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Modeling the U.S. Climate Agenda: Macro-Climate Trade-offs and Considerations

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Modeling the U.S. Climate Agenda: Macro-Climate Trade-offs and Considerations

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ABSTRACT: The run up to the 26th Climate Change Conference has brought tackling climate change to the fore of global policy making. In this context, the U.S. administration has recently unveiled new climate targets. This paper elaborates on the administration's plans and uses two models developed at the IMF to illustrate key macro-climate trade-offs. First, a model with endogenous fuel-specific technological change shows that subsidies cannot substitute for explicit carbon pricing and that even a moderate carbon tax can greatly economize on the overall fiscal cost of the package. Second, a rich sectoral model shows that there are only very marginal economic costs from front-loading the decarbonization of the power sector but there are large accompanying environmental benefits. Regulations can be effective in the power sector because they provide an appropriate shadow cost to carbon. However, a carbon tax would still be more efficient and easier to administer. Finally, as the economy transitions away from fossil-fueled power generation, there would be a significant reallocation of labor across sectors and locations that would need to be handled carefully to limit the social costs of the transition.

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I. INTRODUCTION

The climate crisis is an important global challenge and bold action is needed. This year's 26th Climate Change Conference comes at a pivotal time for climate action. Global temperatures continue to rise (UN, 2021a), as greenhouse gas (GHG) concentrations reach record levels (WMO, 2021a). Extreme weather events are becoming increasingly frequent across the globe (WMO, 2021b). At the same time, climate policy actions of large emitters have not been sufficiently ambitious (UN 2021b).

In the last few years, greenhouse gas emissions have declined in the U.S. despite a lack of determined policy action. The U.S. has been on a multi-decade transition away from coal-powered electricity generation, due to the increasing availability of cheap, domestically sourced natural gas – a direct result of the fracking revolution (EPA, 2021). However, climate policies have played a limited role in the gradual reduction of GHG emissions. As a result, the emissions reductions have been moderate, and would be insufficient to help keep global temperatures from rising to dangerous levels.

The new administration has declared its intention to tackle the climate crisis. The administration pledged to re-join the Paris agreement in its first day in office and announced a few months later a much more ambitious Nationally Determined Contribution (NDC) that would see U.S. net GHG emissions decline by 50-52 percent below 2005 levels in 2030. In addition, other goals have been announced, such as a net-zero economy by 2050 as well as fully decarbonized electricity generation by 2035.

The administration is likely to rely on subsidies, investments and regulation, and much less on explicit carbon pricing. The U.S. does not have plans to introduce explicit carbon pricing, either through a carbon tax or an emissions trading system[1]. The rationale is that rather than making carbon expensive, a combination of investments and subsidies can meaningfully reduce the cost of clean energy. Stricter regulations will also be pursued which impose an implicit shadow price on GHGs, although the magnitude of such a shadow price is hard to quantify. This paper documents climate policy actions by the administration including those in the recently signed-into-law Infrastructure Investment and Jobs Act and the Build Back Better Act, that has passed the House but not the Senate, and hence is yet to be signed into law. The analysis of the latter uses the version passed by the House of Representatives and some of the details in the final package may differ.

At a sectoral level, greening the power and transportation sectors is crucial for achieving the announced targets. The two sectors combined account for roughly half of current U.S. GHG emissions. Moreover, there is an important complementarity between them: the mass deployment of electric vehicles (EVs) is green only in so far as electricity generation is itself green. The power sector is also an interesting case study because regulation and technology are well established, and the marginal cost of green alternatives is competitive with

[1] An exception would be the uncertain prospects for the adoption of a Federal Clean Energy Standard.

traditional brown technologies. This is recognized by the U.S. administration, which has set a target to fully decarbonize the power sector by 2035, 15 years ahead of its goal for the wider economy.

This paper tackles two broad groups of questions surrounding key macro-climate trade-offs and considerations underlying the administration's agenda:

1. Economy-wide, can a strategy that relies solely on subsidies and public investments be effective even without explicit carbon pricing? Do R&D subsidies change that calculus?

2. Regarding the power sector, how economically costly is it to decarbonize the sector quickly versus transitioning over a longer horizon?

3. Can regulation in the power sector provide effective incentives?

4. And, finally, what would be the labor displacement associated with greening the power sector?

To address the first issue, we use a model with endogenous fuel-specific technological change to assess the impact of subsidies, including R&D, and compare outcomes to those with carbon taxes. To tackle the second question, we use a detailed sectoral model to study the power sector and illustrate issues related to the timing of decarbonization, the use of regulation and the implied sectoral re-allocation. Both models were developed at the International Monetary Fund.

This paper's modeling builds on and relates to existing literature. The integrated assessment model used to judge whether subsidies are in general a good substitute for carbon pricing is an application of Barrett (2021), which itself builds on Hassler and others (2020) and Golosov and others (2014), and was featured in IMF (2020). Integrated assessment models were pioneered by Nordhaus (see the review in Nordhaus, 2011). The ENV-IMF model used to study options for the power sector is related to "ENVISAGE" model (see Van der Mensbrugghe, 2019) and the "OECD ENV-Linkages Model" (Château and others, 2014). Related is Stock and Stuart, 2021, which assess a wider set of policies for the U.S. power sector and crucially their optimality in a more detailed model.

Our findings are that:

1. On an economy-wide basis, subsidies cannot substitute for explicit carbon pricing and even a moderate carbon tax can greatly economize on the overall fiscal cost of reducing emissions (reducing the need to raise other taxes to pay for the subsidies). R&D subsidies can play a useful role, and may create positive international spillovers, but do not meaningfully change this basic conclusion.
2. Early decarbonization of the power sector is more economically costly initially, but only marginally. The benefits for the environment are, however, large.
3. Regulations in the form of a renewable energy standard can be effective in the power sector insofar as they provide an appropriate shadow cost to carbon. Nonetheless, a carbon tax would still be preferable.

4. Finally, during the transition to green power labor would have to shift across sectors. Supportive fiscal policies would likely be needed to cushion the impact of some of the most geographically concentrated effects as well as to facilitate the reallocation of labor (potentially through interventions to support to acquire new skills, move geographically, incentivize hiring).

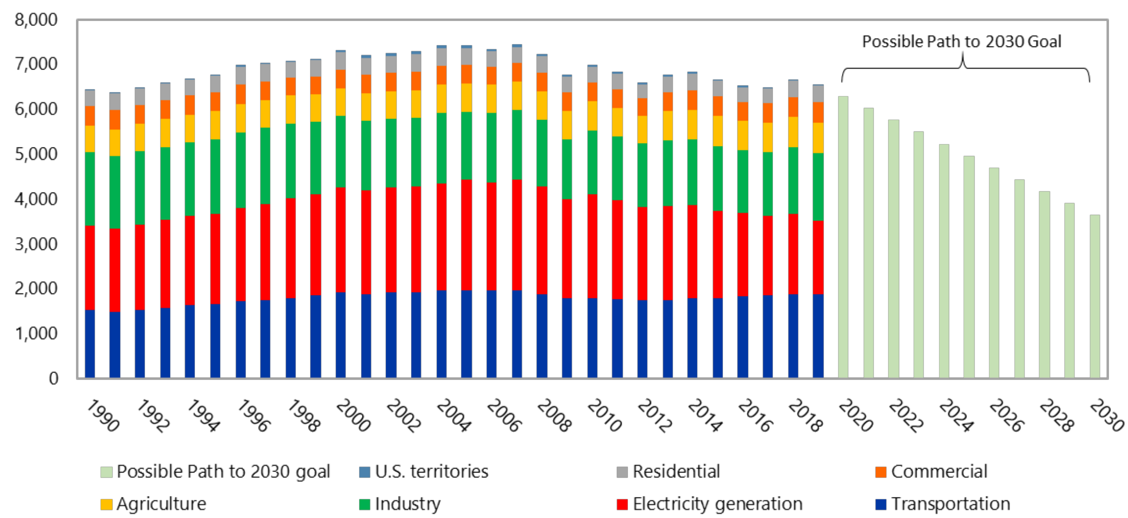
We note that this paper focuses on federal policies. A detailed analysis of state-level policies is outside the scope of the paper, despite their importance for a full picture of climate policy in the United States in at least two dimensions. First, the extent to which any federal climate policy is binding will vary considerably across states, as some jurisdictions have much more ambitious local climate policies already in place. This would be important to consider for the combined effect of federal and state policies. Second, the federal government may have a limited set of levers in several crucial areas. This is true in both the power and transportation sectors, where states have a great saying in how investment is carried out, for example allocations to public transport relative to new roads, or having more renewable energy relative to gas fired power plants.

The paper is organized as follows: section II reviews the U.S. administration's recent climate announcements and puts them in context, section III assesses economy-wide climate policy options including comparing subsidies-only and subsidies-plus-taxes packages, section IV studies the power sector in detail, given its importance, and section V concludes.

II. Ambitious Climate Plans and Recent Actions

The U.S. is the world's largest economy and the second-largest greenhouse gas emitter after China. In contrast to China, however, U.S. emissions –total and per capita – have been high for decades, with levels in 2019 close to those in 1990. The peak in emissions was reached in the period just preceding the Global Financial Crisis. Figure 1 shows that the largest contributors to emissions are electricity generation and transportation which represent on average around 31 and 26 percent of total emissions, respectively.

Figure 1. Gross Emissions in the U.S. by Sector
(MMT CO2 equivalent)



Source: Environmental Protection Agency (EPA) and authors' calculations.

U.S. climate policies of the last decades have been insufficient[2]. Despite having taken part in the initial negotiations of the Kyoto Protocol, the U.S. never ratified the agreement eventually reached in 1997. As part of the subsequent Copenhagen accord, the U.S. pledged to lower 2020 emissions by 17 percent compared to 2005 levels. However, these commitments were generally not backed with sufficiently ambitious policies. In the run up to the 2015 Paris Agreement, the administration at the time announced the Clean Power Plan (CPP), whose aim was to reduce 2030 carbon emissions from the power sector by 32 percent below their 2005 levels, and the Nationally Determined Contribution (NDC) for 2025, that aimed to reduce emissions by 26 to 28 percent below 2005. Even so, both announcements were seen as insufficient to help achieve the Paris Agreement goal of limiting global warming to well below 2 degrees. And in June 2017, the administration announced that the U.S. would not abide by the Paris Agreement. From January 2017 to January 2021, the

[2] See the UN's Second Biennial Report of the United States of America, the IMF's United States Article IV Staff Report 2020 and the Climate Action Tracker, for examples of assessments.

Brookings' Deregulation tracker counts 74 actions that weakened environmental protection.[3] Most prominently, the CPP was revoked and regulations regarding vehicle emissions, hydrofluorocarbon, and methane were eased. Taken together, these policy rollbacks might have added up to 1.8 gigatons of Co2-equivalent by 2035 (Pitt et al., 2020).

The new administration has pledged to make the fight against climate change a priority.[4] On his first day in office, President Biden pledged to re-join the Paris agreement, which entailed setting a new NDC ahead of the UN's 26th Climate Change Conference (COP26) in Glasgow in the Fall of 2021. In April 2021, the administration announced a new NDC that aims to reduce U.S. net greenhouse gas emissions by 50-52 percent below 2005 levels in 2030. In addition, other goals have been announced, such as a net-zero economy by 2050 as well as 100 percent clean electricity generation by 2035. This would need to be achieved through a wide range of policies to reduce emissions from the electricity, transportation, construction, and industrial sector.[5] While the goal is ambitious and broadly in line with the Paris Agreement's goal, determined action will be required to meet these targets. Figure 1 illustrates the significant decrease in emissions that would be required in the next years to achieve the NDC by 2030.

In the U.S., climate policies will focus on investment and subsidies. While other large economies, such as the European Union and China, have introduced or are on their way to introducing explicit carbon pricing to incentivize climate-friendly shifts in private behavior, the U.S. does not have plans to follow suit. Instead, the U.S. aims to couple climate friendly investment and subsidies with stricter regulations.

The lion's share of investment will be concentrated on mitigation measures to reduce CO2 emissions. The recently signed into law Infrastructure Investment and Jobs Act includes around $190bn investments in the power infrastructure, public transport and rail services, as well as electric vehicles. Another focus will be on clean energy for which the Build Back Better Act, which is yet to be signed into law, has $460bn planned. Other significant mitigation measures in these two pieces of legislation focus on energy efficiency, cleaning water supply and other Green House Gas reduction measures. Table 1 provides an overview over the measures passed in the infrastructure and the reconciliation bills.

Adaptation measures planned by the administration, at this stage, seem to be more limited. While mitigation policies intend to reduce emissions in order to mitigate climate change, adaptation measures represent an adjustment to current and potential future effects of climate change. Warmer temperatures increase the frequency, intensity, and duration of heat waves[6],

[3] Brookings Deregulation Tracker and corresponding Analysis for 2017-2021

[4] White House: Priorities

[5] Public Statement on the Unites States of America Nationally Determined Contribution

[6] Climate science special report: Fourth national climate assessment

which can lead to droughts and enable wildfires to spread more easily. Recent evidence also shows that the unnatural effects of human-caused global warming are already making hurricanes stronger and more destructive.[7] For these reasons, the current administration is planning to spend around $70bn on environmental adaptation measures, with a strong focus on supporting resilience against droughts, heat, floods, and wildfires.

Table 1. Spending on major climate measures

Legislation	Target	US bn	Mitgation or Adaptation
Infrastructure Package	Public Transport	105	M
	of which Rail	66	
	Electric Vehicles	7.5	
	Electric Grid	65	
	Clean up Superfund and brownfield sites, reclaim abandoned mine land and cap orphaned oil and gas wells	21	
	Replace Lead Pipes	15	
	Resilience againds droughts, heat, floods, and wildfires	50	A
	TOTAL	**263.5**	
Build Back Better	Clean Energy	460.5	M
	of which tax credits	320	
	Electric Vehicles	21.5	
	Green House Gas Reduction Fund	29	
	Home Energy Efficiency	19	
	Workforce development for climate resilience	20	A
	TOTAL	550	

Source: White House and authors' calculations.

Beyond expenditure measures, new regulations are also expected to be a significant part of the U.S. strategy. Most recently, the administration announced that 50 percent of all new passenger cars and light trucks sold in 2030 should be "zero-emission" through the establishment of new Federal fuel economy standards for passenger cars, as well as light- and heavy-duty vehicles.[8] The administration passed a number of executive orders on "Tackling the Climate Crisis" that included, amongst others: efforts to halt new oil and natural gas leases on public lands and waters[9]; the establishment of a Climate Change Support Office within the Department of State[10]; the revocation of the permit for a key crude pipeline[11]; and the development of a government-wide strategy to assess and mitigate climate-related

[7] Yale Climate Connections

[8] Executive Order 17121 of August 5, 2021

[9] Executive Order 02177 of January 27, 2021

[10] Executive Order 10139 on May 7, 2021

[11] Executive Order 13990 of January 3, 2021

financial risks[12]. Nationwide, the main initial focus of climate regulation was on a Federal clean energy standard (CES), which would require that a certain percentage of retail electricity sales comes from non- or low-emitting sources. However, at this stage it seems clear that a CES does gather the consensus needed for its passage. At the state-level, similar efforts are already ongoing. By August 2021, 31 states and two territories have active renewable or clean energy requirements. In addition, three states and one territory have set voluntary renewable energy goals.[13]

Overall, the U.S.' new ambitions can contribute to slow global warming, but persistent efforts and follow-through in the years to come are needed. Although some experts are worried that the measures might not be sufficient[14], it is reasonable that the success of U.S. climate policies in the near future will depend on several factors. First, the Build Back Better Act, which contains the largest climate policy measures, is yet to be put into law and details in the final bill may still change. Second, the public budget will not be able to bear all the needed climate investments alone, and progress will depend critically on the participation of the private sector. Finally, most of these policy targets will take more than the current political term to realize and recent experience and the polarized debate within the U.S. suggests that policy continuity in this area is an important risk to outcomes.

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[12] Executive order 11168 of May 20, 2021

[13] For an overview, see here.

[14] The Climate Action Tracker rates the policies as "insufficient" to reach the US NDC and contribute a "fair share" to the goal of the Paris Agreement. Resources for the Future analyze different policy proposals, such as the Clean Energy Standard, and show that none of the modeled scenarios achieve the 2050 net-zero target.

III. Subsidies Are Not Perfect Substitutes for Robust Carbon Pricing

This section uses a global model to study the macro-climate trade-offs of subsidizing clean energy and assess whether that subsidization can substitute for explicit carbon pricing. This exercise allows both an assessment of whether the administration's climate pledges can be reached and a measurement of the impact on U.S. economic growth and its fiscal position of pursuing various climate policies.

The model is an application of Barrett (2021) which is summarized here only at a relatively high level. Readers interested in further details of the model are referred to that paper, as well as Hassler and others (2020) on which it builds.

The main global inefficiency is a global climate externality: carbon emissions cause higher temperatures which reduce productivity. Addressing this inefficiency is the motive for policy action. Because emissions feed back into productivity via temperature, this framework is an integrated assessment model.

Energy, along with capital and labor, is an input into the production of aggregate output (GDP). Output is then used for households' consumption and savings. A byproduct of energy generation is emissions. Energy is produced using input fuels. Each fuel has a fixed carbon intensity, and so using more of fuels with higher carbon intensities will produce more emissions. There are eight fuels types in the model: coal, conventional and unconventional (fracked) oil, natural gas, renewables, hydro power, and nuclear. The first four are fossil fuels and have positive carbon intensity.

Energy producing firms can conduct research to improve the efficiency of using different fuel inputs (or, equivalently, lower the cost of extracting energy from them). The extent of research depends on its returns, which in turn are a function of market size. The larger the market for a given fuel, the larger the number of units over which the fixed costs of research can be defrayed, and hence the larger the incentives for research. This means that the direction (i.e. the "greenness") of technical change is endogenous, responding to policy changes which affect market size. As a result, policies have important dynamic effects – by shifting research incentives, climate mitigation policies affect the set of future technologies.

A. The economic determinants of emissions

The economic determinants of emissions can be thought of as operating through two channels. The first and most obvious channel is the quantity channel. Given a fixed ratio of fuel inputs, increasing (or decreasing) total energy use will cause higher (or lower) emissions. Thus, policymakers with concern for the environment will want to reduce the amount of energy used. But because energy is an input in GDP, policymakers with a concern for households' living standards will want to increase the amount of energy used. Of course, these two objectives are in conflict. The quantity of energy used thus induces a trade-off between output and emissions.[15]

The quantity of energy used depends on the *average* cost of fuel inputs. If fuels are more expensive overall, then so too is the energy they produce. The sensitivity of energy to prices depends in turn on a deep economic parameter – the elasticity of demand for energy. If energy demand is more elastic, a given change in the energy price has a bigger impact on the total amount used. Typically, we think of energy as being relatively inelastic, simply because it is hard to substitute out of aggregate energy usage.[16]

The second economic channel which determines emissions is the composition channel. For a given quantity of energy, changes in the composition of fuel inputs used can have a large effect on emissions – imagine replacing coal usage with solar power. Changes in the composition of energy usage depend on changes in the *relative* prices of fuel inputs. If the cost of one fuel increases relative to another, energy firms shift the composition of their fuel inputs out of the relatively more expensive fuel and towards the relatively cheaper one. The extent of this switch is a function of the elasticity of substitution between fuels, which is usually estimated to be relatively elastic.[17] Note that pure composition effects have no impact on the quantity of energy used, and thus on output, and so induce no trade-off between emissions and output.[18]

B. Building intuition for the effects of different policies

These two channels determine the differing impacts of policies. To illustrate this, we consider two simple examples, computing the approximate responses

Carbon tax. First, a carbon tax. For simplicity, we imagine that this applies to coal only. In reality, other fossil fuels will also be subject to a carbon tax, but coal is one of the largest contributors to emissions not just in the U.S. but worldwide. Per ton of oil equivalent,[19] coal produces four tons of CO2 and costs in the order of $80 (prices of course, fluctuate considerably at high frequency, but this is close to the average cost of coal in the last decade). As a result, a low carbon tax of $10 per ton CO2 implies cost increases in the order of 50 percent (i.e. rising from $80 to 80+10*4=$120 per ton oil equivalent).

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[15] It is technically more accurate to describe the trade-off as between output today and output tomorrow because emissions lower future productivity. Emissions are not (economically) costly in their own right but only through their impact on productivity in future. Nevertheless, describing this as a trade-off between output and emissions is a more vivid description, and so used as shorthand for this trade-off between present and future output.
[16] It is hard to see how one could transport goods, or make steel, or even provide a haircut without using energy.
[17] This is, at least in part, because energy from different sources are often highly substitutable. For example, electricity from fossil fuels and from solar power are perfect substitutes.
[18] This model does not include considerations on time-to-build capital or issues related to stranded capital stock which would further increase the cost of shifting quickly from one energy source to another.
[19] Ton oil equivalent is the quantity of fuel with the energy content equivalent to one ton of oil. As it is a measure of energy, it means that prices expressed in these units are true (marginal) input costs.

Given that the tax applies only to coal, this means that the relative price of coal increases by around 50 percent. With an elasticity of substitution of 2 (a standard value in the literature) this implies that coal use relative to other fuels will fall by approximately 55 percent via the composition channel alone.[20] And because the emissions share of coal in the U.S. is around 10 percent, this implies that total emissions will fall by around 5.5 percent due to the quantity effect alone. To compute the impact through the quantity channel, we need to calculate the impact on the average price of energy. The expenditure share of coal in energy is around 3 percent, meaning that a 50 percent increase in the cost of coal will raise the overall cost of energy by around 1.5 percent. With an elasticity of demand of 0.25 (again a standard value in the literature) total emissions will fall via the quantity channel by around 0.4 percent (i.e. one quarter of the price increase), resulting in a total decline in emissions in the order of 5.0 percent.

Overall, this simple example illustrates why carbon taxes are so effective. Carbon taxes punish cheap, dirty fuels. Of a total reduction in emissions of nearly 6 percent, almost all comes from a composition effect. This is because the relative price increase is largest for cheap, dirty fuels like coal and the elasticity of substitution is large. Because the carbon tax relies mostly on the elasticity of substitution, the welfare effects are typically quite small – households energy usage falls only in line with the quantity channel. However, at higher tax levels the carbon tax is not as effective – ever larger increases in the carbon tax cause ever smaller relative increases in input costs.

Green Production subsidy. An alternative to a carbon tax is a green production subsidy, and one that can also be calculated (at least approximately) by hand. This is relevant to the U.S. proposals, as they rely heavily on subsidies.

A subsidy of 30 percent on green fuels is fiscally approximately equivalent to a $10 carbon tax in the sense that the expenditure on such a subsidy would roughly be of equal US$ magnitude as the revenue from the tax. That is, together they are fiscally neutral. With the US annual CO2 production of 5 gT, a $10 carbon tax produces revenues of $45bn (as emissions fall ~10 percent in response). Under the assumed elasticities, a 30 percent subsidy causes a near-doubling the renewables market from around $80bn to $150bn. The cost to the public purse is thus 30 percent of $150bn, or around $45bn.

Note that because subsidies make energy cheaper overall, they incentivize *more* energy usage overall, so the composition and quantity effects go in opposite directions. In this example, the composition effect would cause the input share of renewables to grow 3 percentage points, from 5 percent to about 8 percent.[21] Because the expenditure share of renewables is approximately 10 percent, then the price of energy overall would fall by around 3 percent.

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[20] As the ratio of relative prices after the shock increase by a factor of 1.5, then the post-tax composition effect is approximately $1.5^{(-2)}=0.45$. This is approximate as it reflects only the marginal effect of the tax on the composition margin and ignores second round and other effects.

[21] Because relative costs fall 30 percent, relative usage increases by $1.3^2-1=69$ percent. Again, effects here are approximate, based on first-order approximations which.

With and elasticity of demand of 0.25, this would cause demand for all fuels to grow by 0.75 percent. So the overall impact of the policy would be emissions to decline by 2.25 percent, split into a 3 percent reduction via the substitution channel and a 0.75 percent increase via the quantity channel.

Together, these examples illustrate the key differences between taxes and subsidies in reducing emissions. For a given fiscal impact, carbon taxes are more effective because they 1) discriminate more sharply against the most socially undesirable fuels (i.e. cheap, dirty ones), and 2) the composition and quantity effects pull in the same direction – both have the result of reducing emissions. R&D subsidies are much like production subsidies in the short term, but have a larger long term impact. That is because production subsidies do not alter the cost of production, just redistribute it (to the government). In fact, they have a (second-order) research-deterring effect: firms don't bother to innovate if it is an input is already. In contrast, R&D subsidies encourage research that causes permanent changes in the set of technologies available, making them greener throughout all subsequent periods. However, this effect is quite slow, meaning that carbon taxes end up being an essential tool for reducing emissions in the short run – they can bridge the gap until the induced technical change effects takes over.

C. Policy experiments: subsidies only vs. subsidies plus carbon tax

Armed with this intuition, the model can be used to assess different ways to meet the U.S. administration's climate targets. Specifically, we aim to assess whether these climate goals can indeed be met by a policy package which relies on subsidizing green energy rather than taxing carbon, and how much higher a fiscal price tag this would have when compared to a policy package which also uses taxes.

In the baseline scenario, there are no climate mitigation policies. As a result, emissions continue to rise, starting at around 5 gigatons CO2 per year and doubling by mid-century.[22] Although ongoing research in renewable fuels pulls down their cost and thus increases their share in the energy mix, this is not enough to offset the increase in overall energy usage as the economy and population grow over time.

The administration's climate goals are translated into a path for emissions which is below the 2005 level by 50 percent in 2030 and by 90 percent in 2050.[23] To illustrate the impact of different policies, we consider policy packages which deliver this outcome (see Table 2 for a summary of the three packages considered).

[22] This baseline is in line with other laissez-faire scenarios in the literature, such as Golosov and others, 2014, and Hassler and others, 2020.

[23] This later target is meant to capture the ambition to be carbon-neutral by 2050. Implementing this literally causes problems in the model. If the elasticities of demand for dirty fuels are finite then the only way to produce zero emissions is with infinite taxes or subsidies.

- Package #1 (P1): This package includes subsidies for production of renewables alone, starting at around 40 percent and rising to over 90 percent by 2050. Such high subsidies are necessary because these policies are relatively ineffective – as discussed above, they lower the overall cost of energy, thereby increasing its usage and undermining the shift in the composition of inputs. P1 results in a considerable fiscal burden. If fully funded by government borrowing, the debt-to-GDP ratio would rise by around 30 percent points by 2050. As a result, private consumption will fall as (Ricardian) households save in anticipation of higher future taxes to pay off the public debt (see Figure 2).

- Package #2 (P2): This extends P1 by adding subsidies for research and development (R&D) in renewable energy at the same rate as the subsidy for production. R&D is often seen as a panacea for climate action and the administration is keen to expand efforts in the area. In this framework the effect of R&D is minimal, allowing the emissions targets to be met at an only fractionally reduced fiscal cost – government debt in 2050 is less than 1 percentage point lower than the pure subsidy case (see Figure 2). The reason that research subsidies are so ineffective is that their immediate impact acts through the same margin as production subsidies – making renewables cheaper. Given that the marginal efficacy of the production subsidy is low already, replacing it with a research subsidy does nothing to improve its effectiveness. One important difference between research and production subsidies, though, is that research subsidies have a larger effect on the long-run direction of technical change, allowing the carbon tax to be reduced sooner (although still after 2050). However, because the starting share of renewables in energy is small, this effect is slow and has a minimal effect before 2050. The R&D may also create international spillovers (as the new technology is adopted elsewhere) but these are not the focus here. The reader interested in learning more on the latter should see Barrett (2021).

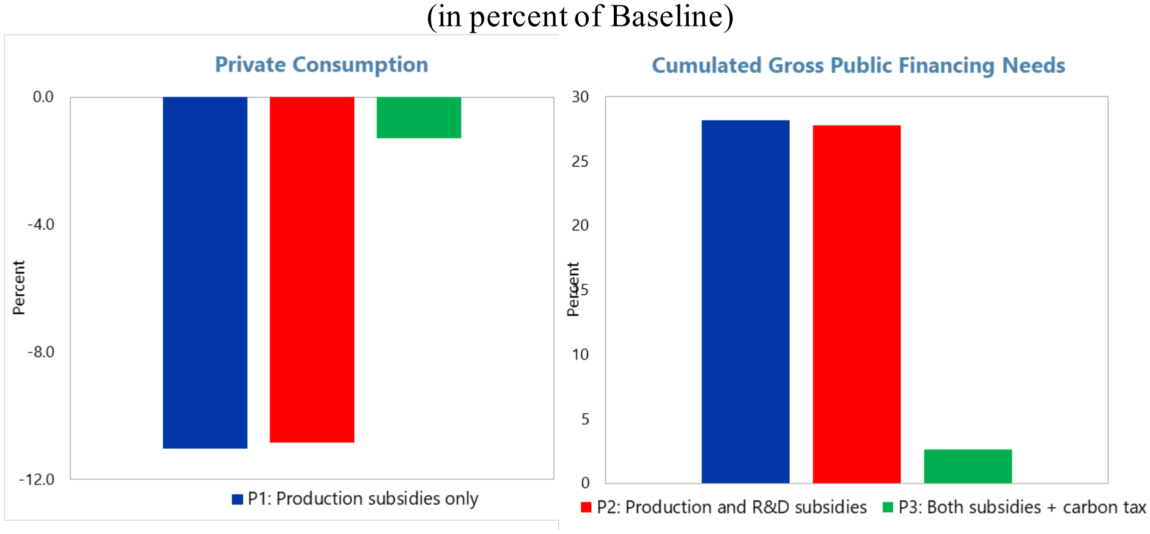
- Package #3 (P3): The third policy package uses a combination of all three instruments: a carbon tax, renewable research subsidies, and renewable production subsidies. The revenues from the carbon tax are used to partially offset the expenditures with subsides. As discussed in the earlier illustration, the carbon tax is very effective at reducing emissions, and the marginal effect is particularly large when the tax is low. As a result, very low carbon taxes can be combined with generous subsidies in the short term to reduce emissions. Here, the pattern of subsidies is also different, with research subsidies optimally being front-loaded. This maximizes the effectiveness of subsidies, by giving research subsidies – which act at relatively long horizons – a long time to have an effect. The resulting fiscal cost is much lower, adding only around 2 percentage points to the debt-to-GDP ratio in 2050. Likewise, household consumption falls only by around 1 percent in 2050, simply because households are no longer expecting to have to pay off a much larger government debt (see Figure 2).

Table 2. Description of scenarios

Policy Scenarios	
P1: production subsidies only	Production subsidies: 40 percent in 2020, rising to 70 in 2030, 80 percent in 2040 and 90 percent by 2050
P2: production and R&D subsidies	Production subsidies: 40 percent in 2020, rising to 70 in 2030, 80 percent in 2040 and 90 percent by 2050 R&D subsidies: 40 percent in 2020, rising to 70 in 2030, 80 percent in 2040 and 90 percent by 2050
P3: production, R&D subsidies and carbon tax	Production subsidies: 5 percent in 2020, rising to 20 in 2030, 30 percent in 2040, and 40 percent by 2050 R&D subsidies: 90 percent in 2020, and remaining roughly unchanged to 2050 Carbon tax: $17 per ton in 2020, rising to $40 in 2030, $100 in 2040, and $230 in 2050.

Source: Authors' calculations.

Figure 2. Macroeconomic Effects of Different Climate Policy Packages
(in percent of Baseline)

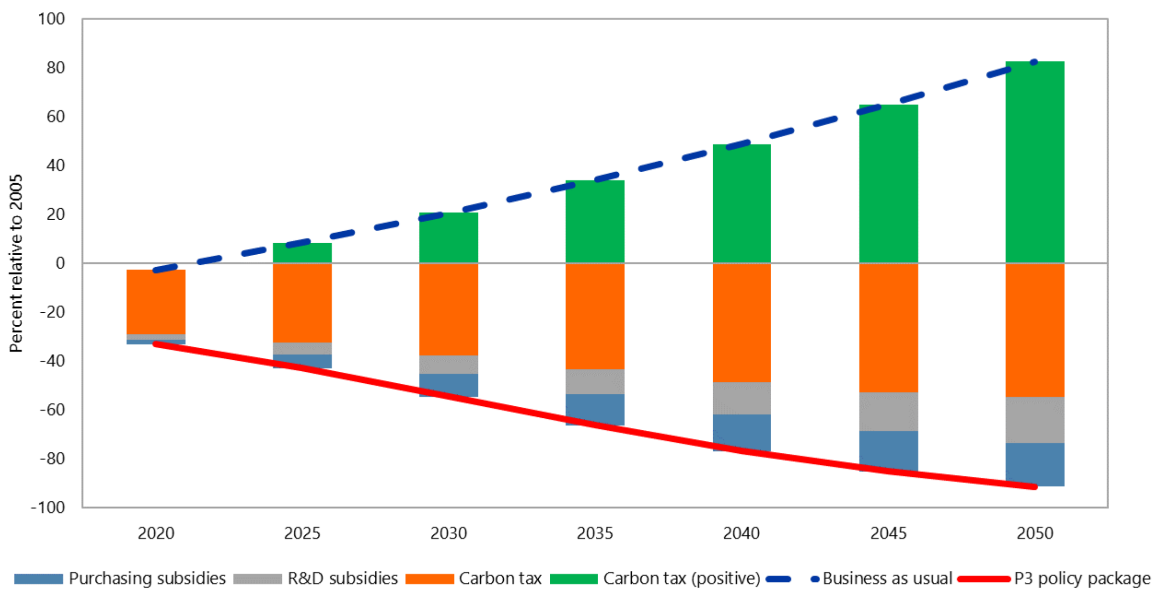


Source: Model simulations.

D. Environmental and economic impacts of climate policies

By construction, all three packages imply the same emissions reduction. Decomposing the reduction in emissions of Policy Package #3 shows that each lever serves a particular role (see Figure 3). The carbon tax acts to drive down emissions fast, exploiting the reinforcing effects of the composition and quantity channels. R&D subsidies lower the long-run cost of reducing emissions by shifting the technological base in favor of clean fuels, improving trade-offs in the long-run and allowing carbon taxes to be scaled back faster than under production subsidies alone. Finally, the production subsidy acts to cushion the impact of the higher carbon tax on the energy prices faced by households.

Figure 3. Decomposing the Reduction in Emissions of Policy Package #3
(in percent relative to 2005)



Source: Model simulations.

The price of energy is endogenous in this model. Under the baseline, energy prices end up falling at around 1 percent per year, given the efficiency gains in the broader economy. Renewable energy prices fall at a slightly higher rate, around 1.5 percent per year, as their high initial price of drives research to lower costs. However, these relative price declines are not sufficient to spur a significant green shift in the composition of energy. When both production and R&D subsidies are used to reduce emissions (Policy Package #2), the price of energy falls much faster – over 2.5 percent per year on average – as higher energy usage increases overall energy-research, driving down input costs and thus prices. In both examples with subsidies, the cost of renewables falls more slowly than the average – at around 1.3 percent in the case with production subsidies alone.[24] This happens because production subsidies lower firms' input costs in green fuels, disincentivizing cost-saving technical progress. In contrast, the introduction of carbon taxes spurs a shift in the composition of energy away from fossil fuels and towards renewables, increasing their market share and stimulating research. As a result, the price of clean energy falls much more

[24] With both R&D and production subsidies the price of renewable falls relatively faster, at 1.5 percent per year, but still more slowly than the average price of energy.

quickly, at nearer 2.5 percent per year, despite an overall increase in the energy price of 0.5 percent per year in the short run due to the carbon tax.[25]

In conclusion, policy packages which rely on subsidies are likely a fiscally costly way to deliver reductions in emissions, driving debt up and reducing household consumption as revenue sources need to be found to cover the costs of that debt. However, when supplemented with a moderate carbon tax, the same outcomes can be delivered at a much lower economic and fiscal cost.

[25] Induced green innovation and a shift into cheaper green fuels mean that this trend quickly turns around. Within 10 years, the average price of energy is falling once more

IV. GREENING THE POWER SECTOR: THE EARLIER, THE BETTER

Given the importance of the power sector to achieving the administration's climate goals, this section discusses considerations and possible pathways to decarbonize the sector. In particular, the section looks at the timing of decarbonization and its interaction with the need to electrify the transportation sector in the coming years. As shown in Figure 1, the electricity generation and transportation sectors account for half of current GHG emissions in the United States. Even with accelerated transport and housing electrification, overall emissions may remain elevated until fossil-fuels are retired from being the main source of primary energy for electricity generation.

The analysis of this section is based on simulations with the ENV-IMF model: a global, dynamic, and sectoral Computable General Equilibrium (CGE) model newly developed by the IMF research department.[26] Dynamic CGE models are well suited for the analysis of structural change and sectoral impacts that result from decarbonization policies. The model allows simulating impacts of climate mitigation policies on emissions, macroeconomic variables, sectoral outcomes and trade. The model is based on neo-classical framework, dealing only with real values and with almost perfect markets for commodities and production factors (labor, capital, land). As a result, the model is not well suited to give insights about transitional issues. For a more detailed description of the model, see Appendix II. Moreover, the model's projections for the very long-run are especially uncertain since disruptive technology innovations could materialize at longer horizons.

A. Policy experiments: decarbonization of the U.S. power sector

We first consider a "no policy scenario" or *business as usual* (see Table 3 for a summary of all scenarios). The BAU scenario projects out the latest trends in terms of both macro-economic development and electric and transport systems and assumes no new climate and energy policies after 2021. Fossil fuels are currently the main primary sources of energy for the U.S. power sector and are likely to remain so absent significant policy changes (Figure 4). In 2020, the share of fossil fuels was 64 percent, with 44 percent taken by natural gas and 19 percent by coal. Because the BAU scenario assumes no major policy shifts, gas stays the predominant source of primary energy for the power sector (accounting for 43 percent in 2050). The market forces that have shaped the loss of competitiveness of coal-powered generation relative to gas and renewables are assumed to continue in the BAU scenario, and coal sees its share decrease to 11 percent, while, at the same time, wind and solar become more competitive and their shares increase from 7 to 15 percent and 3 to 11 percent, respectively.

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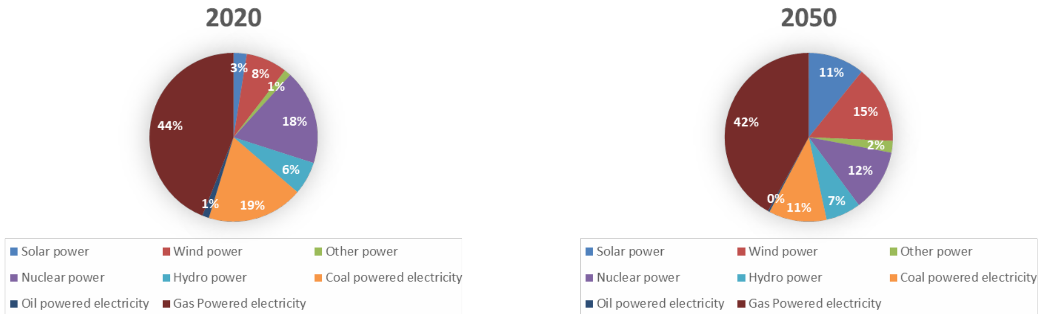
[26] The IMF-ENV model is operational for only a few months now, and some aspects are still under development including drafting its full documentation. Meanwhile, readers interested in the model can consult the documentations of the twin-models on which the current model is built on: the "ENVISAGE" model (see Van der Mensbrugghe, 2019) and the "OECD ENV-Linkages Model" (Chateau et al., 2014).

Figure 4. U.S. Electricity Mix: current and under the business as usual scenario
(Share of total electricity by primary source of energy)



Source: IEA historical data, IMF-ENV model for the business as usual scenario.

Overlaid on top of the business as usual is an aggressive *EV penetration* scenario, which will serve as the baseline scenario for the whole section. Thus, we analyze power sector policies given an ambitious penetration of EVs that is needed to reach the administration's goal of net zero carbon in 2050. The EV penetration scenario assumes EVs reach 100 percent of the stock of cars by 2050.[27] Figure 5 shows historical data and the assumed path of the share of EV in the United States over time ("EV share" in the figure). The version of the model used here does not make an explicit distinction between electric and conventional combustion engine vehicles, instead the assumption of penetration of EV is converted into changes in the mix of energy demanded by transportation (i.e. trend "Ely share" in the figure). This projected share of electricity demand is not 100% in 2050 for two reasons: the first is that some land transportation modes are not entirely 100% electric (train, buses, heavy vehicles, among others) and secondly some energy demanded by the transportation sector are not dedicated to fuel use for displacement (feed stocks, among others). This paper abstracts from the exact policies that would lead to such an aggressive EV penetration, and simply assumes a change in preferences and intermediate demands towards EV. The interested reader on such policies could see Cole and others, 2021.

Finally, we consider two policy scenarios in which the government promotes the phasing out of fossil-fuel powered electricity to accompany the aggressive *EV penetration* scenario:

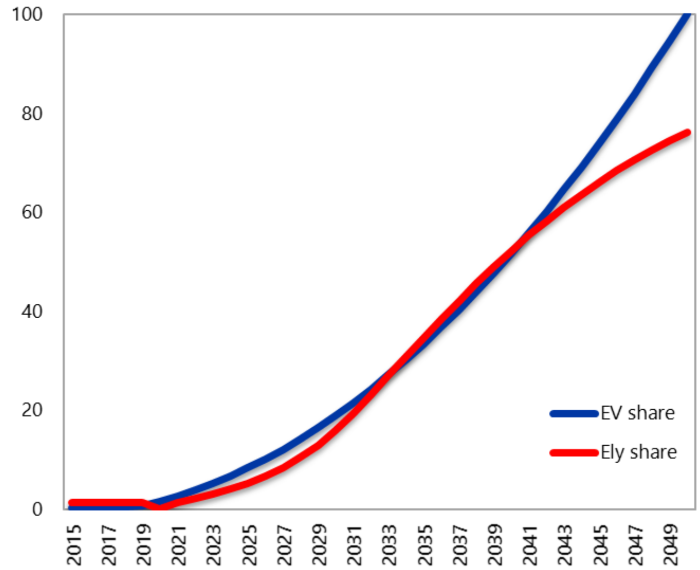
- Both scenarios achieve a common goal of reaching a share of non-fossil fuel powered electricity of 90 percent in total electricity generation.

- The policy instruments used to achieve the above goal are (i) gradually rising production subsidies in the form of feed-in-tariffs for wind and solar electricity generation reaching up to 30 percent of the selling price; (ii) a regulatory constraint that gradually limits the share of fossil-fuel powered generation (see Box 1). The latter is similar in spirit to existing

[27] For this scenario, we use the current stock of EVs from the IEA and we create a forecast of overall vehicle growth using past data from the Bureau of Transportation Statistics. A quadratic function is then used to project EV growth conditional on achieving the 100 percent goal.

state-level regulations that mandate a minimum renewable portfolio (RPS) or to a nationwide Clean Energy Standard (CES).

Figure 5. Projected share of electric vehicles and of electricity in land transportation
(in percent)



Notes: "EV share" is the share of electric vehicles in total road vehicles; "Ely Share" is the share of electricity demand in total energy demand in Mtoe for transportation.
Source: IEA historic and projection for "EV share", IMF-ENV model for "Ely share" business as usual projection.

- An *early decarbonization* scenario achieves the goal above by 2035. Under this scenario, subsidies are gradually phased out during 2035-45 but the regulation constraint remains in place, so the generation mix stays almost unchanged thereafter.

- A second policy scenario -- *delayed decarbonization* – is one in which the target of 90 percent non-fossil fuel powered generation is reached by 2045 instead of by 2035. In this scenario, subsidies are raised more gradually up to 2045 and phased out thereafter.

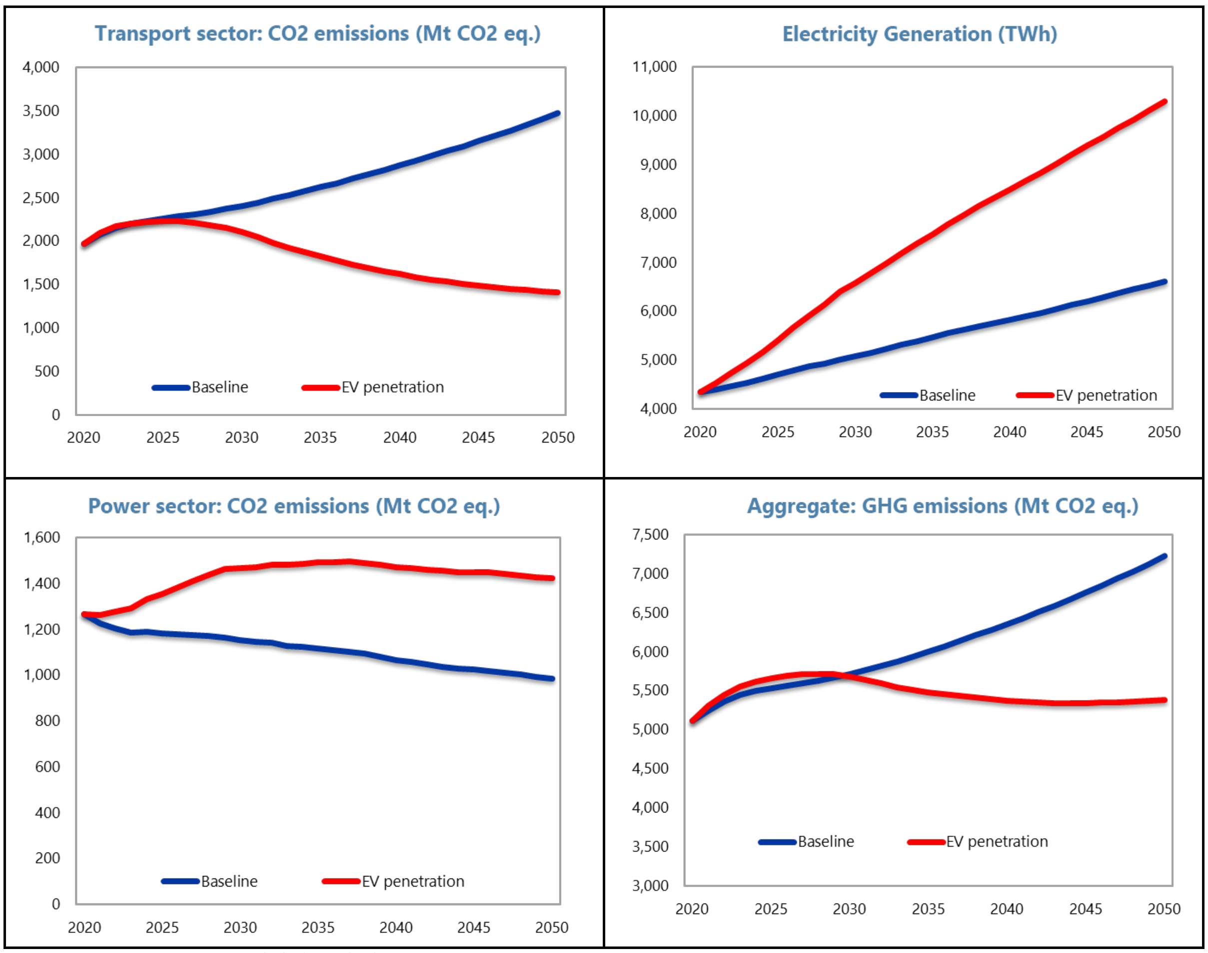
In all these policy scenarios, the government is balancing the budget in each period to maintain the same expenditures as in the *EV penetration* scenario by adjusting wage income tax rates. This means if extra revenues are needed to finance subsidies, or simply if the tax base falls because of depressed activity, then the wage income tax rate will be automatically higher. See Box 2 for the implications of an alternative rule to finance the budget.

Table 3. Description of scenarios

Scenarios prior to power sector policies	
Business as usual (BAU)	
EV penetration	Electricity Expansion from Electric vehicle, serves as a baseline for policy scenarios
Policy Scenarios	
Early decarbonization	o "EV penetration" plus: o Subsidies in the form of feed-in tariffs for solar and wind rise to 30 percent by 2035, then are progressively phased out. o Regulation constraint that non-fossil fuel power equal to at least 90 percent of total power in 2035
Delayed decarbonization	o "EV penetration" plus: o Subsidies in the form of feed-in tariffs for solar and wind rise to 30 percent by 2045, then are progressively phased out. o Regulation constraint that non-fossil fuel power equal to at least 90 percent of total power in 2045
Sensitivity Analysis (Box 2 and Box 3)	
Subsidies only	o "EV penetration" plus**:** o Subsidies in the form of feed-in tariffs for solar and wind rise to 2035, then are progressively phased out.
Regulation only	o "EV penetration" plus: o Regulation imposes a share of non-fossil fuel power equal to the difference between the shares in early decarbonization and in Subsidies only.
Carbon Price	o "EV penetration" plus: o Subsidies in the form of feed-in tariffs for solar and wind rise to 2035, then are progressively phased out. o Carbon tax for power sector endogenously determined to reproduce the same CO2 path as "Early decarbonization" scenario. The revenues from the carbon tax are used to partially offset the expenditures with subsides.

It is clear that greening the power sector is needed for an aggressive penetration of EVs to translate into a substantial reduction of emissions. As EV penetration progresses, the transport sector decarbonizes since internal combustion engine vehicles are replaced by electric cars (Figure 6, top left) but that in turn boosts electricity demand (Figure 6, top right) and results in higher emissions from the power sector relative to baseline (Figure 6, bottom left). In the short-term, this higher demand extends the useful life of older fossil-fuel powered generators that are highly polluting, and thus total emissions actually rise.[28] Greater EV penetration on its own is therefore not sufficient, at least in the next few years, to substantially mitigate GHG emissions in the US (Figure 6, bottom right). The success of EV penetration to curb GHG trajectory in US can only happen if combined with a decarbonization of the power sector.

Figure 6. An aggressive rollout of EVs will not by itself curb GHG emissions



Source: IMF-ENV model simulations.

[28] This net effect includes indirect benefits of greater EV penetration. For example, higher EV penetration reduces the domestic demand for oil refining relative to the needs of internal combustion engine vehicles. However, the reduction in the domestic *demand* of refined products depresses prices, which in turn leads to larger U.S. exports. Hence, domestic *production* of refined products is not as affected.

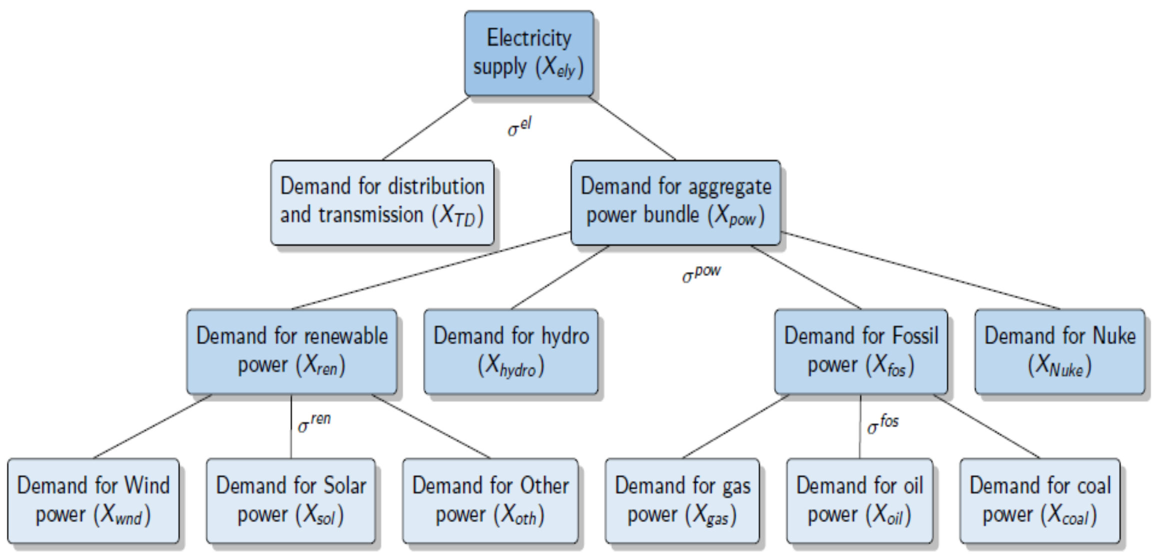
Box 1. Power Sector and regulation on electricity mix in the ENV-IMF modelling framework

The standard representation of electricity supply in the ENV-IMF model assumes that a representative electricity provider chooses an optimal mix of electricity generation:

$$Max\, X_{ely}\,.P_{ely} - X_{TD}\,.P_{TD} - \sum_{powa} X(powa).\,p(powa)$$
$$X_{ely} < F(X_{TD}\,;\; X(powa_1),\ldots,X(powa_n))$$

where X_{ely} is electricity production, which is a combination of $X_{TD,}$ the demand for electricity transmission and distribution services, and the demands, X(powa), for power generation from various primary energy sources: “powa”, including solar, hydro, nuclear, wind, solar, other renewables, oil power, gas power, coal power.

The production function F(.) is a nested CES function of electricity generated by the various primary energy sources



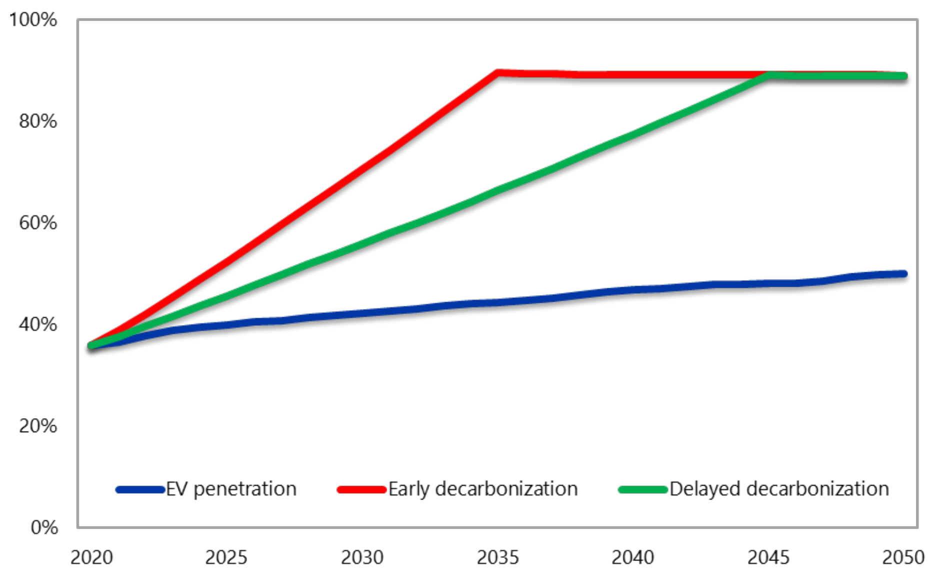
Regulation is modelled as an additional constraint to the problem above that imposes a minimum share of non-fossil power generation (Φ) which is gradually increasing to 90 percent in 2035.

$$Max\, X_{ely}\,.P_{ely} - X_{TD}\,.P_{TD} - \sum_{powa} X(powa)\,.p(powa)$$
$$X_{ely} < F(X_{TD},X(powa_1),\ldots,X(powa_n))$$
$$\Phi.X_{ely} < [X(solar) + X(wind) + X(hydro) + X(nuclear) + X(other)]$$

B. Environmental and economic impacts of power sector climate policies

When the government takes measures to decarbonize the power sector early (by 2035), the share of non-fossil fuel powered electricity rapidly rises to reach the regulated 90 percent of total generation (Figure 7). In the delayed decarbonization scenario, the same target is reached by 2045 only, by construction. The regulation constraint does not discriminate across fossil-fuels and thus the reduction is even across gas and coal (Figure A1 in annex). On the contrary, subsidies directly boost solar and wind power through price incentives, and therefore power generated by both increases by more than other non-fossil powered generation technologies.

Figure 7. Non-fossil-fueled generation across different policy scenarios
(Share of non-fossil-fueled generation, in percent of total)



Source: IMF-ENV model simulations.

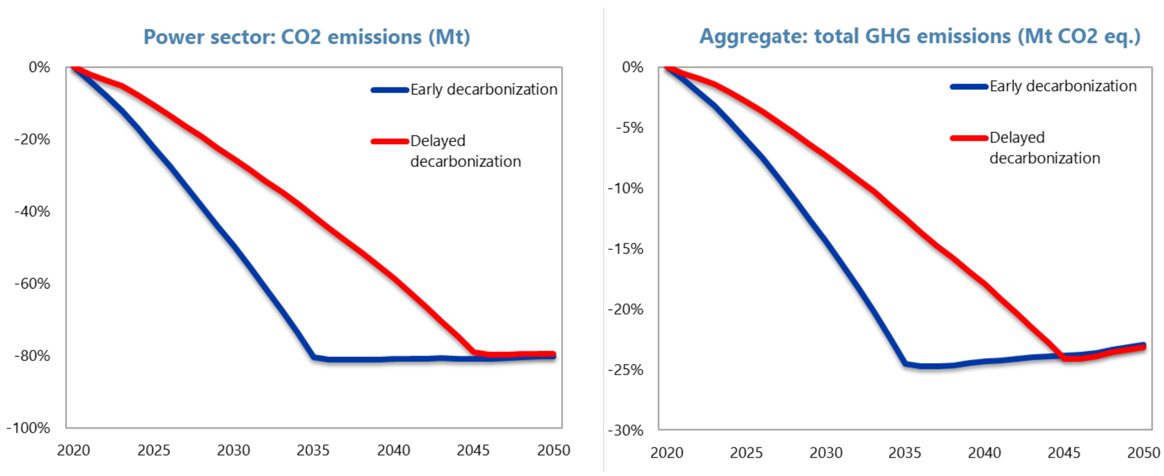
Under either policy scenario, both power sector and total emissions are substantially and permanently reduced compared to the EV scenario (Figure 8). If action is delayed, the level of emissions of the power sector is the same after 2045 only, and thus cumulative emissions over the full period 2021-2050 are higher.

The policy scenarios carry moderate but increasing GDP losses. Figure 9 shows GDP losses up to about 1 percent when the regulation constraint becomes fully operational (2035 under early decarbonization or 2045 in the delayed decarbonizing scenario). Thereafter, GDP losses are progressively smaller, reaching around 0.4 percent in 2050. Costs rise initially because the regulation becomes more and more stringent as time passes and especially because of the growing price distortion associated with rising subsidies, despite the progressive adaptation of the power sector to the new mix through capital reallocation. After reaching their peak, GDP costs decrease over time as subsidies are phased out.

The moderate policy costs at end of the horizon suggest that the regulation is not prohibitively binding, and that power operators have limited incentives to switch back to fossil power even with no regulation once the existing fossil-fuel powered capacity is retired. However, there are notable differences between imposing this regulatory constraint and a carbon tax, with the latter being easier to administer and marginally more efficient (see Box 3). Note that the current version of the model does not include any co-benefits of reducing emissions which would ideally also be factored in and further reduce the costs of the transition. Employment is also similarly moderately decreased.[29]

Figure 8. Emissions across policy scenarios

(deviation from EV penetration scenario, in percent)



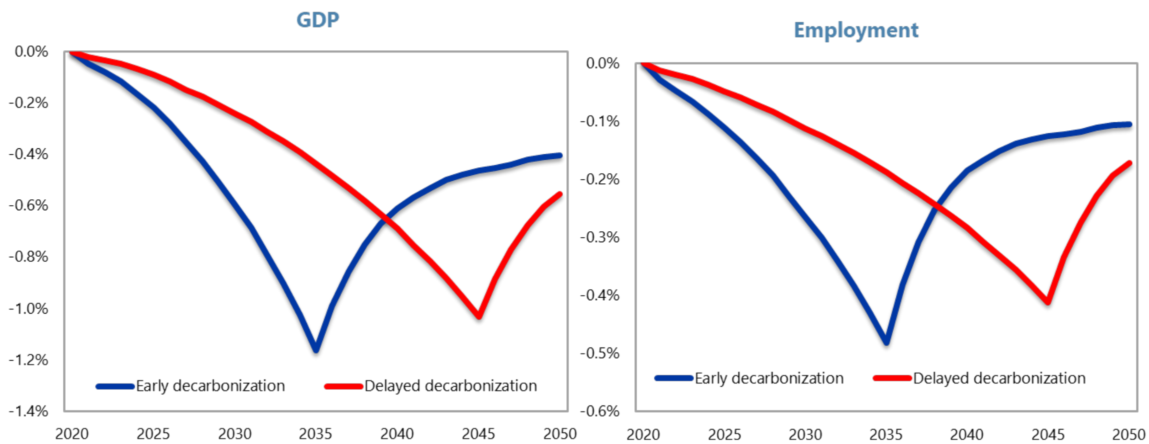
Source: IMF-ENV model simulations.

The net present value of the economic costs to economic activity from a faster transition is marginal. This implies that delaying the decarbonization of the power sector is not justified. In the long run, policies to decarbonize the power sector are very efficient. Power sector emissions are reduced by more than 80 percent (from more than 1200 tons of CO2 today to less than 280 tons in 2050[30]) at relatively moderate GDP costs. While delaying the decarbonization of the power sector, delays GDP costs but the present value of those GDP costs is not substantially lower in the delayed decarbonization scenario. On the other hand, cumulative emissions when decarbonization is delayed are much higher leading to greater global warming.

[29] This model includes adjustment costs to build new capacity and also captures additional losses due to stranded capital, both of which are important considerations when deciding the timing of decarbonizing the power sector.

[30] Emissions from the power sector are not reduced by 90 percent, but instead by 80 percent only, because the regulation does not target the carbon content and therefore does not discriminate between coal and gas power unlike the carbon tax (see later discussion).

Figure 9 GDP and employment across policy scenarios
(deviation from EV penetration scenario, in percent)



Source: IMF-ENV model simulations.

Prices for commodities and factors are endogenous in all scenarios. For liquid and gaseous fossil fuel, international prices drive domestic prices. The former are projected to steadily grow by 0.8% and 0.35% per year respectively from 2021 to 2050 under the BAU scenario, while international coal prices decline by 0.1% per year in the same period. Under the EV penetration and policy scenarios, these international prices are only marginally affected, because other countries are assumed to not take any new actions. But US producer and consumer prices vary across these scenarios. Under EV penetration, demand for refined oil decreases, resulting in lower US production prices of refined and crude oil by 4% and 8%, respectively, in 2050, relative to BAU scenario. Over the same period, higher EV penetration boosts electricity demand and therefore US electricity production price rises by 5%, which in turn boosts demand for energy used by the power sector, resulting in an increase of 7% in the price for coal, while gas prices are roughly unchanged since this price is mostly determined in international markets. Under the early decarbonization scenario, the demand for coal and gas by the power sector falls drastically, as does their production, which ends up 3% and 2.5% lower in 2050 relative to the EV scenario. Consumer prices for fossil fuels rise with production prices, but to a lesser degree due to offsets from taxation. Electricity consumption prices fall up to 7% in 2035 as subsidies are rolled out (relative to EV scenario). After the phasing out of subsidies in 2035, consumer and electricity prices increase by about 6% in 2050 (relative to EV scenario).

C. Sectoral impacts of power sector climate policies

Small aggregate impacts hide large sectoral changes across few economic activities, for both value added and employment, since early decarbonization aims at deeply shifting away from fossil fuel power (Figure 10). A strong reallocation is to be expected by design, as fossil fuel power is almost shut down in 2035, while renewable power is strongly boosted.

Moreover, fossil fuel extraction and production sectors also see contractions. Coal extraction, in particular, is heavily affected with a production cut of more than 50 percent relative to the EV penetration scenario. On the other hand, natural gas and oil extraction are only slightly impacted. This differential impact is driven by differences in the international competitiveness these sectors. Unlike coal, the fall in the domestic demand for gas (gas distribution and manufacture decline by more than 40 percent) is largely offset by a rise of exports and thus natural gas production only declines by 7 percent.

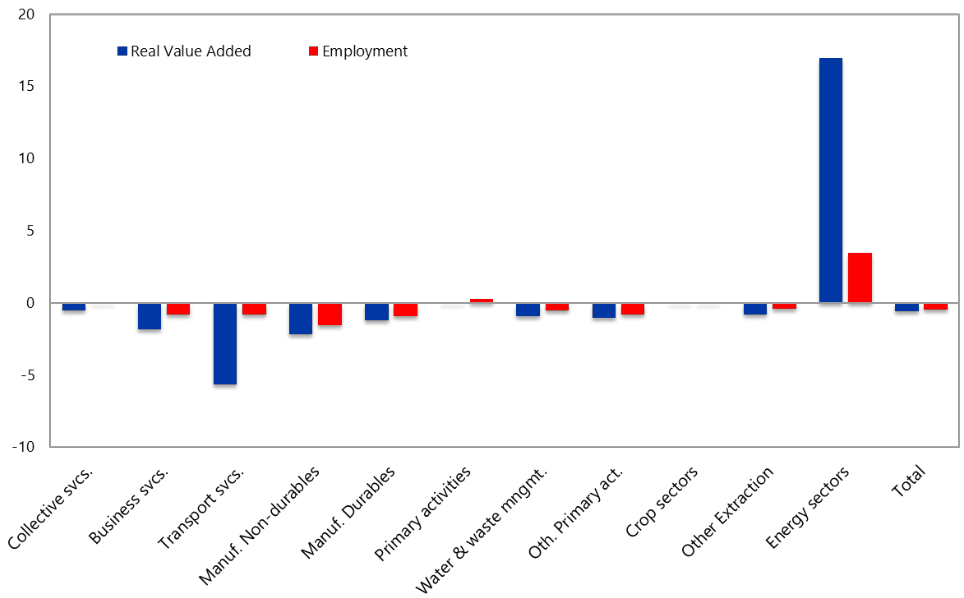
Some sectors other than energy are impacted indirectly through higher electricity prices. Transportation sector activities are reduced by 5 percent as response to increasing fuel price for electric vehicles. Business services are also impacted, and their production reduced by 1.5 percent, but this reduction of service production, and employment is only temporary, it is associated with the increasing cost of labor in response to the increase of wage tax to finance electric feed-in tariffs (i.e. production subsidies). Once electricity subsidies are completely phased out (by 2050) the reduction of service production almost entirely disappears.

Employment in each sector generally follows changes in activity but by a lesser degree. Indeed, when a sector's activity contracts (expands), the wage bill in that sector declines due to changes in both wages and labor demand, and thus not all of it is borne by lower employment. Nevertheless, for some sectors, like coal extraction or gas manufacturing and distribution, the large reduction in employment (respectively around than 70,000 and 100,000 job losses in 2050 relative to 2020 level) following the decline of activity needs to be carefully taken into consideration. On the other side, employment in electricity sectors almost fully offset job losses in the fossil fuel sectors.

These job losses need to be taken seriously and policy efforts will be needed to help reallocation labor out of those shrinking sectors and into other areas of the economy. First, note that while this model has some allocational frictions (for example regarding capital) which interact with labor demand, actual unemployment could rise more than predicted by the model, especially in the transition because of unmodelled labor market rigidities. Moreover, it could be that the skills mix needed in a decarbonized economy is different and so efforts will be needed to retrain. It may also be that workers will need to move geographically and so there is a role for the government to facilitate. There may also be a need to target redevelopment resources to particular geographic areas that are hardest hit by the transition. It would be wrong to assume this transition will be frictionless and without welfare implications. Finally, the quality of the jobs created and lost—beyond just the wage rate received—may not be comparable. Much would depend on the bargaining power of labor (including level of unionization), the ability of labor to receive its marginal product, the ability of greener technology jobs to offer benefits such as healthcare and retirement benefits, and other factors.

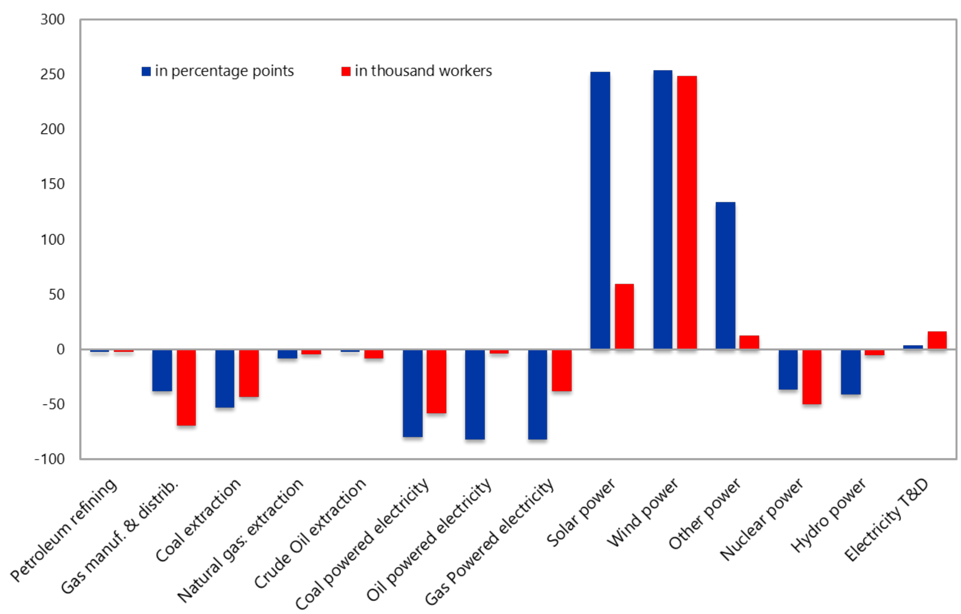
Figure 10. Sectoral reallocation of early decarbonization scenario

Panel A. Broad Sectors in 2035 (changes in percentage points relative to *EV penetration* scenario for real value added, in blue, and employment, in red)



Source: IMF-ENV model simulations.

Panel B. Employment in energy sectors in 2035 (in percentage points relative to *EV penetration* scenario, in blue, and in thousand workers, in red)



Source: IMF-ENV model simulations.

Box 2. Sensitivity Analysis and Decomposing the Early Decarbonization Scenario

Sensitivity to financing assumptions. The substantial subsidies in the policy scenarios imply significant expenditures. All scenarios thus far assume that the government balances the budget by adjusting wage income taxes. The table below contrasts that assumption with one where the government balances the budget with lump sum taxation.

	Budget Balance through adjustments to wage taxes			Budget Balance through adjustments to lump sum Taxes		
	2025	2035	2050	2025	2035	2050
Real GDP	-0.2	-1.1	-0.4	0.1	-0.9	-0.1
Household Consumption	-0.3	-1.5	-0.6	0.1	-1.3	-0.3
Gross Investment	0.0	-0.1	-0.1	0.1	-0.1	0.0
Employment	-0.1	-0.5	-0.1	0.2	-0.2	0.2
Real gross wage	-0.3	-1.1	-0.3	-0.8	-1.2	-0.4
CO2 fossil combustion	-7	-32	-33	-7	-32	-33

Notes: Numbers in percent deviations from the EV penetration scenario. Source: IMF-ENV model.

Lump sum taxation generates, by definition, more benign aggregate impacts, especially in the short run, while achieving the same electricity mix and CO2 emission reductions. The distributional impacts could also be different across financing assumptions, although this cannot be assessed by the model since it has a representative consumer.

Decomposing the early decarbonization scenario. The policy scenarios involve two main instruments: subsidies and regulation. The table below decomposes the respective macro-impacts of the two instruments in isolation (“Subsidies only” and “Regulation only”).

	2025	2035	2050	2025	2035	2050
	Real GDP			Household Consumption		
Subsidies only	-0.15	-0.68	-0.02	-0.21	-0.86	0.00
Regulation only	-0.05	-0.43	-0.39	-0.07	-0.67	-0.64
Early decarbonization	-0.20	-1.11	-0.41	-0.28	-1.53	-0.64
	Employment			CO_2 from fossil combustion		
Subsidies only	-0.08	-0.29	0.01	-5	-17	-1
Regulation only	-0.02	-0.17	-0.11	-2	-14	-32
Early decarbonization	-0.10	-0.45	-0.10	-7	-32	-33

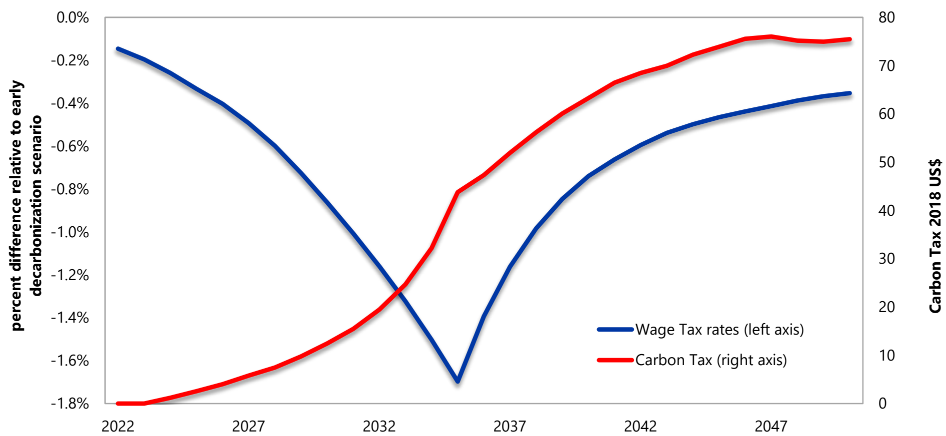
Notes: Numbers in percent deviations from the EV penetration scenario. Source: IMF-ENV model.

In the short run, most adverse impacts on GDP, consumption and employment come from the distortive electricity subsidies, while regulation is more important in the medium-term. In 2035, when subsidies start to be phased out, regulation and subsidies contribute close to equally to the decline in CO_2 emissions, but subsidies appear to be more costly in terms of GDP losses and employment, due to the increase of wage taxation needed to finance these (see above). By 2050, subsidies are close to fully phased out and thus any lingering effects come from regulations.

Box 1. Measuring the shadow cost of regulation with a carbon tax

How can we compare climate regulation (i.e. the multiplier Φ discussed in Box 1) with conventional climate fiscal policy? In this box, the shadow cost of regulation is approximated with a carbon tax. Under the *carbon tax* scenario, the carbon tax is endogenously adjusted so that power sector emissions follow same path as in the *early decarbonization* scenario.

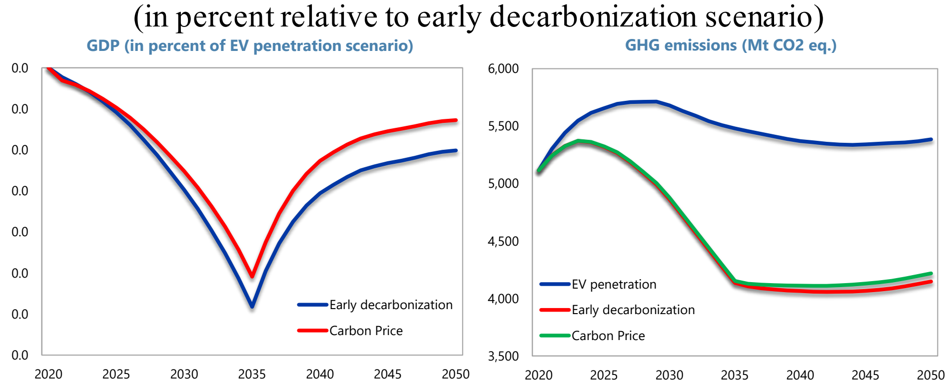
Figure 11: Carbon Tax scenario: carbon price in power and wage income tax rate
(in percent relative to early decarbonization scenario)



Source: IMF-ENV model simulations.

The carbon tax implied by the regulatory constraint in the early decarbonization scenario is one that gradually rises to US$44/t$CO_2$ by 2035 and US$76/t$CO_2$ by 2050. The two scenarios though are not identical for two reasons that highlight the greater efficiency of the carbon tax. First, under the *carbon tax* scenario the adjustment in income tax rates to balance the budget is lower than in the decarbonization scenario (2 percentage points lower in 2035), since the carbon tax finances half of the solar and wind subsidies. Second, the regulation constraint does not discriminate across fossil fuel sources according to carbon content, unlike the carbon tax. Thus, under the regulatory constraint fossil fuel sources are uniformly reduced (see Figure A1).

Figure 12. Carbon Tax scenario: carbon price in power and wage income tax rate
(in percent relative to early decarbonization scenario)



Source: IMF-ENV model simulations.

V. CONCLUSION

Aside from ambitious targets, it is imperative that the U.S. takes determined climate policy actions. The administration has laid down ambitious goals and now it needs to follow-through with policies, be it subsidies, investments, regulations and explicit carbon pricing.

This paper argues that the relative mix of the climate policies that are ultimately pursued has macro implications. A policy package that relies only on subsidies and investments will be very fiscally costly and will not achieve the climate goals efficiently. R&D subsidies which are often touted as a panacea are useful but cannot deliver the targets, either on their own or combined with other subsidies.

Greening the power and transport sectors is analyzed jointly, but efforts in other sectors are also much needed if the ambitious targets laid out by the administration are to be achieved.

Decarbonizing the power sector early is critical and not very costly. Early action allows phasing out expensive subsidies sooner and thus, while generating short-term marginal losses, it quickly becomes less costly than delayed decarbonization. It also will lessen the cumulative emissions and, as such, reduce the degree of climate change. Regulation can be very useful in the power sector, particularly because it is much better understood than in other sectors and is much easier to administer and enforce.

Finally, the green transition will likely create winners and losers in the short-term. Benefits will be widespread while costs may well end up concentrated in a few regions. These effects are illustrated for the particular example of greening the power sector. Such a transition will require supporting policies that can cushion the brunt of the economic effects, sustain social support for these policies, and prevent a stop-go environment for in climate policies

Finally, carbon taxes have several benefits highlighted in this paper, but may also impose uneven costs across different households (see for example Känzig, 2021). Any package that contains carbon taxes could thus include flanking measures for low-income households to encourage the social acceptability of carbon taxation and mitigate the unequal effects of carbon taxation on household consumption.

The road ahead for U.S. climate action is long and winding. Safe navigation entails not only persistent efforts but also a greater understanding and appreciation of the key macro-climate trade-offs involved.

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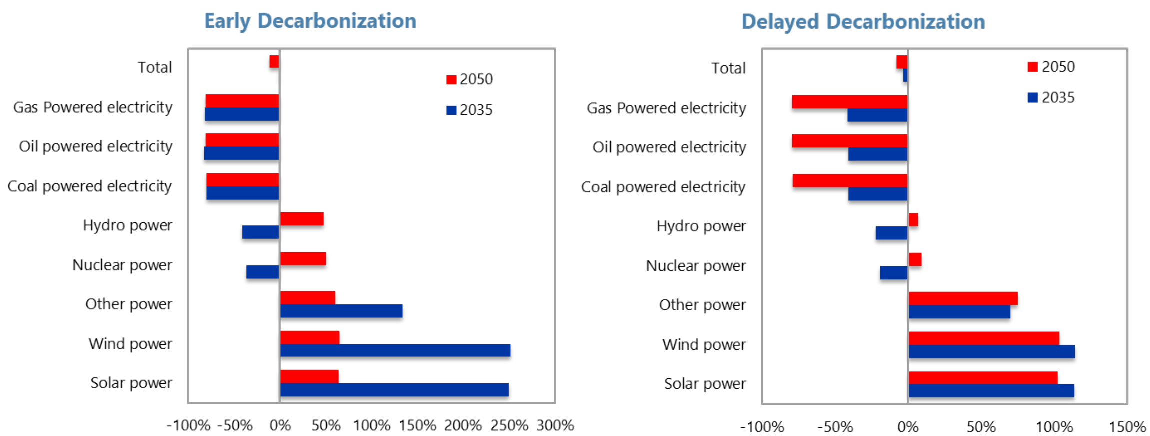
APPENDIX I. ADDITIONAL FIGURES

Figure A1. Changes in Electricity mix under policy scenarios: 2035 and 2050 (in percent of the *EV penetration* scenario)



Source: IMF-ENV model simulations.

APPENDIX II. THE IMF-ENV MODEL

The model is a recursive dynamic neo-classical, global, Computable General Equilibrium (CGE) model, built primarily on a database of national accounts and set of bilateral trade flows. The central input of the model is the GTAP V10 database.[31] The database contains country-specific input-output tables for 141 countries and 65 commodities and real macro flows. The database also represents world trade flows comprehensively for a given starting year. The currently used version 10 is based on data from 2014. The model describes how economic activities and agents are inter-linked across several economic sectors and world countries or regions.

The model is based on the activities of the key actors: firms, households, and markets. Firms purchase inputs and primary factors to produce goods and services. Households receive the factor incomes and in turn demand the goods and services produced by firms. Markets determine equilibrium prices for factors, goods, and services. Finally, countries exchange goods on international market. Frictions on factor or product markets are limited.

The model is recursive dynamic: it is solved as a sequence of comparative static equilibria. The factors of production are taken exogenously at each point in time and linked between time periods with accumulation expressions, like the dynamics of a Solow growth model. Production follows a series of nested constant-elasticity-of-substitution (CES) functions to capture the different substitutability across all inputs. International trade is modeled using the so-called "Armington" specification that posits that demand for goods is differentiated by region of origin. This specification uses a full set of bilateral flows and prices by traded commodity. Factors of production are almost perfectly mobile across sectors (real rigidities make adjustments sluggish in short run) but not across countries.

The model also links economic activity to environmental outcomes, specifically to the emission of greenhouses gases and other pollutants. An important feature of the model is that capital stocks have vintages such that firms' production and behavior are different in the short and long run. Only real economic flows are considered in the model. Firms and households are homogeneous.

The model can be used for scenario analysis and quantitative policy assessments. For scenario analysis, the model projects up to 2050 and contains an internally consistent set of trends of all economic, sectoral, trade-related, and environmental variables. In this context, the model can be used to analyze economic impacts of various drivers of structural changes like technical progress, increases in living standards, changes in preferences and in production. For scenario analysis a set of external projections are generally required. A second use for the model is quantitative economic and environmental policy assessment for the coming decades, including scenarios of a transition to a low carbon economy. In this case the model assesses the costs and

[31] https://www.gtap.agecon.purdue.edu/

benefits of different sets of policy instruments for reaching given targets like GHGs emission reduction.

The focus of this paper is on the U.S. economy, therefore for sake of simplicity the world is divided in 10 regions/countries and for each of these regions the economy is split in 55 sectors. Since the focus of the analysis is on climate mitigation policies, the main sectors contributing to GHGs emissions are modeled separately. This includes 5 fossil fuels goods (coal mining, crude oil, refined oil, gas extraction and gas distribution), 8 power generation sectors (Coal, oil and gas-powered electricity, Hydro power, Wind, Solar, Nuclear and other power) and energy intensive industries (Iron and steel, Non-metallic minerals, chemicals, Pulp and paper, non-ferrous metals).

List of countries and Regions

United States of America
Japan
Australia
Europe
Rest of the OECD
China
India
Rest of the World
Russian Federation
Oil-Exporting countries

List of sectors
1.) OMN : Minerals n.e.s.
2.) pdr : Paddy Rice
3.) wht : Wheat and meslin
4.) gro : Other Grains
5.) v_f : Vegetables and fruits
6.) osd : Oil Seeds
7.) c_b : Sugar cane and sugar beet
8.) pfb : Plant Fibres
9.) ocr : Other Crops
10.) lum : Wood products
11.) ppp : Paper & Paper Products
12.) nmm : Non-metallic minerals
13.) fmp : Fabricated metal products
14.) mvh : Motor vehicles
15.) otn : Other transport equipment
16.) ele : Electronics
17.) ome : Machinery and equipment n.e.s.
18.) eeq : Electrical equipment
19.) bph : Basic pharmaceuticals

20.) rpp : Rubber and plastic products
21.) omf : Other manufacturing (includes recycling)
22.) i_s : Iron and Steel
23.) nfm : Non-ferrous metals
24.) frs : Forestry
25.) fsh : Fisheries
26.) coa : Coal extraction
27.) oil : Crude Oil extraction
28.) gas : Natural gas: extraction
29.) p_c : Refined Oil
30.) gdt : Natural gas: manufacture & distribution
31.) cns : Construction
32.) trd : Trade (including accomodation, wharehousing)
33.) osg : Other collective services
34.) edu : Education
35.) hht : Human health and social work
36.) obs : Other Business Services nec. and communication
37.) wtp : Water Transport
38.) atp : Air Transport
39.) otp : Transport n.e.s.: Land transport and transport via pipelines
40.) crp : Chemical products
41.) cow : Livestock: Cattle and Raw Milk
42.) nco : Livestock: other animals
43.) clp : Coal powered electricity
44.) olp : Oil powered electricity
45.) gsp : Gas Powered electricity
46.) nuc : Nuclear power
47.) hyd : Hydro power
48.) wnd : Wind power
49.) sol : Solar power
50.) xel : Other power
51.) etd : Electricity transmission and distribution
52.) osc : Other Financial services (including Dwellings, insurance,real estate)
53.) wts : Water supply; sewerage; waste management and remediation activities
54.) fdp : Food Products
55.) txt : Textiles