GridLab, RENEW Wisconsin, Clean Wisconsin & Evolved Energy Research

The economic impacts of decarbonization in Wisconsin

cambridge econometrics
clarity from complexity

Final Report

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Contents

Executive Summary

The state of Wisconsin is currently heavily reliant on fossil fuels for its energy; the U.S. Energy Information Administration estimates that in 2020, 42% of net electricity generation in state was from coal-fired power plants, and a further 34% was from gas-fired plants.[1] The transition to low- and zero-carbon electricity therefore involves a substantial change to Wisconsin's existing power sector. Further, the evolution of demand for energy (for example, accelerated electrification of transport and household heating) will require the development of new power sector capacity to meet higher electricity demand.

The report builds on energy system analysis carried out by Evolved Energy Research to assess how different levels of investment in low- and zero-carbon power generation and demand-side technologies could affect the Wisconsin economy over the same period. In this study the statewide economic impacts of the energy system's transition are assessed with the E3-US macroeconomic model. Two decarbonization scenarios are compared to a baseline in terms of jobs and GSP and the economic effects on sub-regions of Wisconsin are evaluated as well as the occupation job impacts.

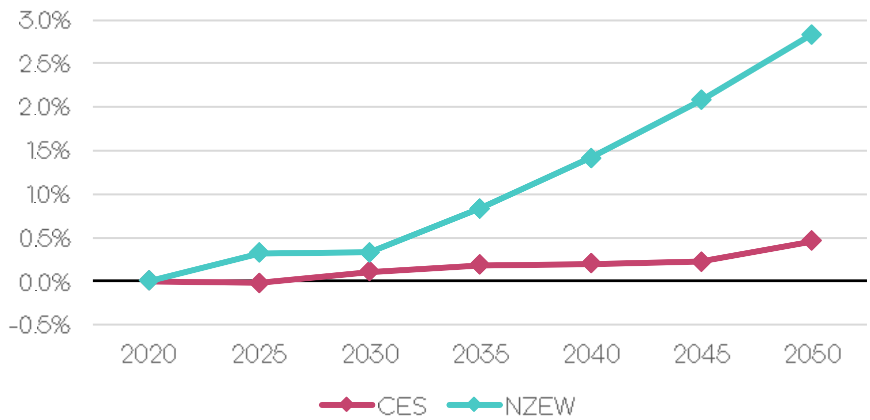
The key findings are:

- Decarbonizing the electricity supply in Wisconsin (the Clean Electricity Standard, or CES scenario) will lead to small economic gains, of up to 0.5% of Gross State Product (GSP) by 2050, as shown on the figure below. These impacts are primarily as a result of increased investment in new clean energy generating capacity in later years.
- An economy-wide decarbonization (the Net Zero Economy-wide, or NZEW scenario) in Wisconsin through a combination of clean electricity generation and demand-side energy and emissions reductions, could have much more substantial economic benefits. Shifting away from the use of fossil fuels and increasing energy efficiency across the economy results in up to a 3.0% increase in GSP and 68,000 additional jobs by 2050.
- Jobs would be created across the Wisconsin economy in accordance with the scale of climate action. Key sectors impacted include electricity generation, but also manufacturing and construction activities (linked to the investment in new generating capacity and other technologies), and business and consumer services (as a result of lower spending by households on energy, which increases disposable income for spending on other goods and services).
- Within the energy sector, such a transition is building on existing trends: Wisconsin's coal-fired power plants will likely be shut by 2035 according to existing utility plans. At the same time, the state already has an existing sector focused on low-carbon technologies including firms such as Johnson Controls, Rockwell, Eaton, Generac, Kohler, AO Smith, Husco, LEM, ABB, and DRS Technologies, who could reasonably expect to expand their Wisconsin operations as the economy decarbonizes and demand for their power sector technologies increases.

[1] Wisconsin State Energy Profile

- More broadly, the Wisconsin labor market is well positioned to benefit from the transition. It has a highly skilled workforce that has the potential to take up the new jobs created, with the relevant training and reskilling. Decarbonization is expected to create employment opportunities at all skill levels, part of a more inclusive economy transition.
- The greatest winners of the transformation are the regions of Wisconsin with significant construction and manufacturing industries, such as the Bay Area and Waukesha-Ozaukee-Washington. Nonetheless, the two other large Workforce Development Areas[2], Milwaukee and South Central, can be expected to attract the high-skilled and skilled non-manual workers, reflecting the existing presence of low carbon industries and their expected continued expansion.
- The key challenge within the labor market will be helping workers to make the transition from fossil fuel activities into clean sectors, and this will require coordination between the fossil fuel firms as they reduce in scale, local actors such as the Wisconsin Workforce Development Boards, and the firms offering new jobs in the future.

Wisconsin GSP results compared to baseline (%)



[2] Wisconsin Department of Workforce Development - Wisconsin's Workforce Development Areas

1 Introduction

The state of Wisconsin is currently heavily reliant on fossil fuels for its energy; the U.S. Energy Information Administration estimates that in 2020, 42% of net electricity generation in state was from coal-fired power plants, and a further 34% was from gas-fired plants.[3] The transition to low- and zero-carbon electricity therefore involves a substantial change to Wisconsin's existing power sector. Further, the evolution of demand for energy (for example, accelerated electrification of transport and household heating) will require the development of new power sector capacity to meet higher electricity demand.

This study assesses the potential macroeconomic impacts in Wisconsin of changes, both to the energy supply sectors, but also to energy demand within Wisconsin, on the path to decarbonizing the power sector and the wider economy as a whole. It builds on energy system analysis carried out by Evolved Energy Research to assess how different levels of investment in low- and zero-carbon power generation and demand-side technologies could affect the Wisconsin economy over the next 30 years.

We applied a state-level macroeconomic model of the US economy, E3-US, to capture the impacts at the state level on Wisconsin. Full detail on the model is included as an appendix to this report. Sub-state level analysis was then conducted based on the most recent employment data available for the 11 Workforce Development Areas (WDAs) of Wisconsin, sourced from the Job Center of Wisconsin, to evaluate how the jobs created might be allocated across the WDAs, and the different occupations that could be expected to be impacted, and the relevant skills and qualifications required to fill those anticipated job opportunities.

The rest of this report is set out as follows:

- **Chapter 2** sets out the scenarios that were developed to inform the analysis and are required to model the macroeconomic impacts.
- **Chapter 3** focuses on the state level E3-US macroeconomic modelling exercise and the impacts of decarbonization on the fossil fuel industries.
- **Chapter 4** presents the results of the sub-state level economic outcomes at WDA level.
- **Chapter 5** sets out the conclusions of the study.

[3] Wisconsin State Energy Profile

2 Alternative clean energy and net zero scenarios

2.1 Outlines of the scenarios

The scenarios that we modeled drew from energy sector modeling carried out by Evolved Energy Research (EER) as part of this larger project for GridLab and Wisconsin partners. They explored a number of different scenarios, evaluating different state-level policy options affecting the energy system. Of the seven alternative future energy scenarios evaluated by EER, the macroeconomic analysis focused on three:

1. A Reference Case (*baseline*), broadly consistent with continued 'business as usual' deployment of energy generation technologies and energy demand as outlined in the Annual Energy Outlook 2021.[4]
2. A 100% Clean Electricity Standard (*100% CES*), which required that electricity used within Wisconsin reduces in carbon intensity over time, reaching 100% zero carbon by 2050.
3. A Net Zero Economy-wide (*NZEW*) decarbonization scenario, achieving a 40% emissions reductions compared to the 2005 levels by 2030, and reaching a net zero Wisconsin economy by 2050.

Of these, our analysis focuses on comparing the socioeconomic outcomes from the 100% CES and the NZEW scenarios compared to the baseline. The initial energy system modeling is described in detail in a separate report by EER, and rather than repeating that analysis, in the remainder of this chapter we outline the key outcomes from that energy system modeling that feed into the economic analysis that follows in the next chapter.

2.2 The different elements of the scenarios

The transition towards decarbonization requires major changes in the economy, especially in the energy system. Historically, coal power plants have played a crucial role in the power generation of Wisconsin, providing 82% of the state's electricity generation as recently as 1997 and still representing a major share of the current power generation mix.[5] The replacement of these fossil fuels in the energy mix is a key challenge if decarbonization is to be achieved. Figure 1 shows the evolution of power generation capacity in each scenario.

Coal-fired generation falls to zero by 2035 in all three scenarios in line with announced utility plans. Because the retirement of coal-based electricity generation is included in the base case, the alternative CES and NZEW scenario impacts do not capture either the positive environmental impacts or the negative economic impacts of the shutdown of coal power plants. However, significant shares of gas-fueled generation capacity is replaced with renewable energy sources in the two alternative scenarios – and any remaining gas being used in the system is either waste gases, which qualify

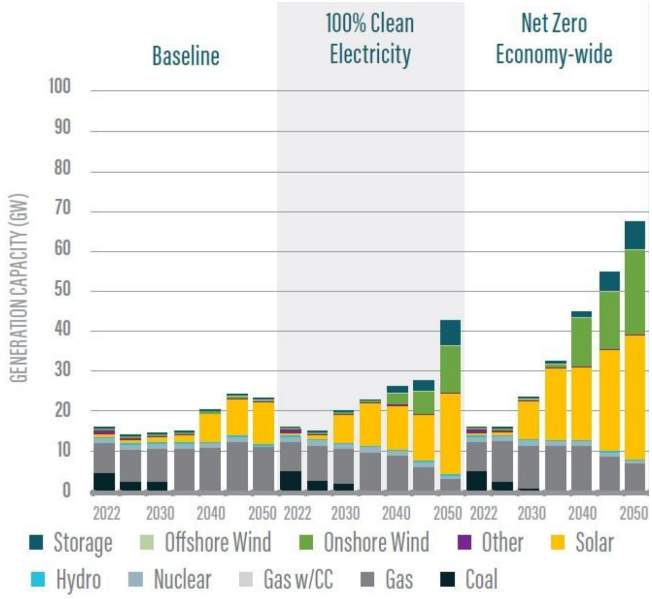
[4] https://www.eia.gov/outlooks/aeo/

[5] Wisconsin State Energy Profile

under a 100% clean electricity standard, or are fossil gases whose emissions are offset by carbon capture technologies.

In all three scenarios new generation capacity investments are dominated by solar in the medium-term as the result of decline in solar costs. In the CES scenario, there is a ramp-up in solar deployment from 2040, plus additional investment in wind and storage. Similar trends taken place in the NZEW scenario, albeit at a much higher level, reflecting the electrification of energy demand across the economy.

Figure 1 Electricity generation by scenario (GW)

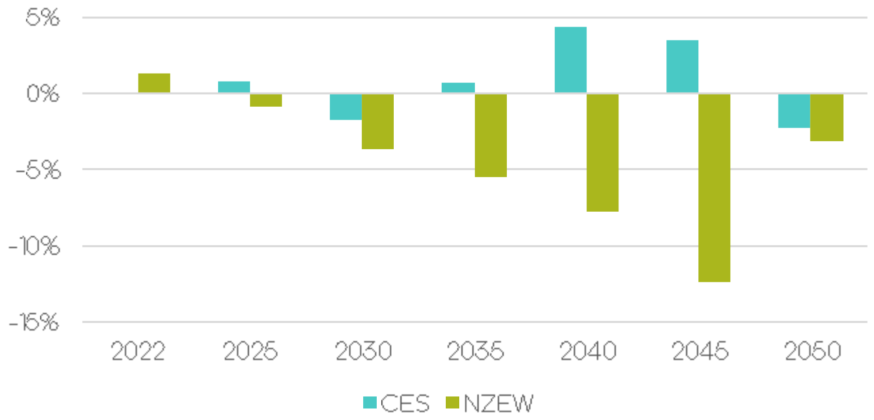


Source: Achieving 100% Clean Energy in Wisconsin (Evolved Energy Research, 2022)

In the CES and NZEW scenarios, total electricity generation capacity is two and three times higher respectively by 2050 than in the baseline. Although electricity demand is equal to the baseline in the CES scenario, more capacity needs to be deployed to replace coal and gas power plants because the capacity factors of wind and solar are lower than coal and gas plants. In other words, as solar and wind energy is not always available, investment in additional capacity is required to replace coal power plants that can generate electricity at a more constant rate. Furthermore, in the NZEW scenario economy-wide decarbonization requires large-scale electrification of energy demand, across both industry and households. The electrification of transport, heating and industrial processes will substantially increase electricity demand in Wisconsin, requiring investment in more renewable energy sources.

A key driver of the economic impacts of the energy transition is the electricity price paid by industry and consumers (see Figure 2). The CES scenario shows electricity prices which are similar to baseline until the 2040s, when the installation of new renewables scales up, and drives up average prices. Conversely, although the NZEW scenario has larger deployments of renewables than either the baseline or CES, it is accompanied by greater demand-side flexibility (such as that provided by electric vehicles), which allows a more efficient use of the supply infrastructure. This reduces the role of infrastructure costs in per unit electricity prices, and therefore drives down the average costs of electricity.

Figure 2 Electricity prices (percentage difference from Baseline)

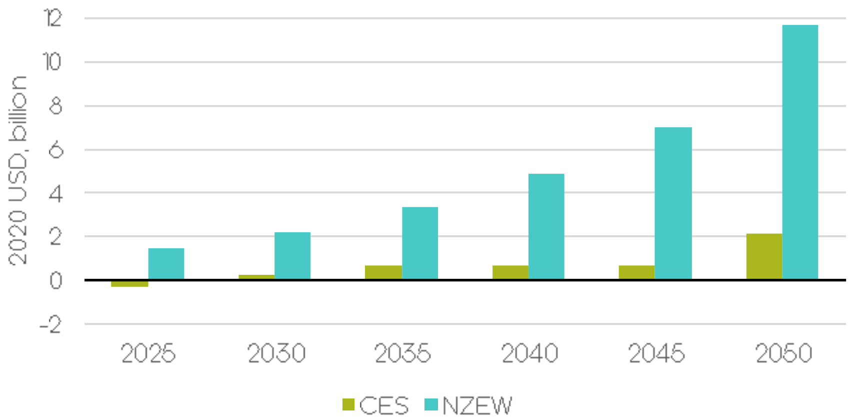


Furthermore, starting from 2035 ambitious transmission capacity expansion is assumed in that scenario, reaching an additional 6 GW on each intertie (interconnection between two electric utility systems) by 2050 (Illinois, Iowa, and Minnesota interties). Facilitated by this expansion, both imports and exports of electricity increase in Wisconsin. Enhanced interconnectedness lowers the overall the cost of decarbonization to the electricity grid, by providing system balancing and access to high-quality out of state clean energy resources.

Finally, demand-side electrification in the NZEW scenario also helps to reduce energy bills for consumers and businesses. Replacing gas boilers with heat pumps and purchasing battery-electric vehicles to replace combustion engine equivalents improves energy efficiency and can be supplied by low-cost renewable electricity. Electrification therefore reduces energy demand and shifts consumption from relatively expensive fossil fuels towards more efficient clean energy sources.

The installation of new clean electricity capacities requires substantial investment. And achieving economy-wide decarbonization requires further demand-side investments. Additional supply-side investments reach $2 bn in 2050 in the CES scenario compared to the baseline, while in the NZEW there is almost $12 bn additional investment – about $6 bn of additional investment by 2050 for supply-side and another $6 bn in demand-side changes (see Figure 3).

Figure 3 Total additional investments compared to baseline (2020 USD, billion)



3 The state level economic impacts of decarbonization

In this chapter we present the state level economic impacts of decarbonizing the electricity system and the whole economy by 2050 compared to the Baseline which is in line with the AEO Reference case. The macroeconomic impacts were modeled using Cambridge Econometrics' E3-US model – detail on the model is provided in Annex 1. This macro-econometric simulation model represents the US economy at the individual state level, so the impacts evaluated are Wisconsin-specific and reflect the unique economic structure of the Wisconsin economy.

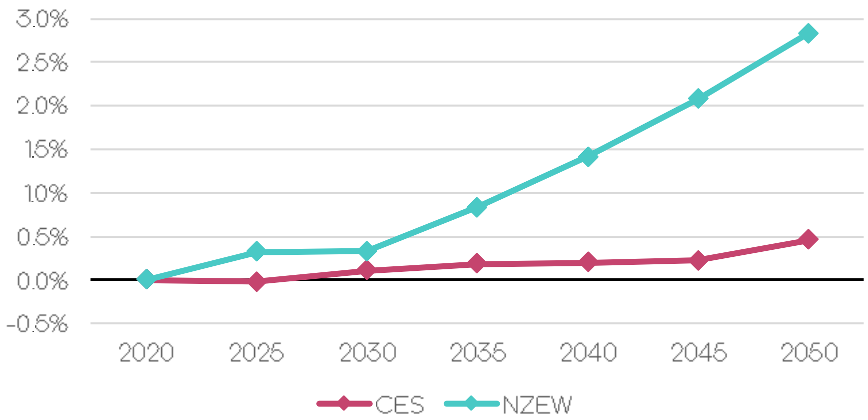
3.1 State-level macroeconomic impacts

Output

Both scenarios analyzed for this study are projected to have positive long-run gross state product (GSP) impacts in Wisconsin, with the economy-wide decarbonization having a greater positive impact on GSP.

In the CES scenario, modest additional investments in clean energy generation capacity, and electricity prices similar to baseline, lead to a modest boost to the economy of Wisconsin, with impacts becoming greater over time as the additional investment scales up in later years to hit 2050 targets.

Figure 4 Wisconsin GSP results compared to baseline (%)



Conversely, in the NZEW scenario, investments to reach a net zero economy provide a much larger stimulus, while lower relative electricity prices reduce costs faced by businesses and households. These investment and cost changes lead to a Wisconsin economy that is almost 3% larger in 2050, as shown in Figure 4. Reduced energy costs divert spending away from utilities and towards other areas of the economy. For consumers, this typically means more spending on consumer services such as retailing, restaurants and accommodation but can also support demand for durable goods such as appliances. While the electrification of the economy drives up demand for electricity, efficiency measures (including the increased efficiency of electric technologies compared to fuel-fired technologies) mean that increased demand for electricity is more than balanced out by reduced demand for other energy sources.

Employment

The employment impacts of decarbonization are positive in both scenarios out to 2050 but vary significantly between CES and NZEW scenarios and affect different sectors and regions of the Wisconsin economy.[6]

Although fossil fuel industries are negatively impacted by the move towards clean technologies, most job losses are already captured in the baseline – in line with existing commitments from utilities to phase out the use coal power plants in Wisconsin by 2035. In 2021, coal powered electricity generation employed almost 2,000 workers across the state.[7] Nevertheless, the jobs that are lost in fossil fuel power will generally be replaced with new jobs in the generation of renewable power. As such, a key question around the long-term impacts of a shift away from fossil fuels is the extent to which workers who lose their jobs in the fossil fuel industries might be retrained and transitioned to job opportunities in other sectors.

Case Study 1 Clean energy supply chains in Wisconsin

The transition of the energy system is expected to create numerous job opportunities in the electrical equipment sector as employment will increase by almost 14,000 compared to 2021 (approximately 50% increase) in an economy-wide decarbonization scenario. With over 1,100 companies and 116,000 industry employment, Wisconsin is the vanguard of the energy, power and controls sector. The state's capabilities show special strength in generation and transmission; storage and distribution; conversion, control and automation; and efficiency and conservation. Taking advantage of academic research and specialized institutions, the companies advance innovation in a collaborative approach.
Notable Wisconsin companies in the sector are:

- Johnson Controls
- Rockwell
- Eaton
- Generac
- Kohler
- AO Smith
- Husco
- LEM
- ABB
- DRS Technologies

These companies have a great opportunity to further expand their business during the energy transition. For example, Kohler Co., headquartered in Kohler, Wisconsin, already announced a 155,000 square-foot expansion of its manufacturing facility in the state to respond to the growing demand for industrial generators and integrated power systems. Kohler Co. Power Group, the subsidiary of Kohler Co., is a global leader in the manufacture of engines and power systems with 18 manufacturing locations all around the world.

Large scale deployment of new solar and wind capacity in the CES and NZEW scenarios will require additional workers in the electricity, construction and manufacturing sectors. The expansion of these sectors opens up major opportunities for energy, power and controls companies. In Wisconsin there are a number of appliance companies, like Johnson Controls, Rockwell and Generac, that are in a good position to benefit from the increased demand for

[6] Historical data for employment is taken from the Bureau of Economic Analysis and refers to the count of jobs, both full-time and part-time. It includes wage and salary jobs, sole proprietorships, and individual general partners, but not unpaid family workers nor volunteers.

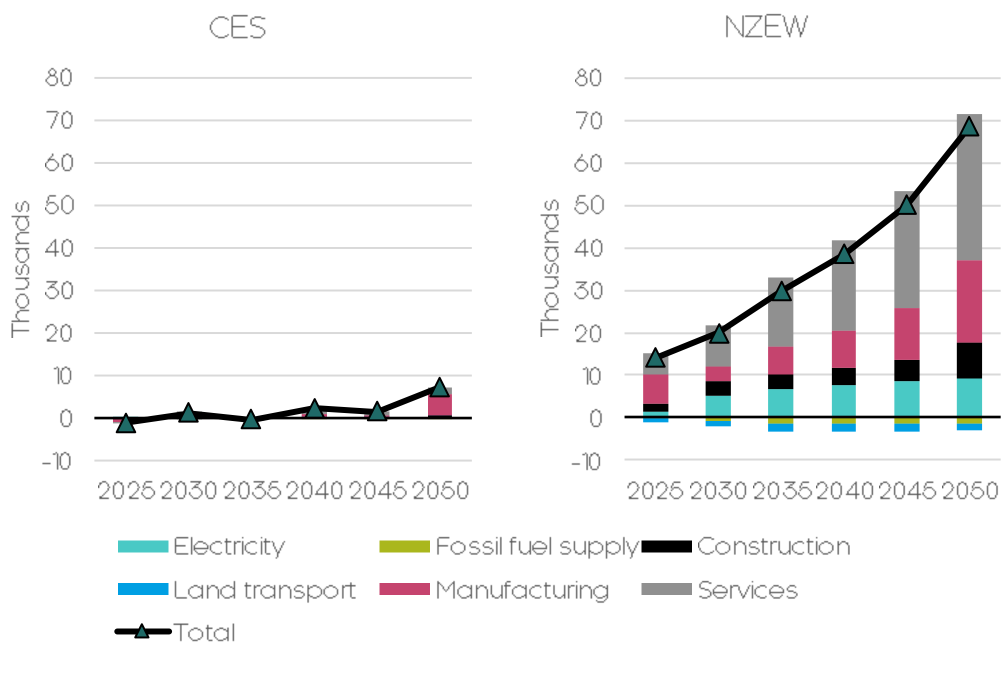
[7] U.S. Energy Employment by State 2022

their products and ensure that a significant proportion of the economic value created from the deployment of renewable electricity can be captured in-state.

In the NZEW scenario, the large investment stimulus has a positive effect on the economy in the short run, with the manufacture and installation of renewable energy capacities and demand-side products generates new jobs in the associated sectors. Furthermore, economic benefits spill over to other industries as consumer spending shifts away from energy, increasing employment in consumer services in particular (due to the high labor-intensity of these sectors). Economy-wide decarbonization is estimated to create almost 70,000 additional jobs across Wisconsin by 2050, of which around half are in electricity supply, construction and manufacturing. The substantial positive impacts are principally the result of the greater investment in new generation capacities, with these sectors forming key parts of the renewable energy value chain. The remaining new jobs created are also linked to renewable energy supply chain services, such as administrative and support services, and to induced effects from reallocated consumer expenditure, e.g., new jobs in retail stores (see Figure 5).

Employment impacts are more modest but still positive in the CES scenario, primarily as a result of the smaller investment stimulus. New jobs are created mostly in the manufacturing and construction sectors, driven by the deployment of additional solar, wind and storage capacities.

Figure 5 Employment impacts by industry compared to baseline (thousands)



Fossil fuel industries

Although the energy transition has positive overall effects on the economy, assets like coal power plants can become stranded and employment in these operations is likely to fall. Since the baseline scenario already incorporates the shutdown of coal power plants, these negative impacts are not reflected in the scenario results. However, it is important that such job losses are evaluated; the ability to manage and absorb the impacts of these structural changes in the economy are essential to ensuring the future prosperity of Wisconsin. As noted above, the almost 2,000 people currently employed in Wisconsin in coal-fired generation are likely to need to find alternative sources of employment by 2035 as existing plants are shut down according to the schedule already set out by operators.

Currently, fossil fuel demand in Wisconsin is almost entirely met by imports from other states or further afield. Coal and some petroleum products are shipped to the ports of Wisconsin, while pipelines carry crude oil, petroleum products, and natural gas across the state en route to markets.[8] Consequently, the fossil fuel supply industry does not play a prominent role in the state's economy. According to the U.S. Energy Employment by State 2022[9] report the energy sector in Wisconsin represents 5.1% of total state employment (141,530 energy workers). However, only 7,400 in 2021 were explicitly linked to fossil fuel supply.

Within electricity generation, around 3,000 jobs were associated with coal (1,958) and natural gas (1,084), while oil and other fossil fuel workplaces were very small (52 jobs). However, employment associated with oil and other petroleum technologies represented more than half of the employment within the fuels supply sector (3,786 out of 7,031, respectively).

Case Study 2 WEC Energy

WEC Energy Group, the largest utility company in Wisconsin, has already committed itself to reach climate neutrality by 2050 and drop coal from its power mix by 2035. WEC Energy group aims to reduce its CO_2 emissions by 60% by the end of 2025, and by 80% by the end of 2030, compared to 2005 levels. Furthermore, they are working to reduce the role of coal in generation - to less than 5% of the power they supply to customers by 2030, and eliminating coal entirely as an energy source by 2035.

WEC Energy Group delivers electricity and natural gas to more than 3 million customers in Wisconsin through its subsidiaries, We Energies and Wisconsin Public Service. The two companies together currently own 4 coal power plants, with 10 units in total. We Energies plans to retire four older units of 1,130 MW generation capacity combined at its Oak Creek site; Units 5 and 6 are expected to be retired in May 2024, with Units 7 and 8 following in late in 2025. According to Brendan Conway, WEC Energy spokesman, around 180 workers at the plant will be impacted by the shutdown of the units; but We Energies and their unions will provide a transition plan for the workers in the coming years.

According to the group, coal will be replaced by carbon-free renewable energy facilities. WEC Energy Group plans to invest $3.5 billion in regulated renewables building nearly 2,400 MW of solar, wind and battery storage capacities. This is likely to increase the overall economic footprint, and employment opportunities, of the firm, even as it switches away from fossil fuels. This highlights the opportunities that are present for utilities that lead the transition away from fossil fuels and towards renewable electricity generation.

[8] U.S. Energy Information Administration - EIA - Independent Statistics and Analysis

[9] U.S. Energy Employment by State 2022

Achieving a net zero economy will inevitably have a negative impact on the fossil fuel industries, leading to job losses. However, a combination of market forces and changing preferences are already leading to change, and more ambitious decarbonization targets principally accelerate the job losses in these industries. And there are multiple opportunities for Wisconsin to capture and retain economic activity and jobs related to clean energy generation and net zero economy initiatives such as energy efficiency investments, solar panel installations, and advanced component supply chain production.

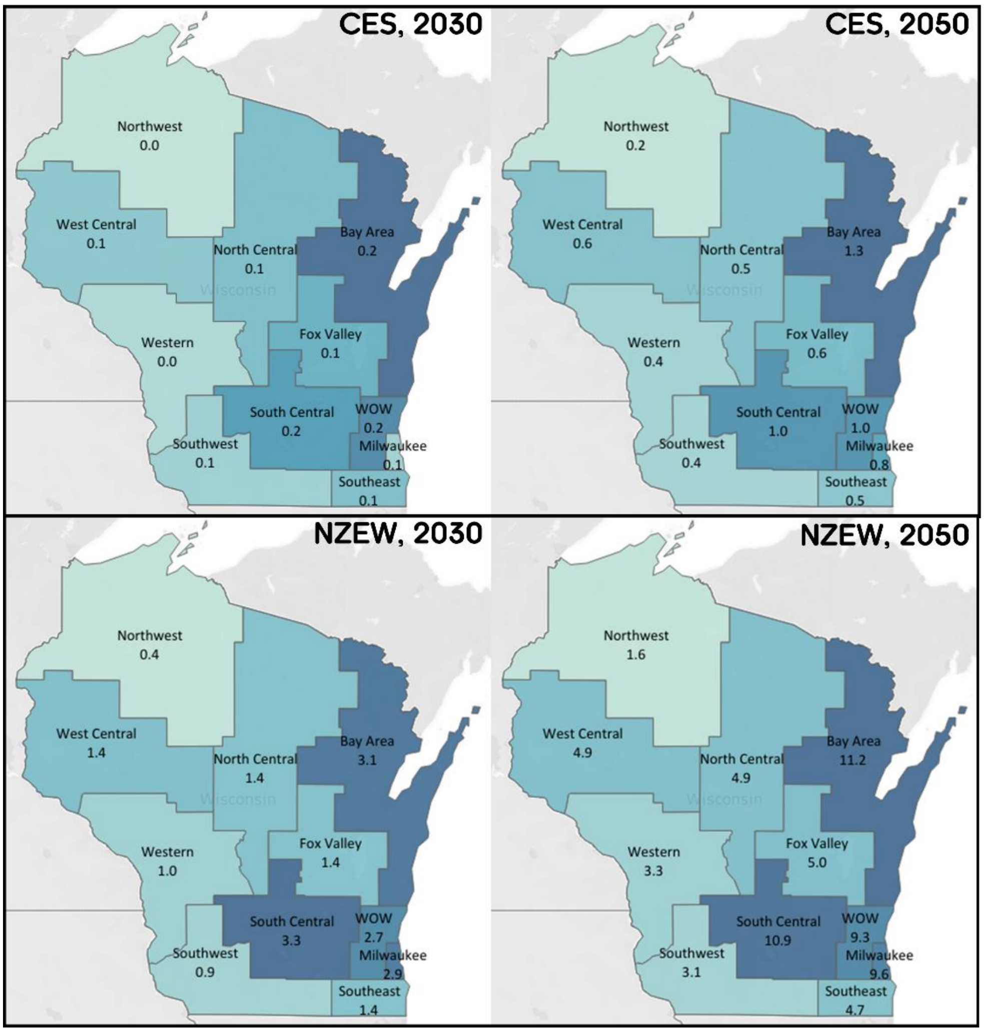
4 Sub-state level economic impacts

The impacts of energy transition will vary across industries, but also across regions of Wisconsin, reflecting the economic scale and different specializations of regions in terms of existing supply chains. The impacts also reflect how the skills of the workforce and infrastructure affect the goods and services that are best placed to be produced there. In the rest of this chapter we assess the impacts at the Workforce Development Area (WDA)[10] level. The WDAs have responsibility for the development of a skilled workforce, by strategically allocating and coordinating resources to address local economic workforce issues.

Employment

To analyze regional impacts, we first assessed the employment structure of WDAs by industry (NAICS) relying on the Quarterly Census of Employment & Wages (QCEW) survey[11]. This widely used data source provides detailed information on employment by industry at the county level. We used the 2021 super-sector (1 digit) level industry data to disaggregate the modeled additional state level jobs to WDA level. This regionalization implicitly assumes

Figure 6 WDA level employment results compared to baseline (thousands)



[10] The constituent counties of the 11 WDAs are available from the Department of Workforce Development

[11] Quarterly Census of Employment & Wages

that new jobs will be created to reflect the existing sectoral size and specialization of the WDA regions.

The pattern of regional impacts is similar across the scenarios (Figure 6). More populous WDAs in the state see the most additional jobs created; specifically the Bay Area, Milwaukee, South Central and Waukesha-Ozaukee-Washington (WOW). The large increase in jobs in these WDAs is driven by multiple factors. The size of the labor market is substantially greater than in other WDAs; consequently, the absolute changes are higher than in smaller areas. However, the employment impacts are also influenced by the industrial structures, e.g., job creation is the highest in the Bay Area which has a relatively large concentration of manufacturing and construction.

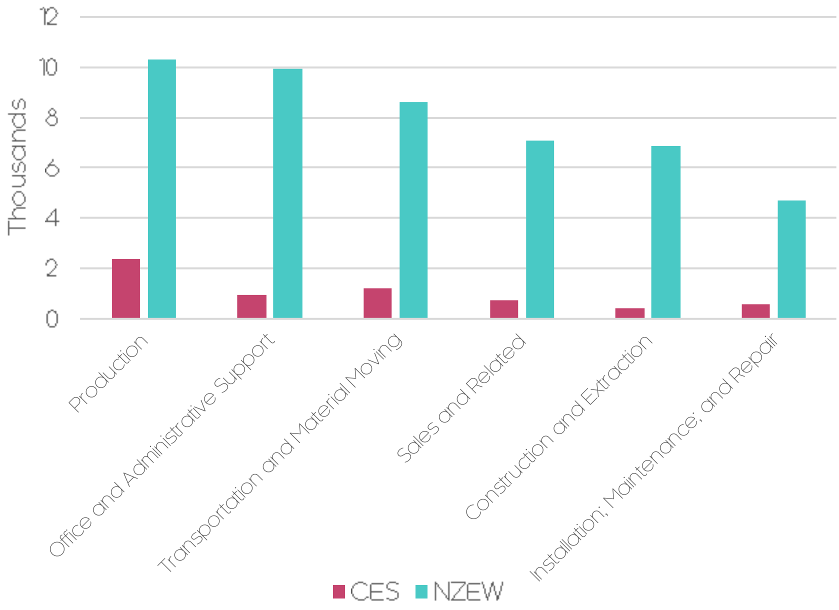
Employment effects are less pronounced in the CES scenario for South Central and Milwaukee areas. In the CES scenario, the majority of additional jobs appear in manufacturing but the scale of manufacturing is relatively limited in these WDAs. However, in the NZEW scenario, these regions benefit more from the positive impacts on professional services and construction. The Bay Area and WOW, on the other hand, have notable employment in both construction and manufacturing sectors and therefore see job creation in both scenarios.

Skills

Seeking to inform policy and business actions in response to changes in employment, we have also analyzed the skills requirements of the new jobs created in the clean energy transition. To explore this, we translated the industry level outcomes to occupational and skills requirement data. We used occupation data from the Industry Employment Projections[12] survey at industry level for 2018 to convert the industrial results to major occupation group level.

One key requirement to minimize job losses and the potential negative impacts of this structural change is the active reskilling of workers where possible. The scale of reskilling is determined by the skills and formal

Figure 7 Top 6 occupation changes compared to baseline, 2050 (thousands)



[12] Industry Employment Projections

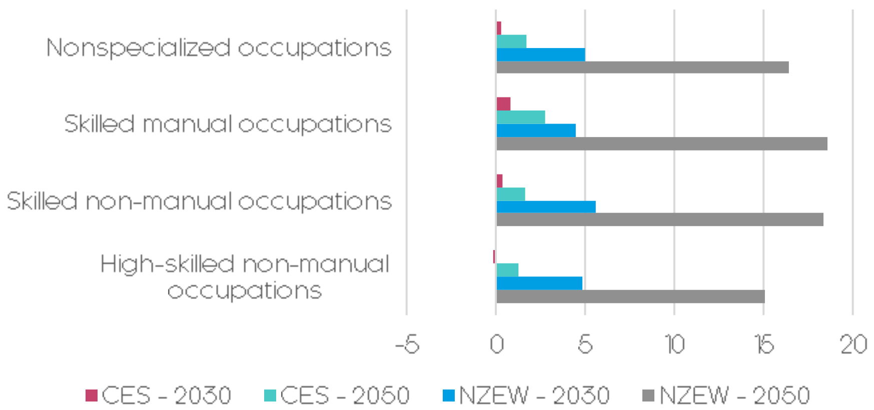
qualifications gap between the jobs lost in fossil fuel occupations and the new jobs created in clean occupations.

The occupations which benefit the most in 2050 are production; office and administrative support; and transportation and material moving occupations in both scenarios, as outlined on Figure 7. Production occupations are associated with new workplaces in manufacturing, while transportation and material moving jobs are heavily concentrated in construction and manufacturing related activities. Office and administrative support workplaces mostly appear in the services sector.

Wisconsin is well placed to reap the benefits of deep decarbonization in terms of skills. The state has the second-highest concentration of experienced manufacturing workers in the U.S. Furthermore, Wisconsin's high quality academic institutions ensure a stable supply of educated workers; nearly 5,000 engineering degrees and certificates were awarded in 2019.[13]

Assessing the skills requirements to fulfil these occupations, we created four categories: high-skilled non-manual occupations; skilled non-manual occupations; skilled manual occupations; and nonspecialized occupations.[14] In the CES scenario, additional jobs are dominated by nonspecialized and skilled manual occupations as shown on Figure 8. These skills cover many of the new production, transportation and material moving, and construction roles that are created.

Figure 8 Skill requirements compared to baseline (thousands)



Skill requirements are more evenly distributed in the NZEW scenario at a state level, due to the wide-ranging list of sectors that are affected. The largest number of jobs is created for skilled manual and non-manual occupations, almost 37,000 workers in total. In addition, more than 15,000 high-skilled occupations are created by 2050, mostly due to the expansion of the financial, engineering, healthcare and management occupations.

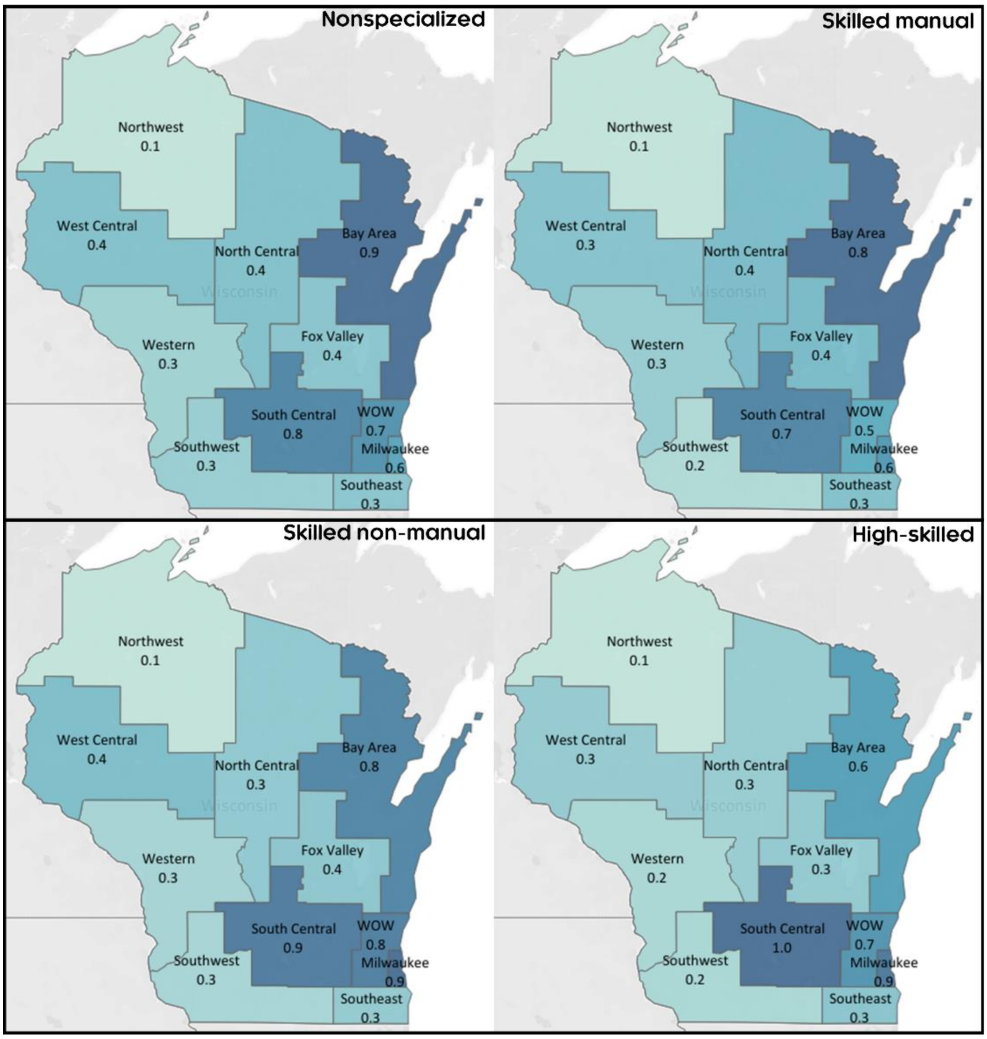
However, the regional differences are substantial. Figure 9 shows the geographical distribution of jobs by skill level for the NZEW scenario in 2030. As the Bay Area's economy is more focused on manufacturing and construction, the majority of the new jobs are nonspecialized and skilled manual occupations. However, in Milwaukee and South Central skilled non-manual and high-skilled occupations dominate. Although the deployment of

[13] Energy-Power-and-Controls-Profile-spreads.pdf (wedc.org)

[14] Skill categories are in line with the ILO ISCO skill levels.

solar and wind capacities occurs locally, generating new jobs in the manufacturing and construction sectors, the non-manual jobs are likely to be concentrated at the headquarters of the associated companies. Milwaukee is already a hub for energy, power and controls sector, since multiple leading companies of the sector are headquartered there, like Rockwell, AO Smith, Briggs and Stratton or Rexnord, and as such would be expected to benefit substantially in terms of skilled non-manual and high-skilled jobs.

Figure 9 Skill requirements by WDA compared to baseline in NZEW, 2030 (thousands)



5 Conclusions

This analysis examined the economic impacts of decarbonizing Wisconsin's economy. The modeling showed that the clean transition can bring substantial economic benefits, and that the number of new jobs created will surpass the baseline (and any job losses in the fossil fuel industries).

- Achieving 100% clean electricity by 2050 (without any further demand-side changes) yields modest but positive economic results, with limited additional in-state investment and mixed impacts on electricity prices.
- The potential gains for Wisconsin from economy-wide decarbonization are substantial. Driven by lower electricity prices and a large investment both in new generating capacity and supply-side measures, Wisconsin's economy could grow to be 3% larger than in the baseline along with almost 70,000 jobs as result of such a transition.

The largest increase in economic activity occurs in the construction and manufacturing sectors, from delivering the deployment of renewable energy generation capacity, while the transformation of the electricity system creates mostly nonspecialized and skilled manual occupations. In addition, the services sector also benefits from the transition due to lower energy costs for households and businesses, which translates into a higher level of disposable income for households, creating high-skilled and skilled non-manual jobs across business and (particularly) consumer services.

In total, economy-wide decarbonization could create 68,000 additional jobs across the state by 2050. Wisconsin's labor market is well prepared to fill the vacancies, with a highly skilled workforce with nearly 5,000 engineering degrees and certificates awarded annually; in particular in Milwaukee. Some fossil fuel jobs are likely to be lost in the transition, but this is largely driven by the emerging economics of electricity generation rather than explicit policies in support of decarbonization, with coal generation across Wisconsin expected to stop by the middle of the next decade.

At a regional level, all parts of the state will benefit from the clean transition as employment effects are positive across the board. The areas in Wisconsin that are projected to have the most new jobs created are the areas with significant construction and manufacturing industries, such as the Bay Area and WOW. Nonetheless, the two other large WDAs, Milwaukee and South Central, can be expected to attract the high-skilled and skilled non-manual workers, reflecting the existing presence of multiple notable energy, power and controls companies headquarters, and the likelihood of future continued centralization of such activities in these regions.

A major challenge in this transition is managing the changes in the labor market. While our analysis shows that the local labor market is well-positioned in aggregate terms, it is important that relevant services are offered to help workers to transition from fossil fuel-based activities to the new jobs and opportunities created in the clean economy. This will involve coordination between the fossil fuel firms as they reduce in scale, local actors such as the Wisconsin Workforce Development Boards, and the firms offering new jobs in the future.

Appendix A E3-US model description

E3-US is an advanced software tool that can be used to assess energy-economy linkages at US-state level. The model design centers on objective to find suitable policy options for state emission reduction, and to evaluate the economic impacts of potential policies on stakeholders. E3-US can be used as a tool to assist policy makers with evidence-based analysis of different policy options.

The technical development of the model was carried out by Cambridge Econometrics. E3-US is a macro-econometric simulation model, meaning it is based on a series of econometric equations. It is similar in design to the internationally recognized E3ME model (see www.e3me.com).

A.1 Policy decisions that can be informed by the models

As a general model of the economy, E3-US can be used to assess a wide range of fiscal and general macroeconomic policies. However, it has been designed to have a particular focus on climate policies. Example of policies that the model can assess, at state, multiple state or national level include:

- Carbon and energy taxes
- Emission trading systems
- Removal of environmentally damaging subsidies
- Revenue recycling
- Direct regulation
- Energy efficiency programmes

A.2 A summary appraisal of the range of results the model can offer

As a global E3 (energy-environment-economy) model, E3-US can provide comprehensive analysis of policies:

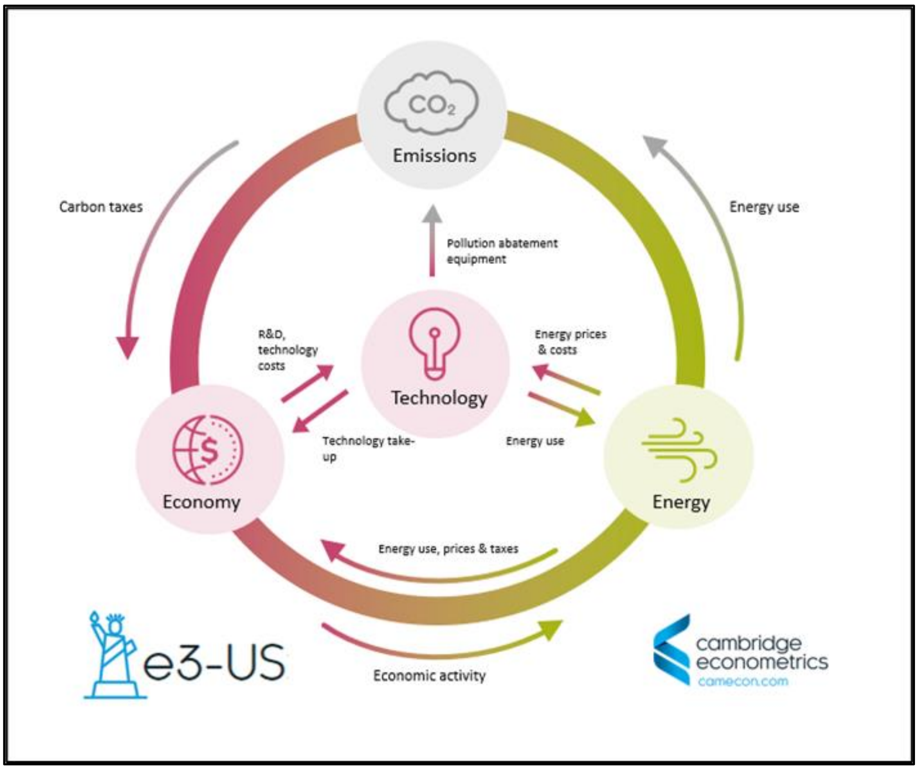
- direct impacts, for example reduction in energy demand and emissions, fuel switching and renewable energy
- secondary effects, for example on fuel suppliers, energy price and competitiveness impacts
- rebound effects of energy consumption from lower price, spending on energy or higher economic activities
- overall macroeconomic impacts; on jobs and economy including income distribution at macro and sectoral level.

A.3 Theoretical underpinnings

Economic activity undertaken by persons, households, firms and other groups in society has effects on other groups (possibly after a time lag), and the effects may persist into future generations. But there are many actors and the effects, both beneficial and damaging, accumulate in economic and physical stocks.

The effects are transmitted through the environment, through the economy and the price and money system (via the markets for labour and commodities), and through global transport and information networks. The markets transmit effects in three main ways: through the level of activity creating demand for inputs of materials, fuels and labour; through wages and prices affecting incomes; and through incomes leading in turn to further demands for goods and services. These interdependencies suggest that an E3 model should be comprehensive and include many linkages between different parts of the economic and energy systems.

The figure below provides a schematic of an idealised model. The current version of the model includes only limited treatment of physical damages (which are often instead calculated off-model) and of pollution-abatement equipment (which is specified exogenously by the model user). These issues remain areas for future development.

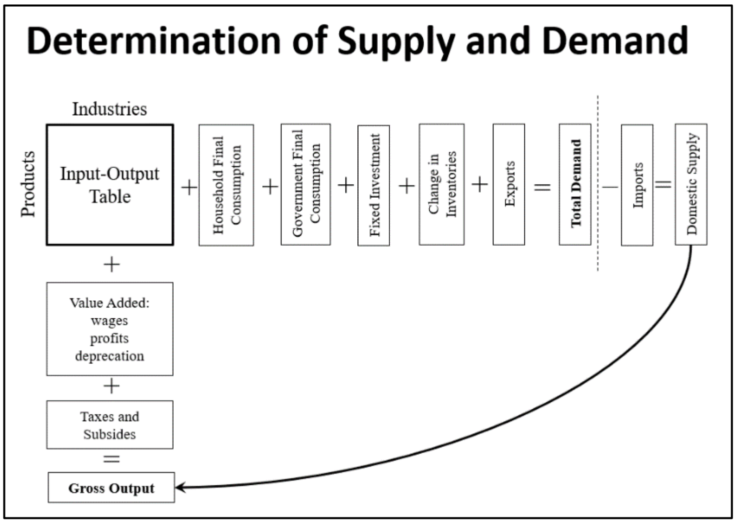


Econometrics model such as E3-US is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimising behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian, demand-driven accounting framework and it is possible to have spare capacity in the economy (see figure below). It is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3-US regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3-US gives the model a strong empirical grounding. E3-US uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects, which are included as standard in the model's results.



Treatment of inter-state and international trade

In a sub-national model, trade represents a major issue in assessing regional economic impacts. Demand in each state can be met either by production within that state, production in another state in the US, or production in another country.

The approach can be summarized as:

- econometric estimation of state's sectoral international import demand
- econometric estimation of state's sectoral international export demand
- Trade between states is estimated using production shares (export) and domestic demand shares (import).

The labor market

Treatment of the labor market is an area that distinguishes E3-US from other macroeconomic models. E3-US includes econometric equation sets for employment, wage rates and participation rates. The first two of these are disaggregated by economic sector while participation rates are disaggregated by gender.

The labor force is determined by multiplying labor market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labor force and employment. This is typically a key variable of interest for policy makers.

A.4 Summary of key strengths

- The close integration of the economy, energy systems and the environment, with some two-way linkages between each component
- The detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios

- Its state-level coverage, meaning policies can be entered at state level.
- The econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- The econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends.

A.5 Key limitations

As with all modelling approaches, E3-US is a simplification of reality and is based on a series of assumptions. Compared to other macroeconomic modelling approaches, the assumptions are relatively non-restrictive as most relationships are determined by the historical data in the model database. This does, however, present its own limitations, for which the model user must be aware:

- The quality of the data used in the modelling is very important. Substantial resources are put into maintaining the E3-US database and filling out gaps in the data.
- Econometric approaches are also sometimes criticised for using the past to explain future trends. In cases where there is large-scale policy change, the 'Lucas Critique' that suggests behaviour might change is also applicable. There is no solution to this argument using any modelling approach (as no one can predict the future) but we must always be aware of the uncertainty in the model results.

The other main limitation to the E3-US approach relates to the dimensions of the model. In general, it is very difficult to go into a level of detail beyond that offered by the model classifications. This means that it is not possible for firm-based level, individuals, labour skills or very detailed product groups to be included in the model. For this type of analysis our recommendation is that the model (which provides an indication of indirect and rebound effects) is used in conjunction with a more detailed bottom-up or econometric analysis (which can capture detailed industry-specific effects).

In additional, other world regions are treated as exogenous. However, it is possible to link the E3ME model to E3-US provide a global context. Similarly, although usually less relevant, attempting to assess impacts on a monthly or quarterly basis would not be possible.

A.6 Basic structure and data

The structure of E3-US is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 16 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices and energy demand. Each equation set is disaggregated by state and by sector.

E3-US's historical database covers the period 1970-2015 and the model projects forward annually to 2050. The main data sources are Bureau of Economic Analysis (BEA) and Bureau of Labour Statistic (BLS), supplemented by energy data from US Energy Information Administration (EIA) and United

States Environmental Protection Agency (EPA), and other sources where appropriate. Gaps in the data are estimated using customized software algorithms.

The main dimensions of E3-US are:

- 50 states
- 71 industry sectors, based on standard international classifications
- 20 categories of household expenditure
- 5 different users of 5 different fuel types
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

The states and sectors covered by the model are listed at section A.8 of this annex.

A.7 Key outputs

As a general model of the economy, based on the full structure of the national accounts, E3-US is capable of producing a broad range of economic indicators. In addition, there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GSP and the aggregate components of GSP (household expenditure, investment, government expenditure and internal and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- trade by sector
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labor supply
- energy demand, by sector and by fuel, energy prices
- detailed power sector technologies
- CO2 emissions by sector and by fuel

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2050.

A.8 Main dimensions of the E3-US model

	States	Industries	Consumer spending
1	Alabama (AL)	Farms	Motor vehicles
2	Alaska (AK)	Forestry & fishing	Durable house equip.
3	Arizona (AZ)	Oil and gas extraction	Recreational goods
4	Arkansas (AR)	Mining, ex. oil and gas	Other durable goods
5	California (CA)	Support act. for mining	Food and beverages
6	Colorado (CO)	Electricity	Clothing and footwear
7	Connecticut (CT)	Gas	Gasoline
8	Delaware (DE)	Water & sewerage	Other nondurable goods
9	Florida (FL)	Construction	Housing
10	Georgia (GA)	Wood products	Gas
11	Hawaii (HI)	Non-metallic minerals	Electricity
12	Idaho (ID)	Primary metals	Other energy
13	Illinois (IL)	Fabricated metal prod.	Water
14	Indiana (IN)	Machinery	Health care
15	Iowa (IA)	Computer & electronic	Transport services
16	Kansas (KS)	Electrical equipment	Recreation services
17	Kentucky (KY)	Motor vehicles	Food & accommodation
18	Louisiana (LA)	Other transport equip	Financial services
19	Maine (ME)	Furniture	Other services
20	Maryland (MD)	Other manufacturing	Unallocated
21	Massachusetts (MA)	Food, drink & tobacco	
22	Michigan (MI)	Textiles	
23	Minnesota (MN)	Leather products	
24	Mississippi (MS)	Paper products	
25	Missouri (MO)	Printing & reproduction	
26	Montana (MT)	Petroleum and coal	
27	Nebraska (NE)	Chemical products	
28	Nevada (NV)	Plastics & rubber	
29	New Hampshire (NH)	Wholesale trade	
30	New Jersey (NJ)	Vehicle & parts dealers	
31	New Mexico (NM)	Food and drink stores	
32	New York (NY)	General merch. stores	
33	North Carolina (NC)	Other retail	
34	North Dakota (ND)	Air transportation	
35	Ohio (OH)	Rail transportation	
36	Oklahoma (OK)	Water transportation	
37	Oregon (OR)	Land transport	
38	Pennsylvania (PA)	Other transportation	
39	Rhode Island (RI)	Warehousing & storage	
40	South Carolina (SC)	Publishing	
41	South Dakota (SD)	Motion picture ind.	

42	Tennessee (TN)	Telecommunications
43	Texas (TX)	Data & info serv.
44	Utah (UT)	Fed Reserve banks
45	Vermont (VT)	Financial services
46	Virginia (VA)	Insurance
47	Washington (WA)	Aux to financial serv.
48	West Virginia (WV)	Housing services
49	Wisconsin (WI)	Other real estate
50	Wyoming (WY)	Rental & leasing
51		Legal services
52		Computer systems
53		Other professional
54		Company management
55		Admin & support serv.
56		Waste management
57		Educational services
58		Ambulatory healthcare
59		Hospitals
60		Residential care
61		Social assistance
62		Arts, sport, museums
63		Recreational industry
64		Accommodation
65		Food services
66		Other services
67		Fed gov. (defense)
68		Fed gov. (non-def.)
69		Fed gov. enterprises
70		State gov. general
71		State gov. enterprise

Source(s): Cambridge Econometrics.