023.

As depicted in Figures 11a-b, the IRA induces a net increase in wages in the solar sector of approximately $30B in 2030 and $70B in 2035, assuming domestic content shares gradually increase as per Figure 9e. In the wind sector, net wage increases are approximately $15B in both 2030 and 2035. This estimate assumes the workforce earns median real wages and does not account for wage increases that may be induced by the labor requirements to qualify for the *bonus* tax rate or any increases in compensation that may be required to satisfy high demand for labor in the expanding wind and solar sectors. We also estimate total wages associated with increasing median wage rates, as shown in Figure 11c. In prior research, we estimate that a 20% increase in installation and construction labor costs would increase the installed cost of utility-scale solar PV and wind projects by only 3% and 1%, respectively[12].

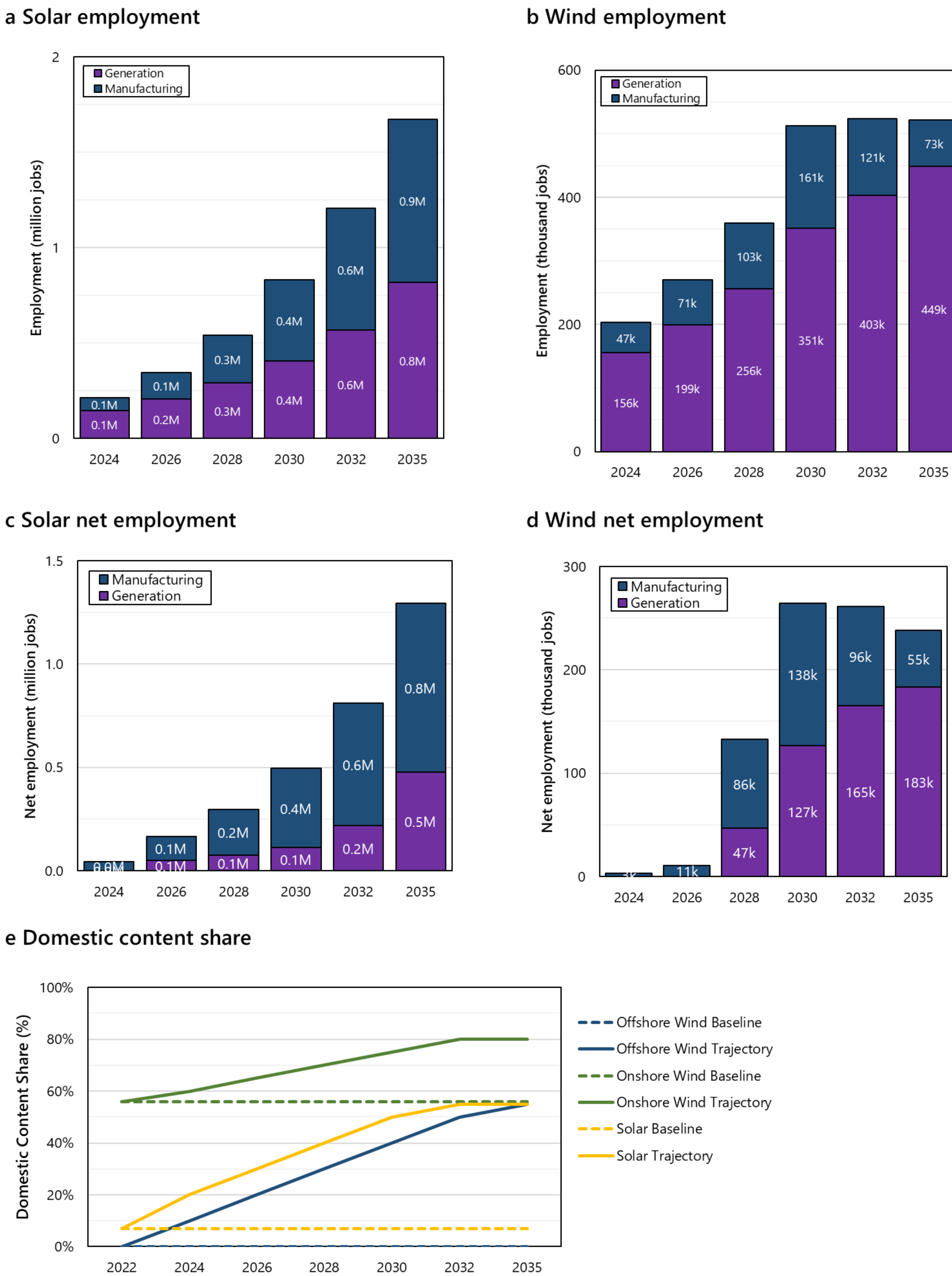

Figure 9. Employment (a-b) from 2024 to 2035 associated with utility-scale solar, land-based wind, and offshore wind deployment assuming increasing domestic content shares as per REPEAT Project assumptions (e). Net employment (c-d) is the difference in employment with the IRA and increasing domestic content shares, and without the IRA and constant domestic content shares.

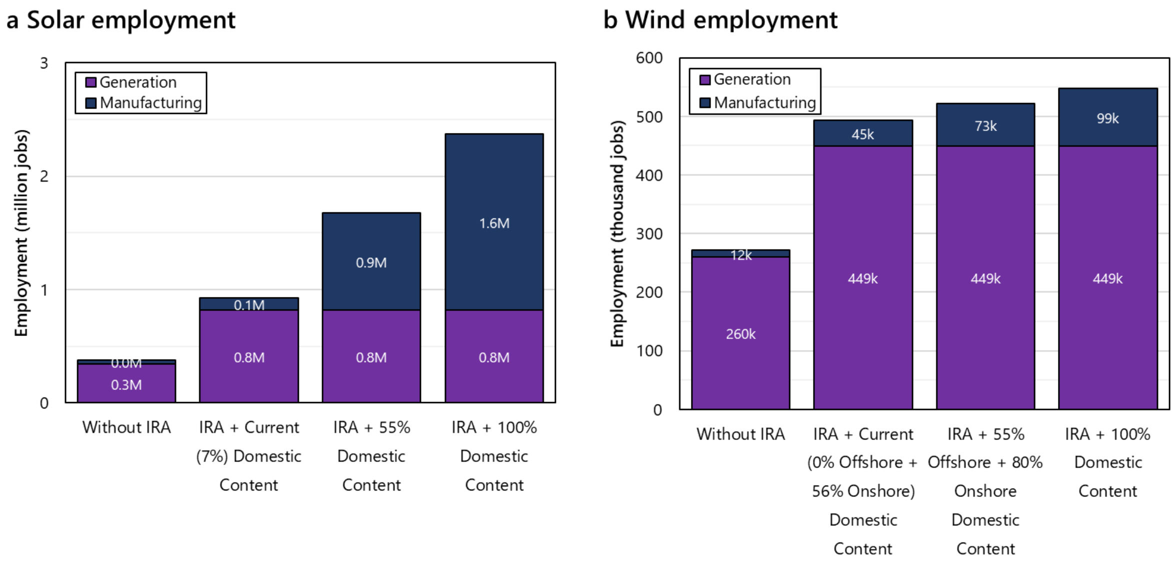

Figure 10. Employment (a-b) in 2035 associated with utility-scale solar, land-based wind, and offshore wind deployment across different policy scenarios (with and without the IRA) and domestic content share assumptions.

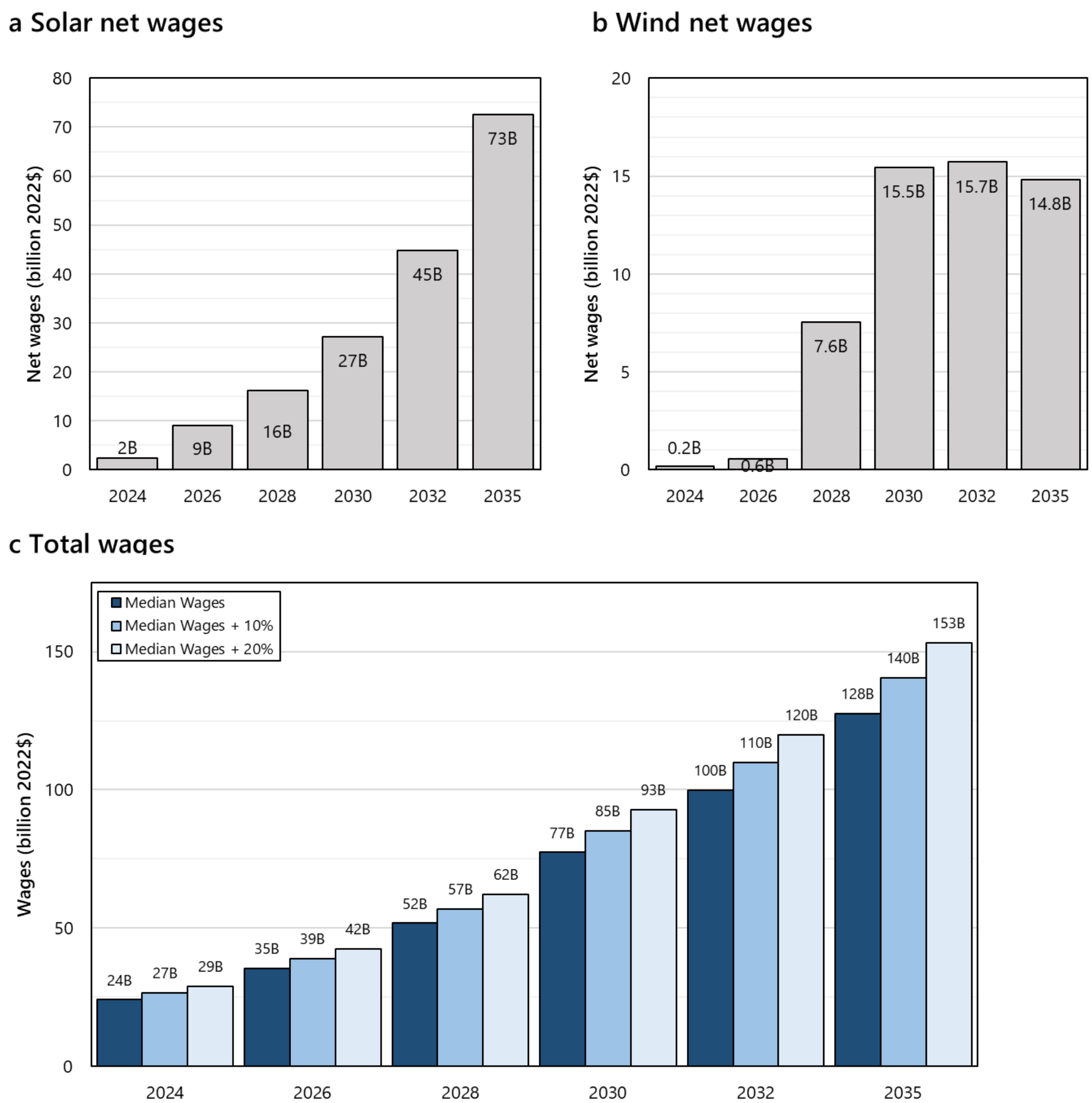

Figure 11. Wages from 2024 to 2035 associated with utility-scale solar, land-based wind, and offshore wind deployment. Net wages (a-b) are the difference in wages with and without the IRA, assuming median wage rates for each occupation. Underlying domestic content share assumptions are shown in Figure 9e. Wages (c) are shown for alternative wage rates for each occupation, including median wage rates, median wage rates plus 10%, and median wage rates plus 20%.

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