Alternative Future Pathways

Two important areas of uncertainty for the future of the energy system are the extent of technological change and the capacity for societal change in response to environmental considerations. Brown et al. (2018) developed a structure to model four potential pathways of the U.S. energy system in the MARKAL energy-economic optimization model. The four pathways consider combinations of forcing values for key parameters that capture these areas of uncertainty. The Conservation pathway envisions a future with stagnant technology development but high motivation to protect the environment driving reduced consumption and existing renewable options. The Muddling Through pathway describes a future in which neither energy technology development nor environmentalism are prioritized, but consumerism dominates the energy demands and technological choices. The Sustainability pathway has advanced technologies powering economic growth while social change prioritizes environmentally-friendly developments. This high-tech, environmental pathway includes increased telework, online shopping, and mass transit. The Go Our Own Way pathway follows a desire for domestic energy which increases technological development and energy efficiency, although not with an environmental intent. These four pathways describe potential evolutions of the energy system, but are independent of additional policies that might be implemented. The following analysis expands upon the four pathways by evaluating how an energy policy might evolve within each of these pathways, and its robustness across pathways.

Renewable Energy Standards

Many states are implementing versions of a renewable energy standard, sometimes referred to as a renewable portfolio standard. This type of policy defines a set of electricity generation technologies as “renewable” and sets a production target for electricity from these technologies. These policies are typically defined by requiring that a minimum percentage of electricity generation comes from technologies identified as renewable.

There are variations in this category of policy. There is inconsistency in the definition of which technologies qualify as renewable. Each state’s proposal also has a different timeline and ultimate target. The percentage of energy desired from renewable sources ranges from 10 to 100% and the target year by which the change is desired ranges from now until 2050 with some goals already having been achieved (National Conference of State Legislatures, 2019). In this analysis, we evaluate a simplified national standard to compare the performance of a uniform policy across the U.S. for each of the four pathways. These proposals are sometimes voluntary, but this analysis assumes the national target will be satisfied. The timeline is held constant in each analysis, with the final goal being reached in 2050 and an intermediate goal in 2030. The technologies considered to be renewable in each case are biomass combustion, combined heat and power, geothermal, hydropower, landfill gas-to-energy, waste-to-energy, solar photovoltaic (utility and rooftop), solar thermal, and wind. A range of stringencies is tested from 40-80% in 2050, testing in 10% increments for each of the four pathways. Five policy runs for each pathway were simulated creating 20 scenarios, although not every combination had a feasible solution. This analysis is not intended to be representative of any proposed policy, but evaluates how a general renewable standard might be influenced by external factors that reflect broader uncertainties that may affect key drivers over this time horizon.

Research Results

The Conservation scenario was able to reach 80% renewable electricity by 2050, and all scenarios were able to reach at least 60% renewable energy by 2050. The mix of electricity generation technologies differed across the various pathways. For instance, the Go Our Own Way pathway, which prioritizes domestic resources, begins to increase electricity from biomass at a much lower renewable fraction than the other pathways. The two pathways that prioritize air quality used very little waste-to-energy until more than half of the electricity was required to come from renewable sources, while the other two cases started using it for all renewable levels. Wind and solar contribute significantly toward meeting the mandates in all cases, but the relative proportion of each varies by pathway.
Air emissions in scenarios with a binding renewable energy standard were always lower than without the policy, but the emissions benefit varies. With less aggressive policies, the sulfur dioxide (SO₂) emissions tended to be determined more by the overall pathway. As the renewable requirement increased, SO₂ emissions decrease. Carbon dioxide (CO₂) emissions are strongly tied to the overall renewable fraction, decreasing linearly with increased renewables, as almost all displaced energy is fossil combustion, and the renewable technologies are carbon neutral.

**Implications**

A renewable energy standard, or any other energy policy, is only one factor influencing the evolution of the energy system. Many other factors impact what choices will be made at both the individual and infrastructure levels. In some pathways toward the future, particularly those that are already environmentally focused, the impact of a renewable standard is small because significant investment in renewable energy technologies would have occurred anyway. In other futures, especially *Muddling Through*, achieving high penetrations of renewables might be difficult if technological development cannot keep pace with demand for energy. It is important to consider not only the cost and benefits of a policy, but also how those costs and benefits might be impacted by external factors, such as general societal trends.

The upper limit of renewable energy penetration described here is not indicative of a maximum level of renewable electricity, but rather an indication that 100% penetration would require broader changes in energy technologies and underlying energy demands beyond the scope of what policies for renewables targets generally cover. This study was not intended as a feasibility study for renewable penetration, but rather as an indicator of how uncertain external drivers can either facilitate or create obstacles to these transitions.

**References**


**Disclaimer**

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