Intended and Unintended Consequences of US Renewable Energy Policies

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Introduction

Over the past four decades, the US has employed a range of policies aimed at moving the US energy mix towards more renewable and domestic resources. The objectives of doing that have been to reduce GHG emissions, to reduce dependence on foreign oil, and to increase rural incomes (Tyner 2008b). While most economists might suggest a more generic carbon pricing mechanism such as a carbon tax so that the market decides the mix of technologies that would be utilized to achieve emission reductions, policy makers have chosen subsidies and mandates targeted directly at the different renewable energy sources. The size and mechanisms differ, but the mechanisms have amounted to government deciding what technologies will be favored.

For biofuels, the US and governments around the world initially used government subsidies or tax breaks to advance biofuels, but as the budgetary cost of those approaches became clear, most governments (e.g., US, EU, and Brazil) moved to mandates of one sort or another

(Tyner 2008a). Mandates, of course, pass the cost on to consumers instead of the government budget. In this paper, we will review the intended and unintended consequences of the two main biofuel policies in the US – the Renewable Fuel Standard (RFS) and the California Low Carbon Fuel Standard (LCFS).

For wind and solar energy, a mix of subsidies and mandates have been employed. About 30 states have some form of Renewable Portfolio Standard (RPS) requiring some minimum fraction of renewable energy in the electricity generation or consumption mix (U.S. Department of Energy 2017). The federal government has tax credits for both solar and wind energy that have stimulated quite a bit of investment in those technologies. We will also evaluate the consequences of US policies in these areas.

Another area we include in the discussion on what happens if we use renewables at a much higher level than at present is forest carbon sequestration (FCS), which can be used for carbon offsets. The basic idea is that you pay when greenhouse gases (GHG) are released such as via a carbon tax, or you are paid to sequester the carbon through forests. FCS today is well established as a cost effective means of sequestering carbon (Adams et al. 1999, Richards and Stokes 2004, Sheeran 2006, Sohngen, Golub, and Hertel 2009, Sohngen and Mendelsohn 2003, Stavins 1999). But studies to date have only evaluated the impacts of relatively low levels of FCS.

One of the important conclusions of this analysis on unintended consequences of renewable energy policies is that the impacts differ if we move from relatively low levels of renewable penetration to high levels that might be needed if we are to achieve the COP21 Paris agreement levels of GHG reduction. We find that the consequences are much more dramatic at high levels of penetration and that much of these more significant consequences have not been well addressed in the literature.

In doing the evaluation, we will assess the policies using the following criteria:

1)To what extent did the policy achieve the objective of increasing production and consumption of the targeted renewable energy.

2)What was the cost of achieving the renewable energy increase, and how does it compare with the government estimated social cost of carbon (around $40/ton) or with the carbon price often associated with achieving the aims of the Paris accord ($160/ton or higher).

3)To what extent did the policy reduce US dependence on foreign energy?

4)What were the unintended consequences of the policy, and what are their impacts?

Criterion 1 – effectiveness at achieving higher use of renewable energy

The answer to this question is straight-forward. For both biofuels and wind and solar, the policies have clearly increased renewable market penetration far above what would have happened through market forces. Figure 1 shows that US ethanol production went from essentially zero in 1980 to above 16 billion gallons/year by 2016. There has been similar percentage growth in biodiesel. These industries were essentially created by government incentives, initially tax subsidies (U.S. Congress 1978) and later by renewable fuel mandates (U.S. Congress 2007). There is extensive literature on the advantages and disadvantages of subsidies versus mandates (de Gorter and Just 2009, 2010), but the reality is that the combination of subsidies and mandates - the Renewable Fuel Standard (RFS) did at least partially achieve the objective of increasing penetration of renewable fuels in the marketplace. However, the RFS has not been successful in achieving the intended growth of the cellulosic biofuel industry. The original legislated RFS mandate for cellulosics for 2017 was 5.5 billion gallons, but actual production is around 200 million gallons.

For solar and wind electricity generation, the government also played a large role in stimulating growth in the sectors. Figure 2 shows the growth of US solar and wind electricity production. Renewable electricity started growing about 20 years after biofuels. For solar energy, there is a 30% federal tax credit for the installation of solar panels and equipment (Jung and Tyner 2014). For wind energy, there is a production tax credit for each unit of wind electricity produced of $23/MWh (Schmalensee 2016). The state renewable portfolio standards also provide a form of mandate for renewable energy. Again, it is clear that market penetration has been much higher than it would have been in the absence of government incentives.

Criterion 2 – policy cost

The answer to this question is much more complicated. Costs and benefits of the policies are very difficult to quantify. As is often the case, we can more easily quantify the cost of imposing a policy that deviates from a market solution. The costs are often expressed in terms of loss in GDP (Sarica and Tyner 2013) or loss in welfare (Taheripour and Tyner 2014). However, these costs do not take into consideration the benefits from reduced GHG emissions or other benefits.

If we use the estimated social cost of carbon (SCC) of about $40/ton (Interagency Working Group on Social Cost of Carbon 2013), that translates to about $0.19 cents per gallon of gasoline or $0.27/gal. of biodiesel (U. S. Environmental Protection Agency 2017). Of course, ethanol and biodiesel do not eliminate all the carbon emissions from these fuels. Current estimates are that ethanol reduces emissions by about 25%, and biodiesel about 60%. Thus, the savings would be equivalent to about $0.05/gal. for ethanol and $0.16/gal. for biodiesel. Those social cost of carbon values translated to $/gal. are far lower than May 2017 Renewable Fuel Identification Number (RIN) prices, which reflect the “cost” of the RFS. RIN values are market prices reflecting the difference in cost of renewable fuel alternatives and fossil fuels plus any constraints in the supply system such as the blend wall (de Gorter, Drabik, and Just 2013, Tyner 2012). The biodiesel (D4) and ethanol (D6) RIN prices as of May 20, 2017 were $0.92 and $0.67/gal., far above the value of emissions reduction based on the SCC. So the answer to the cost question is complicated, but it is pretty clear that biofuels emission reduction benefits as valued by the SCC are less than the cost imposed on consumers and the economy.

Analysts estimate that the cost of achieving the GHG reductions needed to achieve the objectives of COP21 Paris accord are much higher than the “official” cost of carbon. Several studies put the carbon tax equivalent to achieve Paris at $160/ton or even higher (Marpaung and Shresta 2017, Rezai and Van der Ploeg 2016, Hassler et al. 2016). Even at these carbon prices, however, biofuels emission reductions would still be valued less than the RIN prices cited above. The ethanol and biodiesel emission reduction values at $160/ton would be $0.19/gal. and $0.64/gal. respectively. The reality is that the lower cost options are things like forest carbon sequestration and reducing high carbon electricity generation (Sarica and Tyner 2013).

The State of California has a different means of encouraging renewable energy called the Low Carbon Fuel Standard (LCFS). It is quite different from the RFS. The RFS places a minimum emission reduction threshold for each separate category of biofuels. It is 20% for corn ethanol, 50% for biodiesel and other advanced biofuels, and 60% for cellulosic biofuels (U.S. Congress 2007). Once a biofuel meets the threshold, it can earn Renewable Fuel Identification Numbers (RINs) and qualify for the RFS. Biofuels that exceed the threshold receive the same credit as those that just meet the threshold. The LCFS is quite different. In the LCFS every unit of emission reductions counts. The carbon credits are tradable so those who reduce emission below the standard can sell their excess credits to those short of the standard. For corn ethanol, the credit today is worth about $0.30/gal. gasoline equivalent, so it exceeds the SCC. It is also higher than the cost estimates to meet the Paris accord, and as the LCFS becomes more stringent, one would expect the credit price to increase to meet the tougher standard.

The situation is somewhat different for solar and wind energy. Based on data obtained from (International Renewable Energy Agency 2016), we estimate that the carbon price equivalent for wind energy subsidies amounts to $32/ton, and to $79/ton for solar. Thus, the wind energy subsidy is actually less that the social cost of carbon estimate. Solar is more than the carbon cost, but less than the carbon tax equivalent estimated to achieve the COP21 Paris accord emission reductions. These costs do not include the required added stand-by capacity once solar and wind penetration increases to higher levels. Because solar and wind electricity are interruptible, there must be stand-by capacity (usually gas turbine) ready to come on at any time the renewable supply is disrupted. Alternatively, the solar or wind energy can be stored in batteries or with pumped storage, both of which also impose and added cost on the system. We will cover this "capacity cost" issue below.

Criterion 3 – impact on energy imports

Figure 3 provides the recent history of the share of US oil consumption that is imported. The import share was around 30% in 1980, rose to over 60% by 2007, and then fell again to under 50%. This recent fall occurred during the period of the rapid increase in US biofuels, but biofuels are only part of the story. The recession following the financial crisis of 2008 reduced oil demand considerably. Increased fuel economy standards also reduced oil demand. The oil shale boom was taking off around 2007. The decrease in dependence on foreign oil was driven by all these factors, but biofuels represented the smallest share of the reduction. The largest share was oil shale, which grew rapidly from 2007 to 2014, then dropped off with the plunge in oil prices, but has picked up again since 2016. Biofuels policies have helped reduce oil imports, but not nearly so much as the shale revolution. Renewable electricity subsidies have not reduced energy imports as they have largely displaced domestic coal.

Criterion 4 – policy implementation issues and unintended consequences

There have been implementation issues and unintended consequences associated with the renewable energy policies. We will first cover biofuel policies, then wind and solar energy, and finally discuss an important issue regarding how the impacts of these policies can change as we move from low-level market penetration to much higher market penetration.

Biofuels

When the revised version of the RFS was enacted in 2007, annual gasoline consumption was 142 billion gallons and was expected to continue to increase as it had in the past (about 1.3%/year). Had that happened, gasoline consumption would have grown to over 150 billion gallons annually by 2014, and would have absorbed the RFS level of 15 billion gallons of corn ethanol. However, following 2007, gasoline consumption fell and did not even reach the 2007 level again until 2016 when it reached 143 billion gallons. Thus, the 15 billion gallon RFS mandate could not be absorbed by the gasoline market creating what is known as the blend wall. The drop in gasoline consumption was due to two main factors. First, the great recession of 2008-09 led to a large drop in gasoline consumption, and it took quite a while for growth to begin again. Second, the US enacted much more stringent fuel economy standards, which meant consumers could drive more miles with less fuel. High oil prices also encouraged consumers to purchase more fuel-efficient vehicles and perhaps to drive a bit less.

As it became clear that the blend wall was going to become a significant issue, RIN prices began to increase substantially. RIN prices had generally traded in the $0.02 - $0.04 range through 2012. Essentially, the RIN price was the transaction cost. The RFS was not really binding, and there were no major blending issues. Starting in 2013, the market could see the upcoming blend wall, and corn ethanol RINs increased in price substantially topping $1/gal. Subsequently in the fall of 2013, EPA took the blend wall into consideration in establishing the RFS levels and reduced the legislated mandate level for 2014. Since then, EPA has gradually increased the mandate level to the point it will reach the legislated 15 billion gallons. This "demand pull" has kept RIN prices around $0.70/gal.

Another characteristic of the RFS is the complicated nesting structure with four different categories of biofuels each with its own mandate. The nesting structure is illustrated in Figure 4. There is a separate mandate for cellulosic biofuels of 16 billion gallons ethanol equivalent by 2022. Biodiesel also has its own mandate. Both biodiesel and cellulosic biofuels can also be used for the other advanced biofuel mandate (nested) and for the overall mandate. Only corn ethanol can be used to meet the implied conventional biofuel mandate. Since there are four categories, there are four separate kinds of RINs (D3-D6), each with its own market price. The ethanol (D6) and biodiesel (D4) RIN prices were mentioned above, and the other advanced (D5) is $1.03, while cellulosic (D3) is $2.60 (Progressive Fuels Limited 2017). Thus, the RIN price for each category reflects the relative scarcity of that biofuel relative to the mandate level and the cost of production difference between fossil and renewable fuel in the category.

Cellulosic biofuels have not developed as expected when EISA was passed in 2007. Every year, all or part of the cellulosic mandate has had to be waived by EPA. For example, in 2016, the mandate was 4.24 billion gallons, but the actual mandate was 0.23 million gallons, or 4.5% of the legislated level. Any time EPA waives any part of the cellulosic mandate, they must offer a waiver credit which obligated parties can purchase and use in lieu of purchasing actual cellulosic biofuel. Congress created this off-ramp to cap the consumer cost of compliance in case cellulosic biofuels ended up being very expensive. The waiver formulae is a negative function of previous year gasoline prices, and the value for 2016 was $1.33. To meet the obligation, one would also have to purchase an “other advanced” (D5) RIN and receive credit for a D6 RIN. The total cost of avoiding the obligation then is $1.33 +$1.03 - $0.67 = $1.69. Thus one could use the waiver to avoid paying $2.60 for a cellulosic RIN. That means that the cellulosic component of the RFS is not very binding, which helps explain why there is so little investment in cellulosic biofuels.

Another issue that has arisen after the 2016 election relates to the point of obligation for the RFS. Under the current system, obligated parties are refiners and petroleum product importers. There are about 140 of these obligated parties, all of which are large entities with the administrative competence to handle the RFS reporting requirements. However, some of the obligated parties do not have retail outlets, so they have no way to absorb ethanol in their marketing system. These are called merchant refineries. They refine crude oil and sell the products to intermediaries. But since they are obligated parties and blend no biofuels, they must purchase RINs on the market to meet their obligation. Only about 20-25% of total RINs are traded, but for these entities, it is like a tax on their refined products. Integrated companies purchase biofuel, and blend it with fossil fuel, thereby separating the RIN and using it to satisfy their blending obligation.

The merchant refineries would like to move the point of obligation away from the refinery and importer further up the supply chain to blenders and towards retailers. EPA estimates that there would be over 1000 and perhaps as many as 1400 of these points of obligation. Many of these companies are smaller with less experience dealing with this kind of administrative process. Some believe such a change would put the whole RFS in jeopardy. Others believe it could be managed, but may be difficult with the possible budget cuts faced by EPA.

Renewable electricity

As indicated above, renewable electricity is supported by federal and some state tax incentives plus about 30 state renewable portfolio standards. These standards vary significantly from state to state with some being production mandates, some consumption, and some a combination. Other states have goals but not mandates. One of the issues with renewable electricity is how it fits with electricity pricing regimes and the extent to which states allow/require net metering. Retail net metering provides a significant advantage for renewable electricity as it requires the utility to "buy" the customer generated electricity at retail instead of its normal wholesale purchase price. For wind energy in particular, this can be costly as wind energy tends to be stronger at night during off peak periods. If a state has flat rate pricing, as most do, that wind energy can be very expensive. Solar peaks are closer to utility peaks, so the net metering policy is not normally as expensive for the utility. If a state has peak period pricing, the impact of net metering would be different because the price would be the retail price during the period in which the power was generated and transferred back to the utility. In the future, it is likely that peak pricing for net metering plus other options will be considered by many states. Retail net metering imposes a cost on non-solar utility customers because it increases the cost the utility pays for electricity.

At low levels of penetration, these issues may not impose significant costs on the utility or on non-solar or wind customers. However, there is clearly an added cost for non-renewable customers. In essence, the current system in most states subsidizes renewable energy supplying customers with higher fees from other customers. Below we will discuss another important cost issue for renewables as the scale increases.

Renewable energy issues at high penetration levels

The impacts of renewable energy on the total energy and economic environment depend on the renewable share in the total for the system. There is ample evidence that adverse impacts of renewable energy on the system can become quite substantial at much higher penetration levels, but the mechanisms differ significantly depending on the type of renewable energy. For forest carbon sequestration, renewable electricity, and biofuels, it appears that impacts at high penetration levels can be significantly larger than impacts at small penetration levels.

Forest carbon sequestration

Although not a category of renewable energy, FCS expansion to large scale can have significantly different impacts than at small scale. Previous studies have examined the impacts of different levels of carbon taxes and FCS subsidies on agricultural land use change, prices, consumer and producer welfare, etc. McCarl and Schneider show a substantial decline in area of traditional crops, and an increase in bioenergy crops and afforestation at a carbon price of $100/ton (McCarl and Schneider 2001). They also find that the level of emissions and land use changes depends significantly on market adjustment assumptions and scope and region of mitigation alternatives (Schneider and McCarl 2006). Alig, et al. also find that land payments for forest carbon sequestration can have a significant impact on increasing forest area and reducing traditional cropland area (Alig et al. 2010). All of these studies used a US agricultural sector model.

We used a global model to estimate the impacts of a carbon tax and equivalent FCS subsidy at the global level. We used a version of the GTAP model named GTAP-BIO-FCS (Pena-Levano, Taheripour, and Tyner 2015). We simulated two cases – carbon tax only and carbon tax plus equivalent FCS subsidy. In other words, you can release the carbon dioxide and pay the tax, or sequester it and receive the subsidy. We calibrated the values to achieve the COP21 Paris agreement limit of no more than 2 degree increase in temperature. The calibration result for the carbon tax alone was $155/ton $CO_{2eq.}$ The calibrated level for the carbon tax plus FCS subsidy was $100/ton. Both these levels include climate change induced yield shocks on all major crop categories. The tax and tax plus FCS levels are a bit lower if the climate change induced yield shocks are ignored. As would be expected, for the carbon tax only case, there is little or no FCS but a major reallocation of resources in the economy with major emission reductions in the electricity sector (41%). However, for the carbon tax plus FCS subsidy case, 14% of the emission reductions come from FCS. In part because forests are so efficient at reducing sequestering carbon at low cost, the subsidy makes it very attractive to convert pasture and cropland to forest. As a result, crop production falls significantly, and there are major increases in commodity and food prices around the world, with some developing countries being especially hard hit. In fact, the estimated price increases are so large that it is clear they would be politically and socially unacceptable. Governments would likely choose to accept the adverse climate impacts rather than face the large food price increases. The bottom line is that FCS at the scale that would be needed to achieve the COP21 Paris agreement would likely have very serious adverse consequences. These consequences occur, in part, because FCS is such an efficient way to sequester carbon. Since land at the end is the limiting resource, the problem arises as we push the land resource to the limit, and is not seen at all at low levels. There are clear non-linearities as ultimately we approach land supply limitations at large scale FCS. Of course, with higher investments in adaptation, we could reduce to some extent the adverse consequences.

Biofuels

The food-fuel issue has been important for biofuels at least since the commodity and food price spikes in 2008 (Abbott, Hurt, and Tyner 2008, Abbott, Hurt, and Tyner 2011). See (Sajedinia and Tyner 2017) for a review of the vast literature on the food fuel issue. While the studies differ in their conclusions, most recent studies show relatively small commodity price impacts at the levels simulated. However, most of the analyses in that literature simulate biofuels at relatively low levels compared with total liquid fuels production and consumption. For example, the largest corn ethanol simulation in the US amounts to about 7% of national gasoline consumption on an energy basis. One study examined larger scale use of biomass for both liquid fuel and electric power (Reilly and Paltsev 2009). They reached a biofuel penetration level of 55% but at the expense of converting the US from a large exporter of agricultural commodities to a net importer. Of course, commodity prices also increased. There is no doubt that if we were to simulate 30% or more of liquid fuels globally from biofuels, there would be much more serious food price impacts. So again, the low-level impacts we have evaluated are likely quite different from what we could expect at higher levels.

Renewable electricity

Both solar and wind are intermittent sources of electricity and as such there are issues with integration to the grid on a large scale. As the penetration of both solar and wind increases, it is important to examine issues and costs related to intermittency. The options for dealing with the intermittency issue are to curtail demand when the renewable energy is not available, to make use of large-scale energy storage, or to provide supplemental generation capacity that can be dispatched quickly (Clack et al. 2017).

Both sources have different levels of predictability based on factors such as technology, forecasting and weather (Gowrisankaran, Reynolds, and Samano 2016). In the case of solar, electricity can only be generated during daylight hours. As such, there are costs associated with the intermittency of solar and wind electricity. Given that there are no current economically viable storage capabilities, electricity supply and electricity demand has to be equated at all times to avoid blackouts and cascading problems (Gowrisankaran, Reynolds, and Samano 2016). As such, there needs be to a backup generation source that can come on quickly, and it is typically a nonrenewable source such as natural gas.

There are studies that examine issues related to high levels of penetration and costs of intermittency of solar and wind (Hirth 2013, 2015, Hirth, Ueckerdt, and Edenhofer 2015, Lueken, Cohen, and Apt 2012). Hirth et al. examine integration costs of wind energy and find that at penetration rates of 30–40%, integration costs up to 50% of total generation costs. The market value, defined to be revenue from generation without subsidies, of wind generation is higher than that of a nonrenewable electricity source at low penetration, but the market value decreases to 50%–80% of the original market value when the generation share of wind generation is 30% (Hirth 2013). The study also finds that for solar generation, a similar decrease in market value occurs when the generation share of wind generation is 15%. However, Hirth (2015) finds that for Northwestern Europe the optimal long-run share of wind generation for welfare is 20%, which is three times more than the current share of wind generation. This estimate is highly uncertain and depends on the inherent variability of the wind sources.

In the case of Germany there have been higher electricity costs due to intermittency and high levels of penetration of solar and wind power (Böhringer et al. 2017, Andor et al. 2017). Renewable energy source capacities increased to 98 Gigawatts, while conventional power plants capacities is 104 Gigawatts for 2015 (Andor et al. 2017). This increase has come at a cost as household electricity prices have already doubled since 2000, and are not expected to decrease in the future. Other research suggests that in the light of these high price increases, there is a decrease of 17% in the mean willingness to pay for 100% green electricity (Andor et al. 2017). Another area of concern is that the burden of higher energy prices will be borne by poorer households. One study suggests that changing the subsidy mechanism can help decrease the burden on poorer households (Böhringer et al. 2017).

For solar generation, the short run variability adds value if it occurs at high-demand times and displaces high carbon-intensive generation. The medium-run cost of each installations falls due to experience effects, but the cost of grid integration increases as capacity share increases due to the added “capacity cost” required. The long-run contribution depends on grid integration costs, availability of other low-carbon technologies, and potential for technological advances (Baker et al. 2013).

Lueken et al. (2012) examines the cost of variability of renewable energies and also shows that the variability can affect CO_2 emissions abatement as penetration levels increase for renewable energies. Another cost is the need for backup generation and change in reserves. Brouwer et al. (2014) find that when wind generation increases to 20% of total generation, the combined size of all other reserves increases by 7% of the installed wind capacity. The study also finds that when wind generation increases to over 30% there is oversupply of wind power which causes restriction of wind generation and the increased demand for reserves leads to an increase in direct system cost of 1–6 €/MWh. There are significant impacts on the power system when there are higher levels renewable energy penetration.

Gowrisankaran et al. (2016) combine costs used in other studies to include the ability to forecast (integration costs), variability costs, and back up generation costs to come up with the total social cost. The study finds that for 20% solar generation, there is a cost of $6.1 per MWh for unforecastable intermittency and the total intermittency cost is $46 per MWh. Table 1 shows reserve and total social costs at different levels of solar electricity penetration. Both reserve costs and total social cost increase as the penetration of solar energy increases.

One potential solution to intermittency is energy storage systems. Potential storage systems include fly-wheel systems, compressed air energy storage, pumped hydro, and various advanced battery technologies (Dunn et al. 2011). These systems would be costly, and would be a part of integration costs. They have not been implemented in large scale (Baker et al. 2013). It is possible that with technological advancement and decreases in costs, energy storage systems can be used to address intermittency issues of renewable energies at lower cost than adding additional capacity.

Clearly all the renewable energy or renewable sequestration options present much more serious consequences at larger scale than at low or current levels. For FCS or biofuels, the ultimate constraint is land, and, of course, if both were to grow significantly, then the consequences would be even more severe. For renewable electricity, the issue is intermittency, which require costly backup once renewable electricity becomes a significant fraction of the power generating system.

Conclusions

There are three important conclusions that emerge from this literature review and analysis. First, it is clear that policy makers based on their actions have a preference for regulation as opposed to pricing mechanisms like carbon taxes. Buchanan and Tullock provided an explanation for this outcome in their classic AER paper (Buchanan and Tullock 1975). Basically, their argument suggests that it may be in the interests of those being regulated to have regulations in some conditions rather than taxes to handle externalities. From a political context, there may be interest in getting the costs of incentives for renewable energy off the government budget and in a more indirect (hidden) form via higher prices for consumers. Also, there may be perceived equity reasons why consumers would prefer regulations to taxes. Friedman discussed the choice of rationing versus taxes during World War II, either of which could help bring into balance commodity supply and demand (Friedman 1943). O'Leary explained the rapid move towards rationing after Pearl Harbor (O"Leary 1945). During the 1973 oil embargo, there was an overwhelming consumer preference for rationing as opposed to taxes on gasoline. This issue was explored by Barnaby and Reizenstein (Barnaby and Reizenstein 1976). For all these reasons, the US political process tends to use regulation much more than would be suggested by economists.

Second, there is clearly a difference between low levels of renewable energy penetration and high levels. Forest carbon sequestration is a very cost effective form of reducing atmospheric carbon dioxide. However, at large scale, limited land supply becomes a binding constraint and leads to a non-linear and significant increase in total costs imposed on the economy and society. Biofuels at the scales being practiced today have some impact on food prices, but the impact would be substantially larger if biofuels supplied a large fraction of liquid energy. Similarly, renewable electricity imposes little costs on the electric grid at low levels, but at higher penetration rate, the fact that renewable electricity is interruptible means that standby power must always be available. This "capacity cost" increases the total cost of renewable energy substantially.

Third, as evidenced by this article and many others, it is much easier to quantify costs of renewable energy policies than benefits. We know that there are benefits of GHG reduction in the form of avoided infrastructure damage, avoided health costs, avoided crop yield reductions, and many others. But quantifying the value of those avoided benefits has proved to be challenging and fraught with uncertainty.

In this article, we have explored intended and unintended consequences of US renewable energy policies. Perhaps the most important unintended consequence is the difference between impacts at low levels of penetration and high levels. Most of the analysis done to date has only examined impacts and costs at low levels of penetration. To achieve the goals of COP21 (Paris accord), we will need much more aggressive climate policies, and that means we will be forced to deal with the high penetration level consequences.

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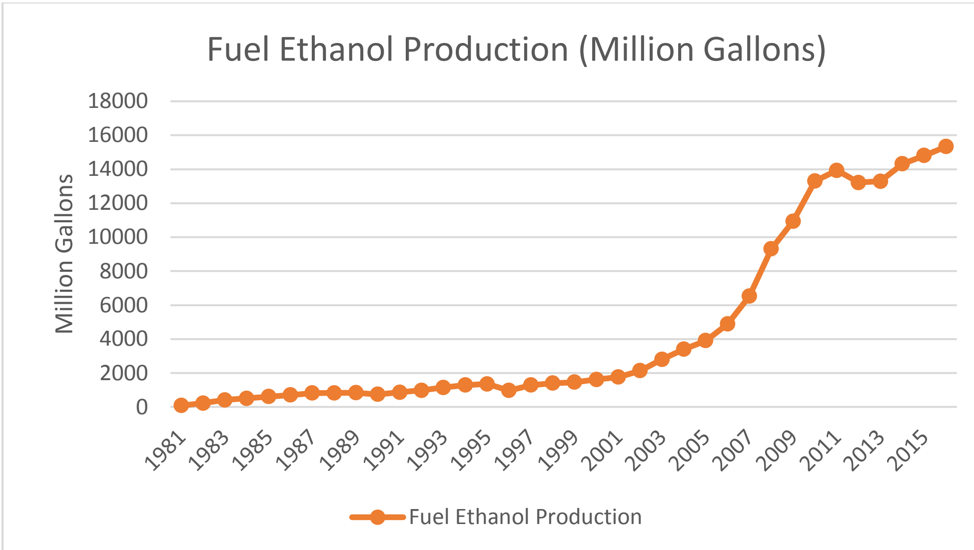

Figure 1. History of US ethanol production

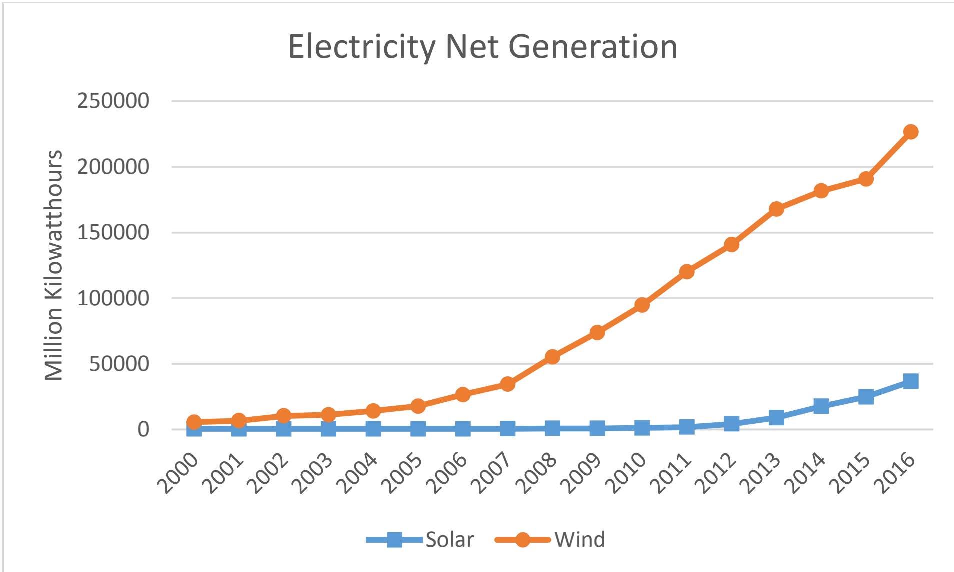

Figure 2. Solar and wind energy growth in the US

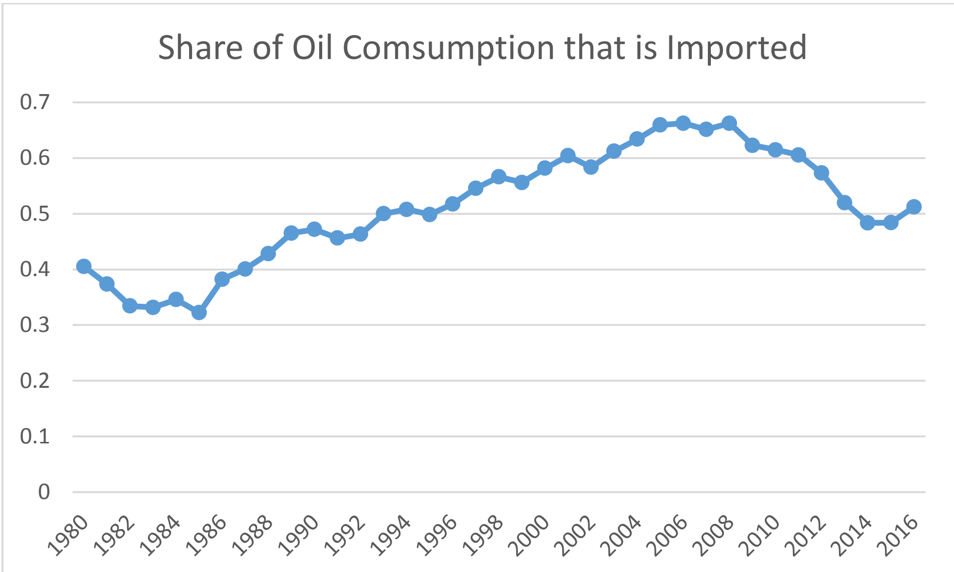

Figure 3. Share of US oil imports through time

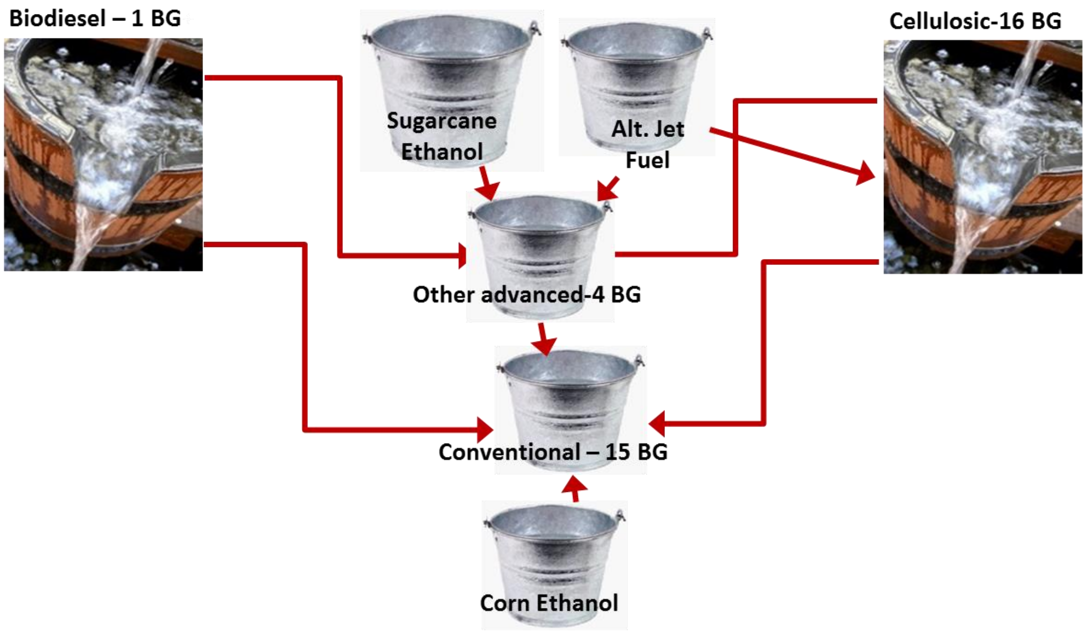

Figure 4. Nested Structure for the RFS

Table 1. Reserve and total social costs at different levels of solar electricity penetration

Solar electricity penetration (%)	Reserves Cost ($ Millions per year)	Total social cost ($/MWh)
0	78.1	0
10	81.5	126.7
15	82.8	133.7
20	84.8	138.4

Source: Gowrisankaran et al. (2016)