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Emissions and Energy Impacts of the Inflation Reduction Act

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Competing interests: Jesse Jenkins is part owner of DeSolve, LLC, which provides techno-economic analysis and decision support for clean energy technology ventures and investors. A list of clients can be found at https://www.linkedin.com/in/jessedjenkins. He serves on the advisory boards of Eavor Technologies Inc., a closed-loop geothermal technology company, and Rondo Energy, a provider of high-temperature thermal energy storage and industrial decarbonization solutions and has an equity interest in both companies. He also provides policy advisory services to Clean Air Task Force, a non-profit environmental advocacy group, and serves as a technical advisor to MUUS Climate Partners and Energy Impact Partners, both investors in early-stage climate technology companies. Ryan Wiser is a senior scientist at Lawrence Berkeley National Laboratory, on partial detail under contract to the U.S. Department of Energy. The other authors declare no competing interests.

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Introduction

If goals set under the Paris Agreement are met, the world may hold warming well below 2 °C (1); however, parties are not on track to deliver these commitments (2), increasing focus on policy implementation to close the gap between ambition and action. Recently, the US government passed its most prominent piece of climate legislation to date—the Inflation Reduction Act of 2022 (IRA)—designed to invest in a wide range of programs that, among other provisions, incentivize clean energy and carbon management, encourage electrification and efficiency measures, reduce methane emissions, promote domestic supply chains, and address environmental justice concerns (3). IRA's scope and complexity make modeling important to understand impacts on emissions and energy systems. We leverage results from nine independent, state-of-the-art models to examine potential implications of key IRA provisions, showing economy wide emissions reductions between 43-48% below 2005 by 2035.

This multi-model analysis provides a range of decision-relevant information. For example, international policymakers and negotiators need to track progress toward Paris Agreement pledges, and assessing IRA's impacts is important to monitor US efforts and to provide a template for measuring the performance of other sectors and jurisdictions. Federal and state policymakers can use this IRA analysis to compare updated baselines with policy targets —for emissions, electric vehicle deployment, and others—to understand the magnitude of additional policies and private sector actions needed to narrow implementation gaps. Electric companies need to know how long IRA incentives will be available, since these subsidies can continue until electricity emissions are below 25% of their 2022 levels, which requires national models to evaluate. Industry- and technology-specific deployment can support investors, technology developers, researchers, and companies to quantify market opportunities.

Modeling IRA Provisions

Some of the models used in our analysis informed legislative debates preceding IRA's passage (4–7). We build on these preliminary analyses by updating IRA representations, increasing the number of models, and providing a systematic comparison of decision-relevant metrics. Multi-model studies highlight the robustness of insights and potential uncertainties to alternate model structures and input assumptions. Models in this study vary in their coverage and implementation of IRA provisions (Table S1). These differences are due to the models' scopes (e.g., 6 models of the full US energy system vs. 3 that focus on the power sector only) and resolutions (e.g., level of technological and sectoral detail). Variations in IRA implementation across models are also caused by the bill's complexity and pending guidance from government agencies, which require subjective judgments from modeling teams. The partial coverage of IRA provisions could imply that models underestimate emissions reductions, though many of IRA's largest provisions are represented and the degree of additionality of the remaining provisions is unclear (SM S7). Other simplifications (e.g., limited representations of frictions associated with infrastructure deployment, supply chains, and non-cost barriers) could result in higher emissions relative to modeled outcomes. These uncertainties imply that model results should not be interpreted as predictions (SM S1).

To evaluate impacts on emissions and energy systems, IRA scenarios are compared to their counterfactual reference scenarios without IRA (SM S2). IRA scenarios focus on central estimates of climate and energy provisions, which are not harmonized across models.

Emission Reduction Pathways

Economy-wide emissions reductions from IRA are 33-40% below 2005 in 2030 across multi-sector models with a 37% average (Fig. 1). This reflects a range of IRA provisions modeled, input assumptions, and model structures (SM S1). The 2030 range with IRA of 33-40% is a significant reduction from the reference without IRA incentives, which is 25-31% below 2005 (28% average). Emissions reductions from IRA grow over time and lead to 43-48% declines by 2035 from 2005 (compared with 27-35% in the reference). IRA helps to narrow the implementation gap in achieving the US 2030 target to reduce net greenhouse gas (GHG) emissions by at least 50% (8–9). The emissions gap is 1.0-1.6 Gt-CO_2e/yr without IRA, falling to 0.5 to 1.1 Gt-CO_2e/yr with IRA (19-25 percentage points to 10-17 p.p., Fig. S6).

Emissions reductions are not evenly distributed across sectors (Fig. 1B). Most IRA-induced mitigation comes from electricity, representing 38-80% of 2030 reductions (64% average) from the reference in economy-wide models. There is consistency across models that IRA will accelerate power sector decarbonization (Fig. S7). In 2030, power sector emissions with IRA are 47-83% (68% average) below their 2005 levels compared to 41-60% (51% average) in the reference. IRA-induced reductions continue through 2035, and the range narrows to 66-87% (77% average) with a 13-36 p.p. reduction from the reference (Fig. S7B), short of the goal of 100% “carbon pollution-free electricity” by 2035 (8). The technology-neutral tax credits under IRA for zero-emitting resources continue after 2032 until electricity emissions are 25% of 2022 levels. Three of nine models reach this threshold by 2035.

Effects of IRA on the Power Sector

IRA includes many electricity-related provisions (Table S1), including investment (30%) and production ($27.5/MWh, 10 year) tax credits for clean electricity resources, tax credits for energy storage and carbon capture, and tax credits to maintain existing nuclear plants. Some provisions involve long-term extensions of pre-IRA tax credits (e.g., for wind and solar), some involve increases in tax credit levels (e.g., carbon capture credits, bonuses for production and investment credits), and others are new (e.g., support for existing nuclear).

Models consistently show that IRA leads to large increases in wind and solar deployment but with substantial variation in magnitudes (Fig. S13A). Across all models, growth rates from 2021 to 2035 range from 10-99 GW/yr for solar and wind under IRA (58 GW/yr average), which is more than twice the average of 27 GW/yr without IRA and higher than the record

33 GW installed in 2021. There is wide variation in the expected increase in energy storage across models, 1-18 GW/yr (7 GW/yr average), compared with 0-8 GW/yr in the reference.

Results also exhibit reductions of unabated coal generation (i.e., without any carbon capture and storage (CCS)), ranging from 38-92% declines from 2021 levels by 2030 with IRA (Fig. 2) versus 3-60% without IRA. Five models show retrofits of some share of coal capacity with CCS, driven by the high value of tax credits for stored CO_2 (increasing from \$50/t-CO_2 historically to \$85/t-CO_2) (Fig. S13). Most models suggest that natural gas generation will decline under IRA relative to today's levels; however, gas-fired capacity increases in all models to provide firm capacity as coal retires and load grows (Fig. S13).

Overall, generation shares from low-emitting technologies—including renewables, nuclear, and CCS—in 2030 vary between 49-82% (68% average) across models with IRA (Fig. S13B), up from about 40% today and from 46-65% without IRA (54% average), an 11–33 p.p. increase. Power sector generation and emissions outcomes under IRA are more closely aligned by 2035 across models (Fig. S7 and S13).

Implications of IRA on End-Use Demand

IRA reduces transport emissions by accelerating electrification. Across models, electric vehicles (EVs) are 32-52% of new light-duty vehicle sales by 2030 with IRA (41% average), compared with 22-43% (31% average) in the reference (Fig. 2 and S14), which is several times 2022 sales levels of about 7%. EV sales decrease or flatten between 2030 and 2035 due to the expiration of IRA tax credits. The electrified service demand share, stock share, and emissions lag new sales, given the turnover rate of the fleet (Fig. S15). EV credits in IRA also exist for commercial vehicles, including vans, buses, and trucks. These incentives help electrify these segments, representing about one-third of transport electricity demand by 2030 (Fig. S17). Transport exhibits the highest growth in electrification, though the magnitude varies by model (2-6% of final energy use in the sector by 2030 with IRA, 1-4% in the reference).

IRA incentives also encourage building efficiency and electrification, especially the adoption of heat pumps for space and water heating. Buildings currently have the highest electrification share of end-use sectors (just under 50% of final energy use in the sector), which increases as end-uses electrify (Fig. S16). Fuel switching from fossil fuels to electricity in buildings, transport, and industrial sectors leads electricity's economy-wide share of final energy to increase from about 21% today to 23-26% by 2030 (Fig. 2) and 25-29% by 2035.

These projected changes in demand may drive the first sustained period of declining petroleum use in US history (Fig. S18). By 2030, IRA scenarios show a 11-32% (22% average) decrease in petroleum consumption from 2005, but much of this happens in the reference (11-31% with 20% average) due to the competitiveness of transport electrification and continued efficiency improvement in the remaining internal combustion engine fleet. Natural gas consumption also decreases with IRA relative to the reference scenario, especially in the power sector, but declines relative to its historical peak are not as high as for petroleum and coal. IRA may catalyze several new markets in industry and fuels, including CCS, hydrogen, biofuels, and sustainable aviation fuels. Tax credits for captured CO_2 may accelerate emissions reductions across a variety of industries and lead to CCS deployment in the industrial sector, fuel production, and the power sector (Fig. S22).

Societal Implications of IRA

The climate-related benefits of IRA are estimated to be substantial (Fig. S10), even though there is uncertainty about the magnitude of the social cost of CO_2 (10, Fig. S9) and model-specific emissions impacts of IRA (Fig. 1B). Climate benefits range from $44-220B annually by 2030 across models using central social cost of CO_2 values with a 2% near-term discount rate ($20-100B with a 3% rate). Implied average abatement costs of IRA incentives per unit of CO_2 reduced range from $27-102/t-$CO_2$ with an average of $61/t-$CO_2$ across all models (Fig. S11). Although these costs are higher for economy-wide models (SM S4), abatement costs are much lower than many updated social cost of CO_2 estimates, even before accounting for co-benefits.

Declining fossil fuel use not only lowers GHG emissions but also conventional air pollutants, which improves public health outcomes. Fig. S12 compares reductions in SO_2 and NO_x in the power sector and across the economy. Individual studies indicate that monetized health benefits from power sector air pollution reductions alone are $9-22B annually by 2030 (11, 12), and $53B annually by 2030 from particulate matter reductions across the economy (8).

These declines in fossil fuel use generally mean that IRA lowers energy costs for households and businesses (Fig. S19), despite increases in electricity spending. The magnitudes of these consumer cost changes vary over time and across the four economy-wide models reporting fuel expenditures, but net spending declines $2-26B/yr by 2030 ($13-190 per household) relative to the reference and $10-52B per year by 2035 ($73-370 per household). Electrification and accelerated investments increase electricity expenditures for most economy-wide models, even though there is a reduction in total net energy service costs. Incentives for the adoption of end-use technologies such as EVs and heat pumps also can lower capital and maintenance costs.

The magnitude and composition of tax credit value under IRA vary by model (Fig. S21). Estimates from economy-wide models suggest that $330-870B could be spent on tax credits through 2030 ($510B average), which suggests uptake of IRA incentives could be greater than initial CBO/JCT estimates indicated (3). Cumulative tax credit expenditures through 2035 span $640-1,300B ($910B average), indicating that some IRA impacts may take longer to materialize. Individual studies perform analysis to understand broader societal implications of IRA, including improving distributional outcomes (11), increasing jobs (5, 6, 12), and bolstering domestic manufacturing (13).

Conclusions and Key Unknowns

While IRA accelerates decarbonization, including beyond 2030, no models indicate that the 2030 US climate target would be met with IRA alone. Overall, the analysis suggests that IRA may have its largest effects in the power sector, as its incentives amplify trends already underway and lower decarbonization costs. Modeling IRA impacts is challenging, since net effects depend on clean energy adoption, producer choices, household purchases, and actions by policymakers. Several key unknowns remain.

For example, lowering clean energy costs may increase ambitions of other federal agencies, state and local governments, and companies, though there are many complex drivers of such goals.

These dynamic effects of ratcheting ambition are not accounted for in the modeled scenarios described here but may be key to closing the 2030 implementation gap. In recent months, the US Environmental Protection Agency has released proposed standards that target emissions from cars, trucks, and power plants. These complementary regulations are aimed at leveraging IRA incentives to further accelerate decarbonization trends and lower costs of future regulations.

Also, expanded and new tax credits in IRA—combined with grants, loans, fees, domestic manufacturing incentives, and Infrastructure Bill incentives—support technologies that have experienced recent growth (e.g., wind, solar, batteries) and catalyze new markets for other decarbonization options (e.g., CCS, new nuclear, hydrogen, biofuels). Making clean technologies cheap to accelerate adoption can, in turn, buy down learning curves and encourage further deployment. By making low-emitting technologies cheaper domestically, IRA may have international spillovers, bolstering the political economy of those making their own investments and policies. Emerging technologies have larger uncertainty about induced technical change owing to their limited deployment and nascent markets.

Finally, models attempt to capture many economic factors that could influence technology adoption, but several implementation challenges are difficult to model, including the scale-up of supply chains and materials, siting and permitting, infrastructure expansion, network effects, non-cost barriers to consumer uptake of incentives, and the economic incidence of subsidies. These questions have prompted debate about permitting reform to streamline the infrastructure approval process and increase the pace of clean energy deployment, though legislative disagreements have emerged about the types of projects included and about balancing these reforms with environmental safeguards and community participation. Broader macroeconomic trends of escalating interest rates, materials costs, and labor costs can lower decarbonization rates, though IRA incentives can help to offset these factors (14). Additional analysis is important for understanding potential impacts of partial coverage of IRA provisions, IRA implementation uncertainties, as well as uncertainties about external factors, including inflationary trends, domestic macroeconomic environment, and global drivers (SM S2).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data and materials availability:

All data and materials associated with the analysis are available at https://doi.org/10.5281/zenodo.7879732.

References

1. Meinshausen M et al. Realization of Paris Agreement Pledges May Limit Warming Just Below 2 °C. Nature 604, 304–309 (2022). [PubMed: 35418633]
2. United Nations Environment Programme, "Emissions Gap Report 2022: The Closing Window" (2022); https://www.unep.org/resources/emissions-gap-report-2022.
3. Congressional Budget Office, "Summary: Estimated Budgetary Effects of Public Law 117-169, to Provide for Reconciliation Pursuant to Title II of S. Con. Res. 14" (2022); https://www.cbo.gov/system/files/2022-09/PL117-169_9-7-22.pdf.
4. Larsen J et al. "A Turning Point for US Climate Progress: Assessing the Climate and Clean Energy Provisions in the Inflation Reduction Act" (Rhodium Group, 2022).
5. Jenkins J et al. "Preliminary Report: The Climate and Energy Impacts of the Inflation Reduction Act of 2022" (REPEAT Project, 2022).
6. Mahaan M et al. "Modeling the Inflation Reduction Act Using the Energy Policy Simulator" (Energy Innovation, 2022).
7. Roy et al. "Retail Electricity Rates Under the Inflation Reduction Act of 2022" (Resources for the Future, 2022).
8. U.S. Government, "Reducing Greenhouse Gases in the United States: A 2030 Emissions Target" (2021); https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf.
9. Bistline J et al. Actions for Reducing U.S. Emissions at Least 50% by 2030. Science 376, 922–924 (2022). [PubMed: 35617382]
10. Rennert et al. Comprehensive Evidence Implies a Higher Social Cost of CO_2. Nature 610, 687–692 (2022). [PubMed: 36049503]
11. Roy N et al. "Beyond Clean Energy: The Financial Incidence and Health Effects of the IRA" (Resources for the Future, 2022).
12. Levin A, Ennis J, "Clean Electricity Tax Credits in the Inflation Reduction Act Will Reduce Emissions, Grow Jobs, and Lower Bills" (National Resources Defense Council, 2022).
13. Jiang B et al. "U.S. Inflation Reduction Act: A Tipping Point in Climate Action" (Credit Suisse, 2022).
14. Bistline J et al. Economic Implications of the Climate Provisions of the Inflation Reduction Act. Brookings Papers on Economic Activity (2023).

15. Bistline J et al. "Data for Bistline, et al. (2023) 'Emissions and Energy Impacts of the Inflation Reduction Act'" (Zenodo, 2023); 10.5281/zenodo.7879732.

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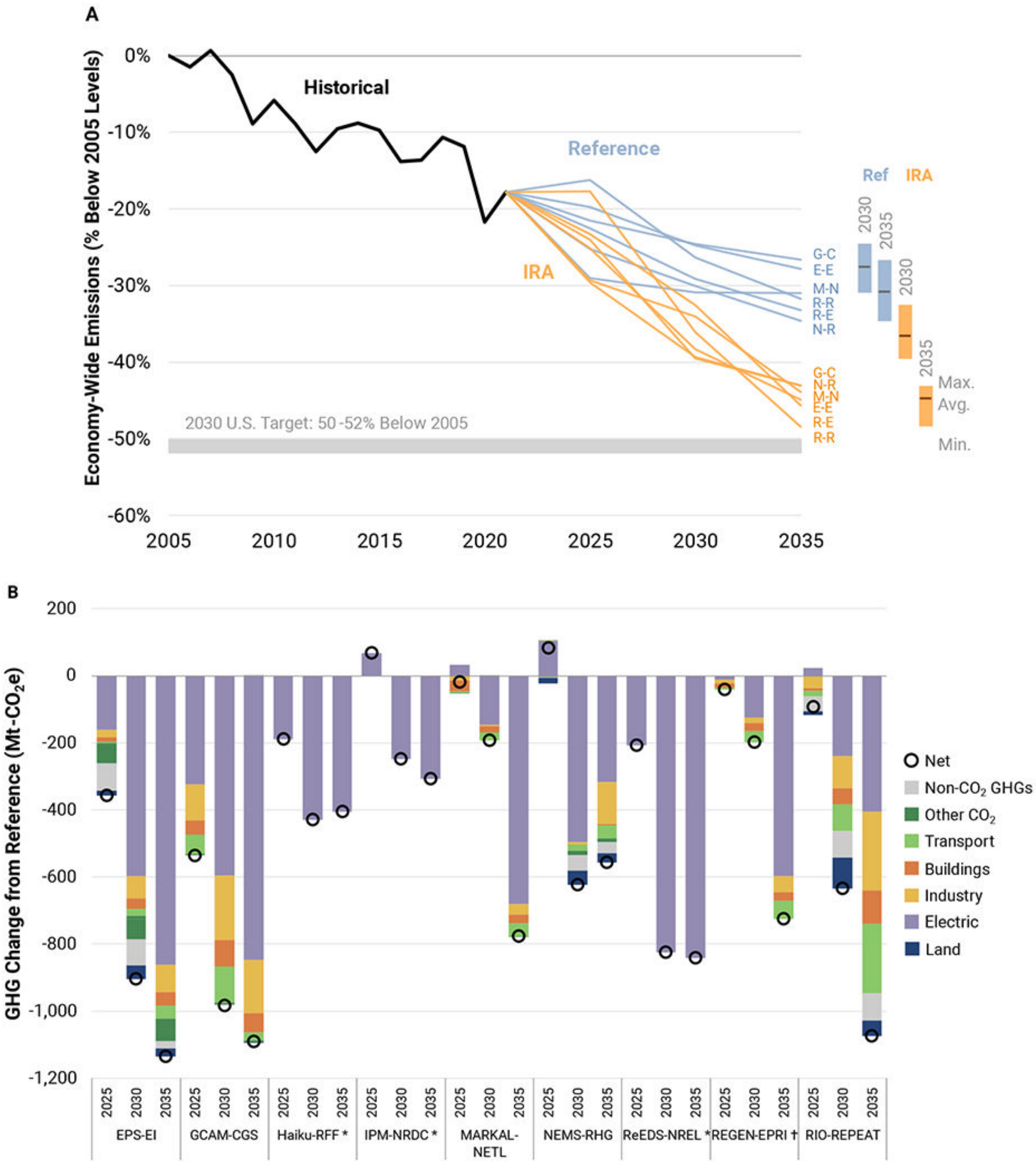

Fig. 1. Cross-model comparison of U.S. emissions reductions under IRA and reference scenarios from 2005 levels.

(A) Historical and projected economy-wide GHG emissions. Historical emissions and 100-year Global Warming Potential values (for models representing non-CO_2 GHGs) are based on the U.S. EPA's "Inventory of U.S. Greenhouse Gas Emissions and Sinks." **(B)** Emissions reductions by sector and model over time under IRA scenarios relative to reference levels. Models with * designate that electric sector IRA provisions only are represented, and † denotes energy CO_2 IRA provisions only. Additional information on participating models and study assumptions can be found in Materials and Methods S1 and S2.

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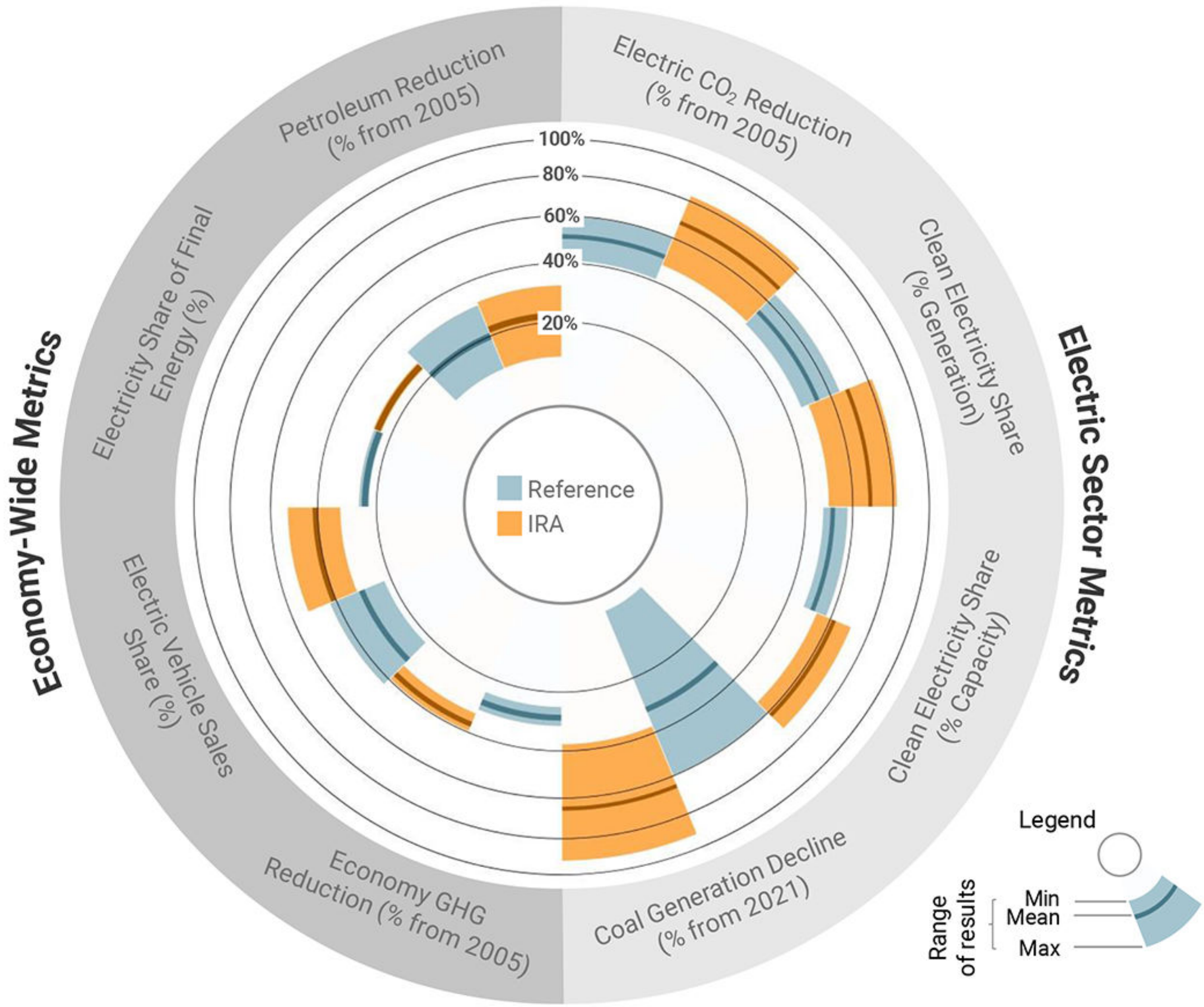

Fig. 2. Summary of key indicators for IRA and reference scenarios across models.

Clockwise from the top, indicators are 2030 electric sector CO_2 reductions (% from 2005 levels), 2030 generation share from low-emitting technologies (%, including renewables, nuclear, and CCS-equipped generation), 2030 capacity share from low-emitting technologies (% installed capacity), 2030 coal generation decline (% from 2021 levels), economy-wide CO_2 reduction (% from 2005 levels), 2030 electric vehicle new sales share (% of new vehicle sold are battery or plug-in hybrid electric), 2030 electricity share of final energy (%), and 2030 petroleum reduction (% from 2005 levels). Model-specific values for these metrics are provided in Table S6.