Economic Analysis of U.S. Decarbonization Pathways: Summary of Findings

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Contents

1 Background 1
2 Main findings 1
3 Methodology 2
3.1 Inputs to Economic Modeling: PATHWAYS Data 3
3.2 Modeling Framework: REMI 3
4 Results 4
4.1 National Level 4
4.2 Regional Results 6
4.3 Sectoral Results 8
5 Conclusion 11

1 Background

The "Pathways to Deep Decarbonization in the United States" report by the Energy + Environmental Economics (E3), analyzes various technological scenarios for the U.S. to achieve 80 percent reduction (from 1990 levels), in greenhouse gas (GHG) emissions by 2050. The report finds several technological pathways that are feasible given today's technology but questions remain regarding their economic feasibility.

This "Economic Analysis of U.S. Decarbonization Pathways" study uses outputs from the E3 report to analyze the potential economic impacts of these decarbonization scenarios. This study analyzes the overall economic impacts in terms of jobs and economic output as well as the distributional impacts on different industrial sectors, households, and regions across the country, using the Policy Insight Plus model, a macroeconomic model of the economy developed by the Regional Economic Models, Inc. (REMI). Data used in the study came from E3's estimates of required capital investments, energy cost changes, and energy use changes. The model and input data cover the nine Census regions of the U.S. (New England, Middle Atlantic, South Atlantic, East North Central, East South Central, West North Central, West South Central, Mountain, and Pacific).

2 Main findings

The study finds that deep decarbonization of the US economy has a net positive impact on the overall economy in terms of jobs, GDP, and income per household. Under different scenarios, the economy could add more than a million jobs by 2030 and up to 2 million jobs by 2050. Certain economic sectors are likely to be big beneficiaries of these job gains, including construction and the manufacturing sectors that are likely to contribute the parts, equipment, and final goods for the technologies of deep decarbonization. While the overall economic benefits outweigh the costs, some sectors and regions, which rely heavily on fossil-fuel based energy and industries, could face job losses due to decarbonization. Regions that face job losses, however, are likely to see increases in disposable income per household, which are estimated to be higher across all regions under these decarbonization scenarios.

Biggest employment gains occur in sectors such as utilities, construction, and the various manufacturing sectors. Meanwhile the biggest losses occur in mining, wholesale trade, and retail trade. Seven of the nine Census regions show positive economic gains with the South Atlantic and East South Central showing the largest benefits in the High Renewables Case in 2050 and New England and the Middle Atlantic showing the largest benefits in the Mixed Case in 2050. Two regions – the Mountain and West South Central – see slower employment growth and GDP growth compared to the Reference Case (i.e., these regions are adversely affected). Both these regions currently depend heavily on the fossil fuel economy, especially in terms of mining, leading to these adverse impacts. These two regions, however, see increased growth in

disposable income per household compared to the Reference Case. This is due to higher quality jobs from deep decarbonization as well as slightly lower population growth in these regions (and consequently smaller labor force) compared to the Reference Case. More details on all of these are found in the Results section below.

The overall results, based on the PATHWAYS data, show that for the nation as a whole, the deep decarbonization produces net economic benefits, whether measured in employment levels, GDP, or disposable income per household. Moreover, the study does not account for the "costs of inaction" typically found in the literature. Such costs will arise from the potentially negative consequences of climate change, such as extreme heat, sea level rise, storm damages and other extreme weather events. The study also excludes additional health, national security, and national energy security benefits that are likely to occur from reductions in fossil fuel based energy consumption. According to some estimates in the literature, these costs could be up to 5 percent of global GDP with confidence intervals extending that from 2.5 percent to 20 percent[1].

3 Methodology

Two scenarios from the PATHWAYS study are modeled and compared to a Reference Case, which represents a business-as-usual trajectory. The two scenarios take different approaches to reducing GHG emissions and are referred to as the High Renewables Case and the Mixed Case. Each of these cases involves three main strategies to reduce GHG emissions. These include energy efficiency, which reduces the amount of energy used by end-use equipment in different sectors of the economy. The second strategy involves energy supply decarbonization, which includes moving from fossil fueled electricity generation to various zero emission and renewable sources of generation. The final strategy involves the switching of appliances, vehicles, and industrial processes from high emission fuel sources to electricity or low-emission fuels. All three strategies require significant additional supporting investments compared to the Reference Case, as the large movement of energy to the electric grid, new carbon neutral fuels, and new vehicle technologies require significant infrastructure development. This includes expanding transmission and distribution lines, retrofitting or building new electric vehicle charging stations and hydrogen fueling stations, and production facilities for hydrogen and synthetic methane, all of which involve significant investments in improving or developing new infrastructure that drive economic activity and lead to positive impacts in the overall economy.

The two PATHWAYS scenarios address the three strategies with different approaches. The High Renewables Case assumes significant investments in new generation from onshore wind,

[1] For a detailed discussion and analysis of published cost estimates see Tol, R. S. (2014). Correction and Update: The Economic Effects of Climate Change. *Journal of Economic Perspectives, 28*(2), 221-226.

offshore wind, and solar. Most of the internal combustion engine (ICE) light duty vehicles are assumed to be replaced by fully electric and plug-in hybrid electric light duty vehicles. Additionally the industrial and commercial sectors see significant fuel switching to synthetic methane. The Mixed Case differs from this in significant ways. Instead of focusing entirely on renewable generation, the Mixed Case in the PATHWAYS data includes a mix of investments in new generation between renewable, nuclear, and natural gas generation with carbon capture and storage (CCS). The Mixed Case also does not rely entirely on electric vehicles (EVs). While EVs still make up about two-thirds of all light duty vehicles, the remaining third are hydrogen powered fuel cell vehicles. Finally, the Mixed Case does not assume the same reliance on synthetic methane as the High Renewables Case.

3.1 Inputs to Economic Modeling: PATHWAYS Data

Differences in the implementation of the decarbonization strategies between the High Renewables Case and Mixed Case result in differing magnitudes of total investments. The High Renewables and Mixed Case annual investments are about equal in 2030 at $150-$200 billion. They begin to diverge shortly after 2030 as the large investments in renewable generation and other technologies in the High Renewables Case increase steadily through 2050. The Mixed Case also sees continued investments, but they don't increase to the same extent. The required annual investments reach a maximum of 2.6 percent of GDP in the High Renewables Case. Thus, although the magnitudes of investments are large, they are relatively small as a proportion of the overall economy.

The main economic drivers from PATHWAYS come from the changes in energy use and investments required by the three decarbonization strategies. Households see significant energy bill savings in 2050 of $41 billion in the High Renewables Case and $51 billion in the Mixed Case. Lower energy bills[2] through 2050 are a function of the significant energy savings from investments in higher efficiency appliances and electrification of appliances. Some of these benefits are offset with increasing costs for purchasing electric and hydrogen fuel cell vehicles instead of ICE vehicles and the replacement of inefficient household and commercial appliances with highly efficient appliances. Other inputs with large economic impacts are the significant investments in constructing new electricity generation facilities, new infrastructure such as transmission lines, hydrogen and synthetic methane production facilities, electric vehicle charging stations, and hydrogen fueling stations.

3.2 Modeling Framework: REMI

REMI's Policy Insight Plus (PI+) model is a dynamic regional economic forecasting and policy analysis model that integrates several analytical techniques, including input-output,

[2] Energy bills consist of the combined spending by households on electricity, heating fuels, and transportation fuels

computable general equilibrium (CGE), econometric, and economic geography methodologies. The model is dynamic, with forecasts generated on an annual basis to include behavioral responses to changes in inputs. The REMI model can be customized to specific industrial sectors based on the North American Industry Classification (NAICS) system, as well as regionally to combinations of different states and regions. For this study, we used a 70-sector (roughly corresponding to 3-digit NAICS), 9 Census region based REMI model. Results in this study are presented up to 2050, consistent with the temporal dimension in the PATHWAYS-based input data.

The first step in the modeling was calibrating the REMI default Reference Case to be consistent with the data used in the PATHWAYS Reference Case. Comparing the REMI Reference Case with PATHWAYS Reference Case showed that the data vintages in the two models were slightly different leading to differences in some future projections for sectoral output and employment. Relevant sectors that required some adjustments included coal mining and the electric utility sectors. These adjustments were made because the coal mining industry has been facing and are expected to continue to face losses under business-as-usual case due to declining coal demand[3]. Moreover, the data on household energy consumption, light duty vehicle purchases, and gasoline demand in the REMI default Reference Case also needed some adjustments in order to be calibrated to the PATHWAYS Reference Case. In addition to baseline calibration, our economic modeling also involved mapping the changes in physical quantities from PATHWAYS to appropriate economic sectors in REMI. Data for this crosswalk came from various sources, including the National Renewable Energy Laboratory's (NREL), "Jobs and Economic Development Impact" (JEDI) model as well as other sources from the literature. Where applicable, data from JEDI was used to identify the appropriate crosswalks to NAICS-based sectors for the inputs to the REMI modeling.

4 Results

Results are presented for the High Renewables and Mixed Cases for the years 2030 and 2050. They are presented at the national, regional, and sectoral level. More detailed results including more sectors, years, and other economic metrics are presented in the accompanying briefing package.

4.1 National Level

At the national level, both the High Renewables and Mixed Cases are expected to provide employment growth over the Reference Case, as shown in Table 1 below. The High Renewables

[3] http://www.nytimes.com/2015/08/07/business/energy-environment/coal-industry-wobbles-as-market-forces-slug-away.html?hp&action=click&pgtype=Homepage&module=second-column-region&region=top-news&WT.nav=top-news

Case shows the transition to clean energy results in an increase of over 1 million jobs in 2030 and almost 2 million jobs in 2050. These increases represent roughly about one-half percentage point (0.6 percent) and close to 1 percent in 2030 and 2050, respectively. The Mixed Case sees similar job growth in 2030 with slightly over 1 million jobs, and roughly steady increases in 2050 with close to 1 million (about 963,000) additional jobs. These translate to about 0.5 and 0.4 percent over the Reference Case, respectively. To put these results in context, Reference Case employment levels in REMI are projected to be about 214 million in 2050.

Table 1: National Level Results

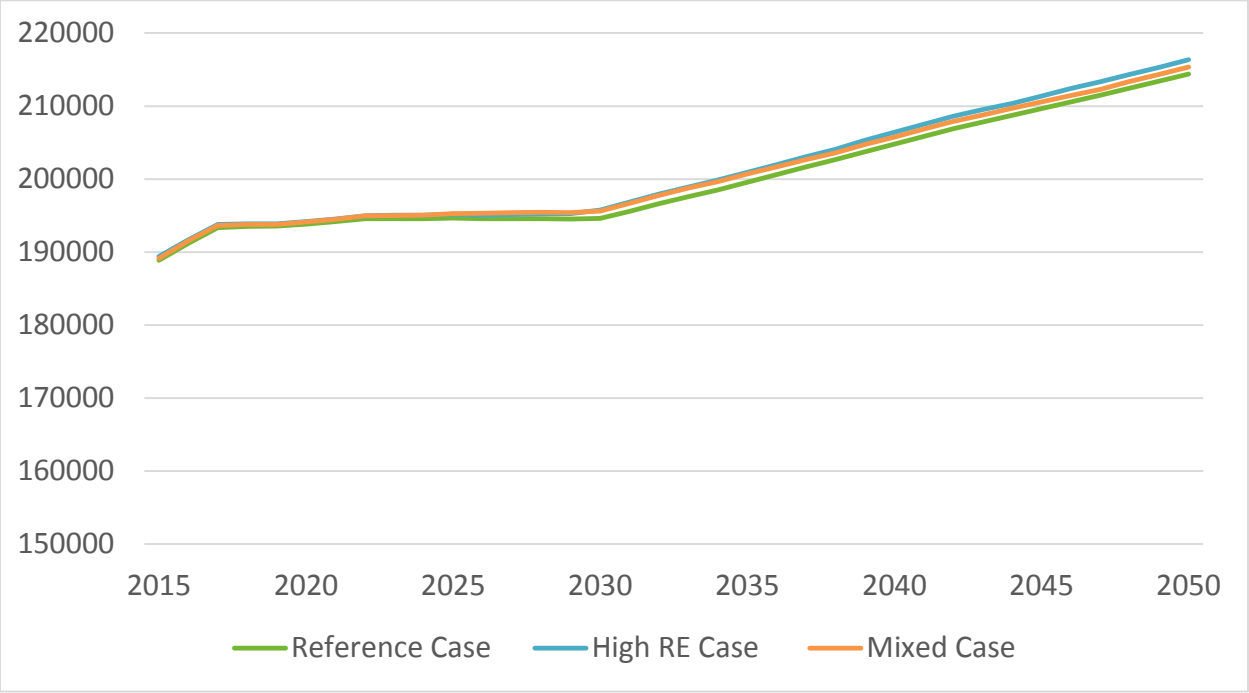
	2030		2050	
	High Renewables	**Mixed**	**High Renewables**	**Mixed**
Employment ('000)	1,110	1,008	1,983	963
% Change	**0.60%**	**0.50%**	**0.90%**	**0.40%**
GDP ($ Billions)	$145	$144	$290	$183
% Change	**0.60%**	**0.60%**	**0.90%**	**0.60%**
Disposable Income per Household	$130,318	$130,283	$154,255	$153,928
Change from Reference Case	**$385**	**$350**	**$654**	**$328**

The differences in job impacts under the High Renewables and Mixed Case are proportional to the different investment levels under each case. Similar to the investment inputs to the model, the job growth over the Reference Case is similar in the High Renewables and Mixed Cases until 2030, after which they begin to diverge.

GDP at the national level shows similar trends to the employment results. Both the High Renewables and Mixed Cases show similar increases in GDP over the Reference Case around 2030 at $145 and $144 billion respectively, or 0.6 percent. They diverge after 2030 as the High Renewables Case increases in GDP in 2050 are about $290 billion and the Mixed Case increases in GDP in 2050 are about $183 billion. Again, as context, REMI projects the Reference Case GDP to be over $31 trillion in 2050. Both the High Renewables and Mixed Cases show similar increases in disposable income in 2030, but in 2050, increases under the High Renewables Case are expected to be almost double those in the Mixed Case. Disposable income per household increases by $350-400 in 2030 in both cases, and by about $650 in 2050 under the High Renewables Case

Viewing these results in a different way, Figure 1 shows the national employment levels over the entire modeling horizon under the three cases, including the Reference Case. Employment growth rates are comparable across the three cases with the two policy scenarios providing a slight boost to overall job growth in the nation over the Reference Case.

Figure 1: National Employment (Thousands of Jobs)



While the deep decarbonization strategies are economically beneficial to the overall economy using the PATHWAYS data, there are distributional effects that lead to disparate outcomes across different regions and sectors in the nation. These results are discussed below.

4.2 Regional Results

The regional changes in disposable income per household, from the Reference Case, are shown in Table 2 below. All regions see increases in disposable income per household throughout the modeling period under both cases, when compared to the Reference Case. The largest increases are in the West South Central region, which has an increase of about $1,000 per household in 2050. This increase in disposable income in West South Central is likely an indication of a smaller labor force due to job losses in the region compared to the Reference Case. This reduces the population *growth* compared to the Reference Case (i.e., overall regional population still grows but not to the extent it would have under the Reference Case), which, combined with improved job quality, results in higher levels of disposable income per household for the region. The story in the Mountain region is the same as it sees increases in disposable income per household and job losses compared to the Reference Case.

In 2030, there are some regions that benefit more under the High Renewables Case and some that benefit more under the Mixed Case. However, in 2050, all regions benefit more from the High Renewables Case.

Table 2: Regional Disposable Income per Household ($)

		2030	2050
New England			
	High Renewables	570	521
	Mixed Case	488	338
Middle Atlantic			
	High Renewables	585	689
	Mixed Case	455	421
South Atlantic			
	High Renewables	454	570
	Mixed Case	252	411
East North Central			
	High Renewables	453	484
	Mixed Case	371	227
East South Central			
	High Renewables	512	977
	Mixed Case	396	426
West North Central			
	High Renewables	339	228
	Mixed Case	352	52
West South Central			
	High Renewables	4	998
	Mixed Case	326	317
Mountain			
	High Renewables	106	468
	Mixed Case	247	98
Pacific			
	High Renewables	346	627
	Mixed Case	339	323

Regional results showing the change in employment from the Reference Case are found in Table 3 below. For employment, 7 regions show gains in 2030 and 2050 while 2 regions show losses. The largest job gains benefit the South Atlantic region with over 670,000 additional jobs under the High Renewables Case and close to 340,000 additional jobs under the Mixed Case in 2050. Many of the offshore wind farms in the PATHWAYS data are assumed to be located in the South Atlantic region leading to significant economic benefits. Two regions that could see job losses are the Mountain and West South Central regions. Since these two regions are historically dependent on mining and other fossil fuel based sectors, they are likely to see job losses due to decarbonization.

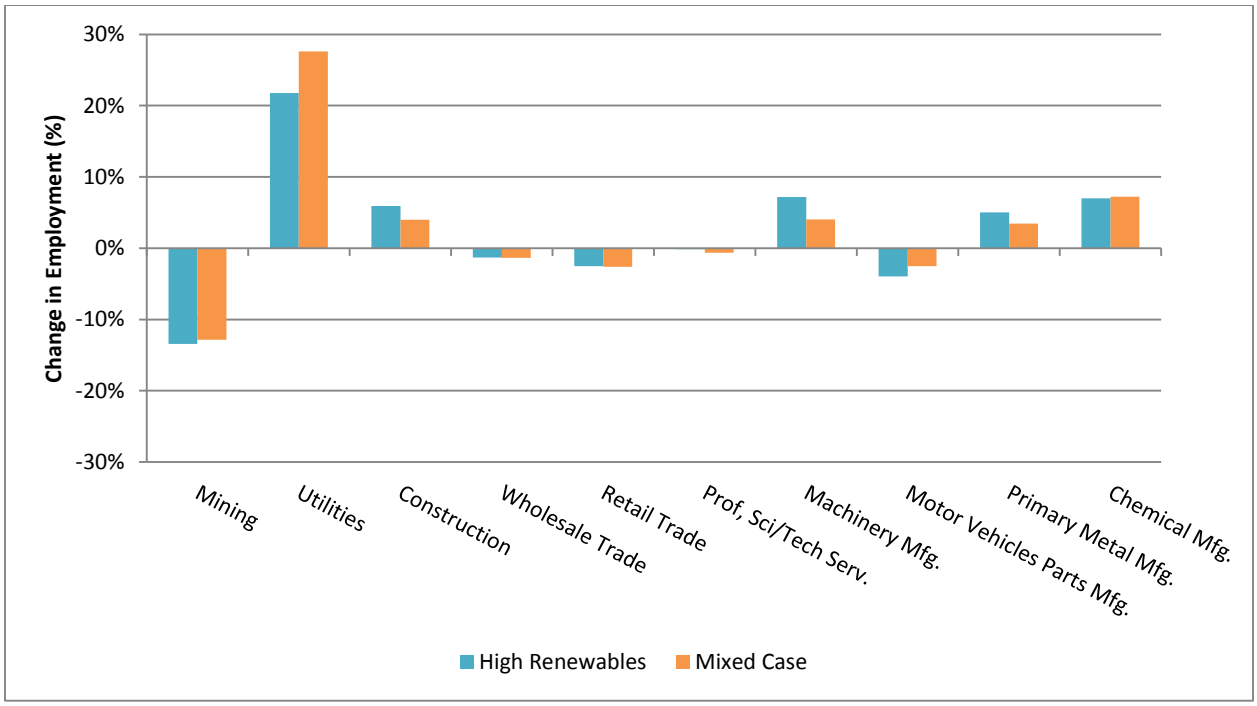
Table 3: Regional Employment (Thousands)

		2030	2050
New England			
	High Renewables	108	187
	Mixed Case	79	113
Middle Atlantic			
	High Renewables	219	369
	Mixed Case	149	257
South Atlantic			
	High Renewables	402	672
	Mixed Case	303	339
East North Central			
	High Renewables	266	384
	Mixed Case	215	101
East South Central			
	High Renewables	99	226
	Mixed Case	93	39
West North Central			
	High Renewables	83	122
	Mixed Case	84	36
West South Central			
	High Renewables	-163	-106
	Mixed Case	-35	-182
Mountain			
	High Renewables	-53	-142
	Mixed Case	-10	-52
Pacific			
	High Renewables	149	270
	Mixed Case	131	312

4.3 Sectoral Results

The sectoral results from REMI breakdown the employment results into some of the main sectors impacted by deep decarbonization. Below, a graphical representation of selected sectors in 2050 is found in Figure 2.

Figure 2: Sectoral Employment (2050)



The sectors that gain are numerous but the ones that show the most job gains are the utilities, construction, and various manufacturing sectors. The utilities sector sees employment gains compared to the Reference Case of over 20 percent in both the High Renewables and Mixed Cases. This amounts to over 100,000 jobs and is due to the high levels of electrification that occurs under these scenarios. The construction sector is another beneficiary with increases of more than 5 percent in the High Renewables Case and more than 4 percent in the Mixed Case.

Numerical results are found in Table 4, below. The construction sector gains 1.1 million jobs under the High Renewables Case and about 800,000 under the Mixed Case. These gains are mostly driven by the large amount of construction that must occur in order to build new generation, transmission lines, distribution lines, new or retrofitted vehicle fueling stations, hydrogen and synthetic methane production facilities, and more. All of these significant investments require construction workers, electricians, and many manufactured components. The increased investments in infrastructure is the main reason for the large gain in many of the manufacturing sectors such as machinery manufacturing (engines, turbines, power transmission equipment), primary metal manufacturing (iron and steel), and chemical manufacturing (hydrogen, synthetic methane), which each see employment increases of 5-8 percent.

Losses occur, in both the High Renewables and Mixed Case, in the mining sector, as it loses about 12 percent of its Reference Case jobs in 2050. The wholesale trade and retail trade

sectors see small percentage losses in jobs as well. These sectors lose jobs due to gas stations shutting down since vehicles no longer need to be fueled with gasoline. These losses are offset by the conversion of gas stations into electric vehicle charging stations or hydrogen filling stations.

Table 4: Changes in National Level Sectoral Employment (Thousands)

		2030	2050
Mining			
	High Renewables	-178.2	-282.3
	Mixed Case	-133.9	-270.2
Utilities			
	High Renewables	27.8	78.7
	Mixed Case	42.1	99.8
Construction			
	High Renewables	465.8	1,186.3
	Mixed Case	462.0	799.5
Wholesale Trade			
	High Renewables	12.2	-78.6
	Mixed Case	-3.3	-80.3
Retail Trade			
	High Renewables	-73.2	-425.0
	Mixed Case	18.3	-443.1
Prof, Sci/Tech Serv.			
	High Renewables	22.2	-28.1
	Mixed Case	-6.2	-136.0
Machinery Mfg.			
	High Renewables	64.8	56.1
	Mixed Case	50.7	31.4
Motor Vehicles Parts Mfg.			
	High Renewables	-23.6	-28.1
	Mixed Case	-15.1	-17.8
Primary Metal Mfg.			
	High Renewables	11.5	10.3
	Mixed Case	8.8	7.0
Chemical Mfg.			
	High Renewables	28.0	29.4
	Mixed Case	24.9	30.4

In addition to the results discussed here, the accompanying briefing package presents additional distributional impacts for different sectors in different regions. All regions see substantial job gains in the construction sector and services sector. The services sector includes not just the technical services needed to transition to deep decarbonization but support services as well, such as health services and education. Utilities also gain in all regions. The construction and services sectors show larger absolute gains, while the utility sector shows larger relative gains. Manufacturing also increases in all regions. In 2050, all regions see losses in the trade sectors (retail and wholesale trade). This is due to the closing of gas stations as people drive fewer miles and use new energy sources for their vehicles. Some gas stations are likely to be retrofitted or replaced by electric vehicle charging stations or hydrogen fueling stations, reducing some of those losses. The West South Central and Mountain regions see losses in fossil fuel sectors. Mining, support activities for mining, professional, scientific, and technical services, and rail transportation sectors are likely to experience job losses in these two regions by more than any other region. The professional, scientific, and technical services sector sees decreases due to a decrease in demand in the fossil fuel sectors for engineers, scientists, and other professionals. The West South Central and Mountain regions see gains in some sectors such as construction, manufacturing, and utilities. While these gains do offset some of the job losses, the net effect is still lower employment than the Reference Case in these regions.

5 Conclusion

The results of this study show that deep decarbonization of the U.S. economy could create positive economic impacts for the nation as a whole. Using the PATHWAYS based modeling assumptions, results indicate that there could be over a million jobs gained by 2030 and, under some scenarios, up to 2 million jobs gained by 2050. In addition, the modeling shows that household disposable incomes are also likely to increase across all regions with the West South Central region having the largest increase. Sectors likely to see the greatest benefits include construction, manufacturing, and the utilities sectors. However, some sectors, such as mining, oil and gas sectors, and gas stations face losses as the domestic demand for fossil fuels decreases. While workers in these fossil sectors are likely to find jobs in the decarbonized economy with additional training and upskilling, analyzing the effect of these shifts are beyond the scope of this study. Seven of the nine Census regions see job gains as they build up their clean energy infrastructure. The West South Central and Mountain regions, which currently rely more heavily on fossil fueled sectors, see job losses due to deep decarbonization. The benefit for these regions, and all other regions, is that new jobs are likely to be higher quality as indicated by increases in disposable income per household across all nine Census regions. These results do not include any costs of inaction under business as usual, or the ancillary benefits to public health and national security that would come from decarbonization.