Strategies for Cost-effective Carbon Reductions: A Sensitivity Analysis of the Clean Energy Future Study

Etan Gumerman[1], Jonathan G. Koomey[1], and Marilyn Brown[2]

Abstract

Analyses of alternative futures often present results for a limited set of scenarios, with little if any sensitivity analysis. This approach creates an artificial impression of certainty associated with the scenarios considered, and inhibits understanding of the factors affecting the scenario results. This paper summarizes the economic and carbon savings sensitivity analysis completed for the Clean Energy Futures study, which leads to a deeper understanding of what drives the results. It provides more details on the direct costs and effectiveness of a carbon permit trading system, demand side efficiency programs, and supply side policies in achieving carbon reductions. It also illustrates how sensitive the advanced scenario results are to an increase in natural gas and oil prices compared to those prevailing in the Clean Energy Futures advanced case. Finally, it answers the question of whether policy options exist that both reduce carbon emissions and save money for society.

The Excel spreadsheets containing all scenario results are posted on the web at http://enduse.lbl.gov/projects/cef.html

Keywords: sensitivity analysis, energy policy, carbon emissions

Background

The Clean Energy Futures (CEF) study explores three central forecasting scenarios using modified versions of the NEMS model, as explained in Brown et al. (2001). This work builds on previous analysis such as the Five Lab Study (IWG 1997) and a previous analysis for the EPA using the LBNL NEMS framework (Koomey et al. 1998). The Business-as-Usual (Bau) scenario assumes a continuation of current energy policies and a steady, but modest pace of technological progress. In contrast, the Moderate (Mod) and Advanced (Adv) scenarios are defined by policies that are consistent with increasing levels of public commitment and political resolve to solve the nation's energy-related challenges.

This article focuses on the carbon emissions and direct cost for two sets of CEF sensitivity analyses. Direct costs include incremental technology costs, policy program costs, renewable portfolio standards costs, RD & D costs, consumers' energy bill costs, and savings from carbon permit fee rebates. These analyses assess the consequences of futures other than those portrayed by the Bau, Mod, and Adv scenarios, and identify the most important trends to emerge from the results.

One important question we seek to answer in this paper is whether there are any options for reducing carbon emissions that also save money at the same time. The sensitivity analyses we explore here show many different combinations of policies and programs, and these analyses can yield important insights into this and related questions.

Methodology

To untangle the driving forces for the CEF scenario analysis, we analyze differing demand side and supply side policies, as well as a range of carbon permit trading programs. We create sixteen sensitivity cases by combining the following policy options and carbon fees in different ways:

1. Demand side policies -- Business as Usual, Moderate, or Advanced
2. Supply side policies -- Business as Usual, Moderate, or Advanced
3. Assumed carbon permit trading price ($1997 per metric ton of carbon) -- $0, $25, $50, or $100

The sixteen combinations that we evaluate in Figures 1-4 are shown in Table 1. We define a policy implementation level as the combination of demand and supply policies. Only five out of a possible nine levels are analyzed, because we do not evaluate Mod supply with Bau or Adv demand or Mod demand coupled with Bau or Advanced supply. All policy implementations have sensitivities for three carbon permit levels.

We only apply a $100 carbon permit price to the Business-as-Usual implementation. The Bau $100 sensitivity is included so that this analysis can be compared with the Energy Information Agency's Impacts of Kyoto study (EIA 1998). The Impacts of Kyoto study evaluates six goals for 2010 carbon reductions, and meeting these goals require carbon prices between $67 -$348 per metric ton of carbon ($1996). The Bau $100 sensitivity shows carbon emissions reductions in line with the reductions seen in the Impacts of Kyoto report for a carbon permit trading fee of this approximate magnitude.

For clarity in this article, every sensitivity name includes the policy implementation level as well as Carbon Permit Trading Price. This is in contrast to the CEF study where scenario names do not explicitly indicate the Carbon Permit Trading Price, although the $50/t carbon permit fee is implicit in the definition of the CEF advanced scenario. The CEF Advanced Scenario is therefore called the Adv $50 sensitivity in this article, the Moderate Scenario is called Mod $0, and Business-as-Usual Scenario is called Bau $0.

Table 1. Sixteen Incremental Sensitivities used for Examining CEF Trends

	Assumed Carbon Permit Trading Price			
Policy Implementation Level	No Trading	$25/t	$50/t	$100/t
Business As Usual	**Bau $0***	Bau $25	Bau $50	Bau $100
Moderate	**Mod $0***	Mod $25	Mod $50	
Advanced	Adv $0	Adv $25	**Adv $50***	
Demand Bau, Supply Advanced	S-Adv $0	S-Adv $25	S-Adv $50	
Demand Advanced, Supply Bau	D-Adv $0	D-Adv $25	D-Adv $50	

* Bolded names correspond to the CEF Study's main scenarios (Bau, Moderate, and Advanced)

During the CEF study review, the authors were asked whether higher natural gas or oil prices would lead to different conclusions. Therefore, we modeled how more pessimistic assumptions affecting natural gas and oil prices would change the results for the advanced case. Figure 5 compares four new sensitivities with seven of the above sensitivities. Table 2 shows the eleven sensitivities that are included in Figure 5. The seven in the first three rows are identical to ones in Table 1. The last three rows contain the four new sensitivities.

For these new sensitivities, we limited the technological progress for oil and natural gas exploration and extraction beyond the normal progress rate in NEMS. Three new sensitivities lead to increases in price of natural gas, and the fourth increases world oil price as well as natural gas prices. The fifth item in the discussion section, below, summarizes the fuel price increase resulting from the natural gas and oil changes. We only performed a limited number of these price sensitivities because the resulting changes were limited and consistent.

Table 2. Sensitivities used for analysis of higher prices in Figure 5

	Assumed Carbon Permit Trading Price		
Policy Implementation Level/Fuel Price Variation	No Trading	$25 /t	$50 /t
Business As Usual	**Bau $0***		
Advanced	Adv $0	Adv $25	**Adv $50***
Demand Bau, Supply Advanced	S-Adv $0	S-Adv $25	S-Adv $50
Advanced, High Gas Prices			HG Adv $50
Dem Bau, Supply Adv, High Gas Price	HG S-Adv $0		HG S-Adv $50
Advanced, High Oil and Gas Prices			HOG Adv $50

* Bolded names correspond to two of the CEF Study's main scenarios (Bau, and Advanced)

Results

We show results in five graphs. The first two Figures, 1 & 2, include the ten Bau, Mod, and Adv policy implementations. Figures 3 & 4 include the thirteen sensitivities with some combination of Bau or Adv supply and demand policies. Of these thirteen, six are new (S-Adv and D-Adv implementations) and the other seven (Bau and Adv implementations) are repeated from Figures 1 & 2. Figure 5 contains two of the policy implementations from Figure 4, and four points representing higher fuel price variations of these implementations.

On all five figures, the x-axis shows the absolute level of U.S. carbon emissions in million metric tons of carbon (MtC). The y-axis shows total direct cost of energy services in 2010 or 2020, expressed on an annual basis. This cost includes the annualized incremental cost of efficiency improvements beyond the business-as-usual case, the annualized program implementation costs, the cost of R&D subsidies in each year, the costs of the production tax credits for the electricity sector, and the cost of electricity and fuel purchases. The direct costs do not include the indirect macroeconomic effects of a carbon permit trading system on the economy. We discuss those indirect effects below using conclusions from the analysis contained in Sanstad et al. (2001).

This type of graph was first developed by Krause et al. (1995), and it is most useful when presenting large numbers of different sensitivities. Each point on the graph represents the direct costs and carbon emissions of different sensitivities. Lines or arrows between sensitivities are used to relate sensitivities to each other. In this article, all of the lines start at the Business-as-Usual $0 case. The lines are drawn to represent groups of sensitivities that use the same set of non-price policies for both the supply side and the demand side, but with varying levels of carbon permit trading fees. The arrows in Figure 5 show the result of adding higher natural gas and oil prices to a given sensitivity case.

Discussion

We identified five important trends from the graphical results.

1. Any policy implementation leads to lower direct costs, if carbon permit trading level stays constant. Comparing Figures 1 & 2 reveals that net savings in direct costs are greater, both in absolute and percent terms, in 2020 than in 2010. The Mod implementation is consistently 6% lower in cost than Bau in 2010 and 9% lower in cost in 2020. The Adv implementation is 8% and 16% lower in cost than Bau in 2010 and 2020, respectively. The extra ten years leads to additional savings due to stock turnover, and because many of the policies implemented are not fully effective until after 2010. Figures 3 & 4 show that the same trend applies to the S-Adv and D-Adv implementations.

2. Adoption of either the advanced supply or advanced demand policies leads to lower net costs nationally at the same time that carbon emissions are reduced. As seen in Figures 3 & 4, the demand-side policies by themselves have a larger effect on reducing costs and emissions than the supply-side policies by themselves. The S-Adv and D-Adv implementations are not independent of one another. Using the BAU as a baseline, the costs and carbon emissions reduced by the Adv policy implementation is less than the sum of those from the S-Adv and D-Adv implementations.

3. All policy implementations are affected similarly by adding a carbon permit trading program. A $25/t permit price reduces emissions by 3-5% in 2010 and 4-7% in 2020 (compared to the same $0 policy implementation). A $50/t permit price more or less doubles that effect, reducing emissions by between 6-9% in 2010 and 9-14% by 2020 in all policy implementations. These reductions occur primarily due to one major future difference. In a carbon permit world, there is less coal generation and more gas-fired plants (which generally have lower emissions than coal plants).

4. The carbon trading policy alone does not reduce carbon emissions as much as many of the non-price policies. The Mod $0 case makes further reductions than BAU $25 and Adv $0 goes beyond the reductions for Bau $50 in 2010. Ten years later the Mod $0 case beats Bau $50 and the Adv $0 even surpasses Bau $100 reductions.

5. Carbon emissions in the advanced policy implementation are hardly affected by higher gas and oil prices. The three higher gas price variations led to similar effects, increased direct costs and only slightly smaller carbon reductions compared to the three similar sensitivities, S-Adv $0, S-Adv $50, and Adv $50. However, the higher oil and gas price variation leads to a small additional carbon reduction while significantly increasing direct costs.

> The discrepancy between the effects of the HG Adv $50 and the HOG Adv $50 variations requires a deeper examination of the results. There are three major reasons that HG Adv $50 and HOG Adv $50 do not have similar effects when compared to the Adv $50 sensitivity.
>
> First, the high oil price effect is stronger than the high gas price effect. HG Adv $50 increases the natural gas price by 10% in 2020 and indirectly leads to a 1% petroleum price increase, while the HOG Adv $50 leads to both the 10% natural gas price increase as well as a 20% petroleum price increase in 2020.
>
> Second, oil makes up a larger share of domestic energy supply than natural gas, so changes in oil prices have larger repercussions than natural gas prices. By 2020 petroleum accounts for 38% of primary energy consumed and natural gas accounts for 28%.
>
> Third, carbon emissions drop in the HOG Adv $50 case because overall energy consumption drops. Energy consumption is the same in the Adv $50 and HG Adv $50 forecasts, but the HOG Adv $50 sensitivity consumes about 1% less energy due to higher prices. Most of this reduction comes from oil use in the transportation sector.

The direct costs discussed in this article do not include the indirect macroeconomic effects of a carbon permit trading system. As discussed in Sanstad et al. (2001), the negative economic impact of a $50/t carbon permit trading fee in 2010 is of the same order of magnitude as the net direct benefits in our advanced scenario with $50/t carbon permit fee. By 2020, the net direct benefit, which grows over time, will likely be larger than these indirect costs (indirect costs will not increase if the carbon permit fee remains at $50/t over time).

These indirect costs do not affect any case without a carbon charge (such as Mod $0 and Adv $0). We can say clearly that these no-carbon-charge sensitivities both save money and reduce carbon emissions, but the question becomes more complex when a carbon charge is involved (see Sanstad et al. 2001 in this special issue). The sensitivities with carbon charges may also achieve net societal savings (depending on assumptions about how the permit fees are recycled) but we have not conducted a comprehensive analysis of the indirect effects in 2010 or 2020 of the range of carbon charges considered here. IPSEP (2001) attempts to estimate the potential impacts of revenue recycling and other policy shifts on the CEF results.

These results directly contradict conventional wisdom in certain academic fields. Some analysts argue, on theoretical grounds, that it is impossible for society to reduce carbon emissions and save money at the same time. These assertions are generally based on ignorance or misunderstanding of the latest research on program evaluation, transaction cost economics, behavioral economics, information economics, and institutional economics. We do not address these issues in detail here, but refer the reader to treatments of them by Decanio (1993,1998), Brown (2001), Sanstad et al. (1995), Sanstad and Howarth (1994), Huntington et al. (1994), Koomey (1990), Koomey et al. (1996), Koomey and Sanstad (1994), Laitner et al. (2000), Greening et al. (1997), Krause (1996), and Krause et al. (1993). Conventional wisdom can often be misleading (Koomey 2001), and in this case it has inhibited discussion of the data and evidence needed to resolve the debate over these issues.

Three other CEF single policy alternative sensitivities are not discussed in detail in this paper. However, the policy change and major effect are briefly described below:

1. **Renewable Energy Policy and Cost Sensitivity**. This sensitivity is just like the Adv $50 sensitivity except that the renewable portfolio standard (RPS) was terminated in 2004, four years ahead of schedule. This causes wind generation to fall by almost 40% in 2020 and carbon emissions to increase by 20 MtC in 2020. Wind generation is still many times that for BAU $0.

2. **No Diesel Penetration in Light-Duty Vehicles Sensitivity.** This sensitivity is just like Adv $50 case but has no diesel penetration in light-duty vehicles. The Adv $50 sensitivity has a penetration of 3.1 million diesel vehicles in 2020. This policy change reduces fuel economy of new light-duty vehicles and increases carbon emissions by 10 MtC in 2020.

3. **Higher Cost of Advanced Fossil Fuel Technology Sensitivity**. This sensitivity examines a less optimistic future for the cost and performance of combined cycle gas power plants. Because of the availability of advanced technologies for renewables and combustion turbines as well as the continued availability of relicensed nuclear plants as backstops, less R&D success for combined cycle technologies does not have a major impact on the overall results.

Future Work

The next steps that should be taken to best continue this work are to:

1. Update the CEF Scenarios using the AEO 2001 version of NEMS to see how the sensitivity analysis is affected by using the updated version of the forecasting model.

2. Explain the driving forces in more detail. Specifically, the interactions between specific policies within each sector have not been analyzed in this paper. Also, the interactions between supply and demand policies as pointed out in the Discussion, point #2 above, need to be understood. Policies that overlap and reduce the same carbon emissions should be identified.

3. Extend the calculation of indirect macroeconomic costs to the $25 and $100/t cases in both 2010 and 2020, and apply those results to every scenario analyzed here. This work should include the potential for revenue recycling to reduce macroeconomic costs. These calculations would give a complete picture of societal costs for the different scenarios.

4. Use a forecasting model other than CEF-NEMS to calculate net direct costs and carbon emissions for the same combinations of low carbon policies as we explore here. A comparison of such results would yield important insights into the sensitivity of the results to the choice of modeling framework. There has been some work in this area (Hansen and Laitner 2000), but more such work is urgently needed so that modeling methodologies can improve.

5. Create pilot programs to test how best to promote adoption of more efficient products at the scale envisioned for the Moderate or Advanced scenarios. While the program experience upon which we based the scenarios is wide ranging and well understood, field testing is critical to develop the most effective implementation strategies in the current energy policy environment.

Conclusions

The sensitivity analyses explored in this article give important insights into the driving factors affecting the costs and potential carbon savings for a variety of programs and policies that could be implemented to reduce carbon emissions and other pollutants. This work also helps us understand the actual trends seen in CEF. Carbon emissions are reduced as a result of both supply and demand side policies, as well as by the carbon permit trading policy implemented in CEF. Additionally, all supply and demand policy implementations reduce direct costs.

Most significantly, while carbon fees are an obvious way to reduce carbon emissions, supply and demand policies alone can lead to larger carbon reductions than a $100 carbon fee when it is implemented in isolation. Carbon reductions from policy implementation alone, i.e. no carbon charge, lead to net societal savings.

Our results show unambiguously that some opportunities exist to reduce carbon emissions and save society money. The exact extent of those opportunities is an issue about which reasonable people can disagree, but that such opportunities exist is no longer in doubt. Their ultimate extent is an empirical question that can only be answered by implementing pilot programs and evaluating the results. Appeals to theory alone should no longer be considered adequate in the debate over the costs of reducing carbon emissions in the U.S. Real program evaluation data are needed to resolve this debate, and we should pursue such data with all due haste.

Footnotes

[1] Lawrence Berkeley National Laboratory, Berkeley, California
[2] Oak Ridge National Laboratory, Oak Ridge, Tennessee

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Acknowledgements

The complete set of output spreadsheets for this analysis can be downloaded at <http://enduse.lbl.gov/Projects/CEF.html>. These spreadsheets contain detailed results for energy use, carbon emissions, and costs for all sectors and end-uses.

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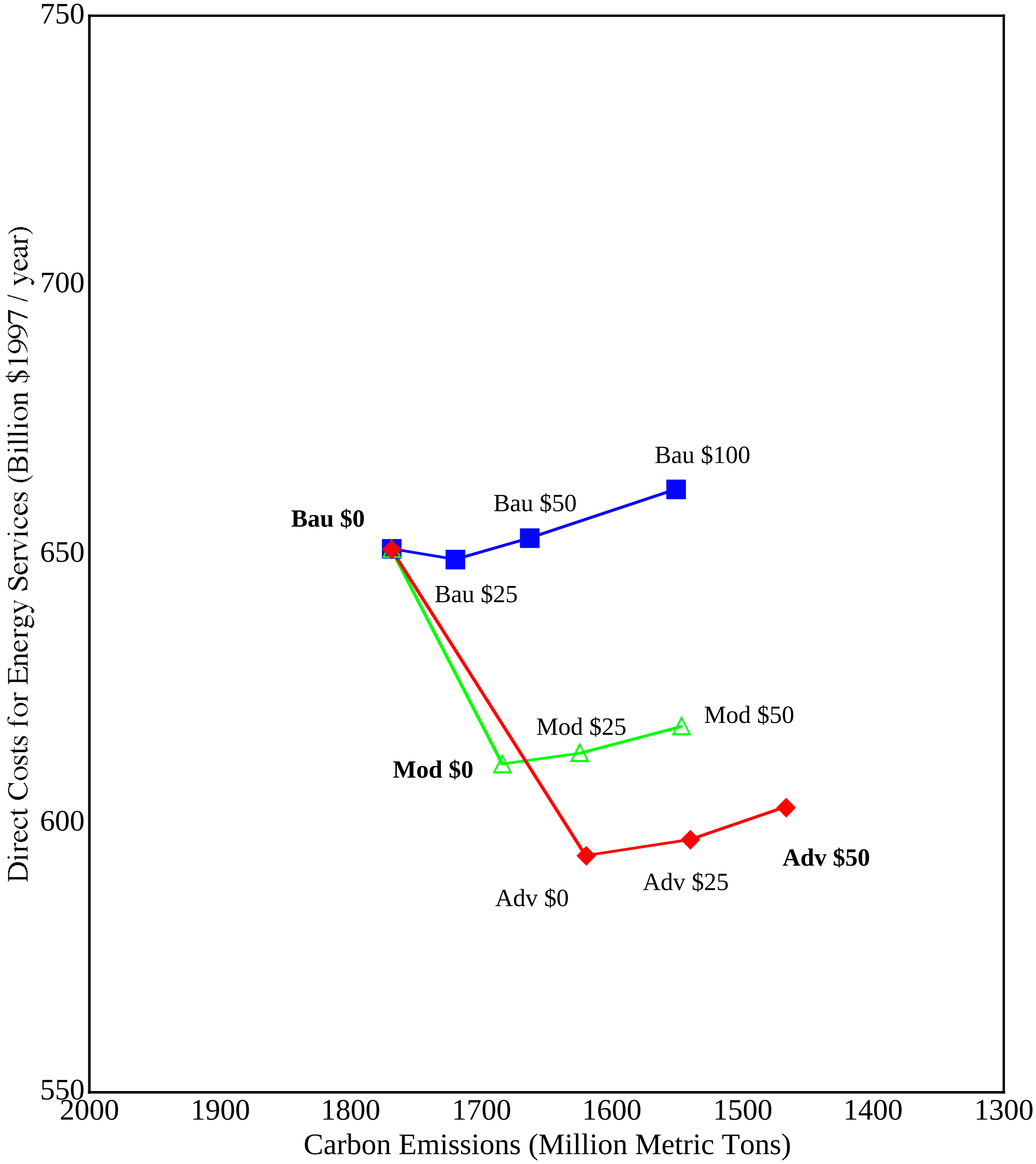
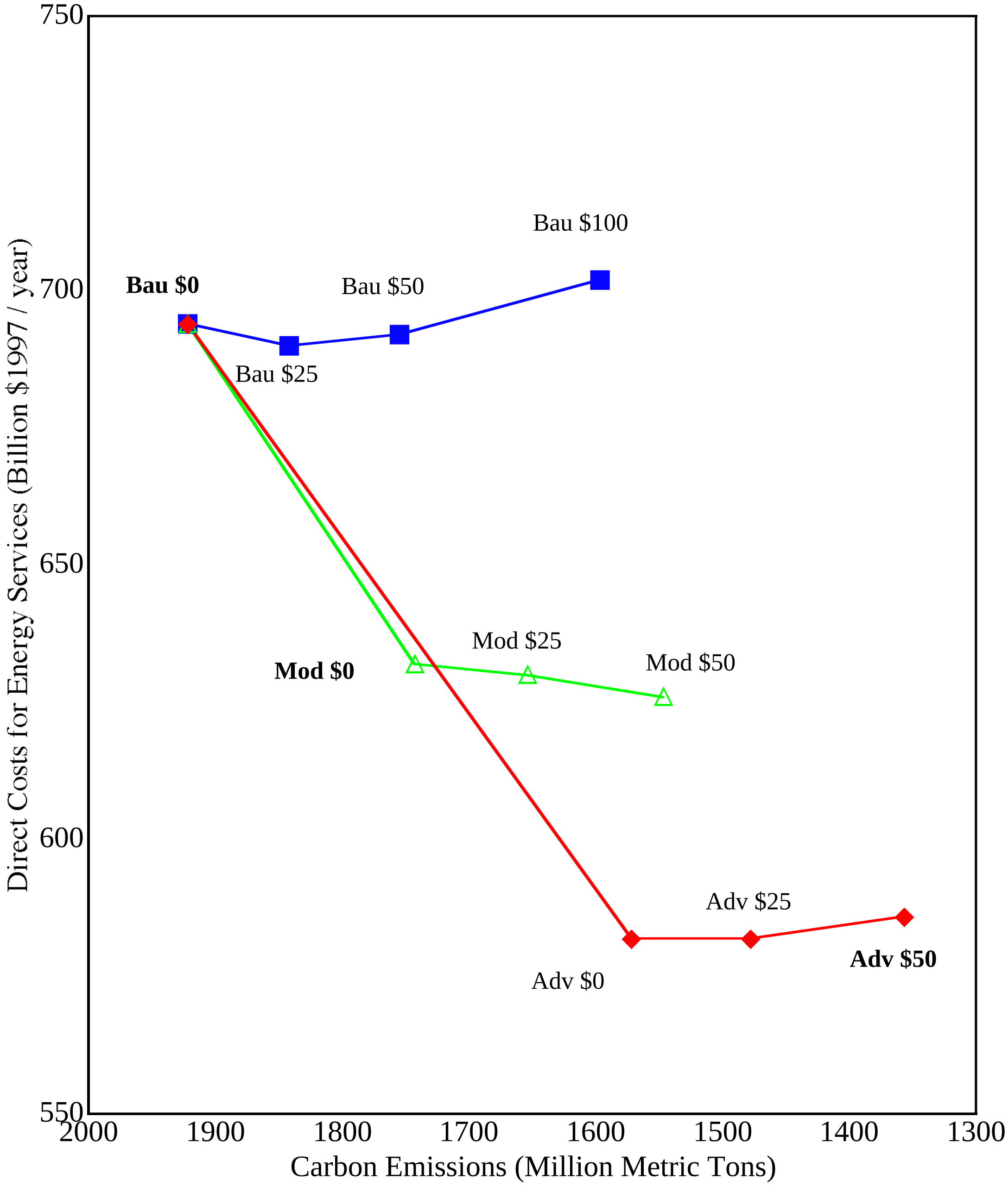
Figure 1. CEF 2010 Direct Costs and Carbon Emissions (Business As Usual, Moderate, & Advanced policy implementations)



Source: http://enduse.lbl.gov/projects/cef.html

Figure 2. CEF 2020 Direct Costs and Carbon Emissions (Business As Usual, Moderate, & Advanced policy implementations)



Source: http://enduse.lbl.gov/projects/cef.html

Figure 3. CEF 2010 Direct Costs and Carbon Emissions (Business As Usual, Supply-only Advanced, Demand-only Advanced, & Advanced policy implementations)

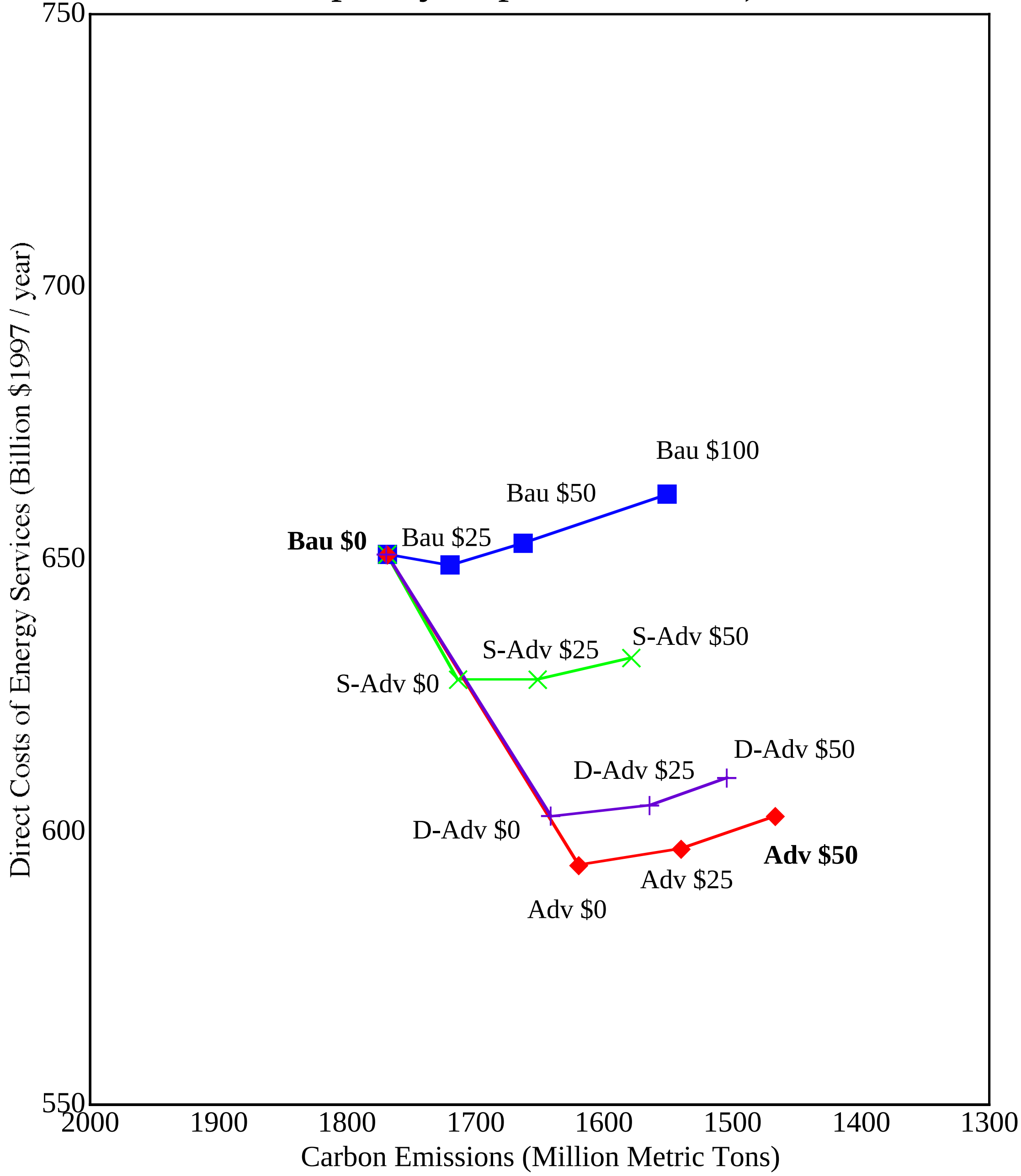


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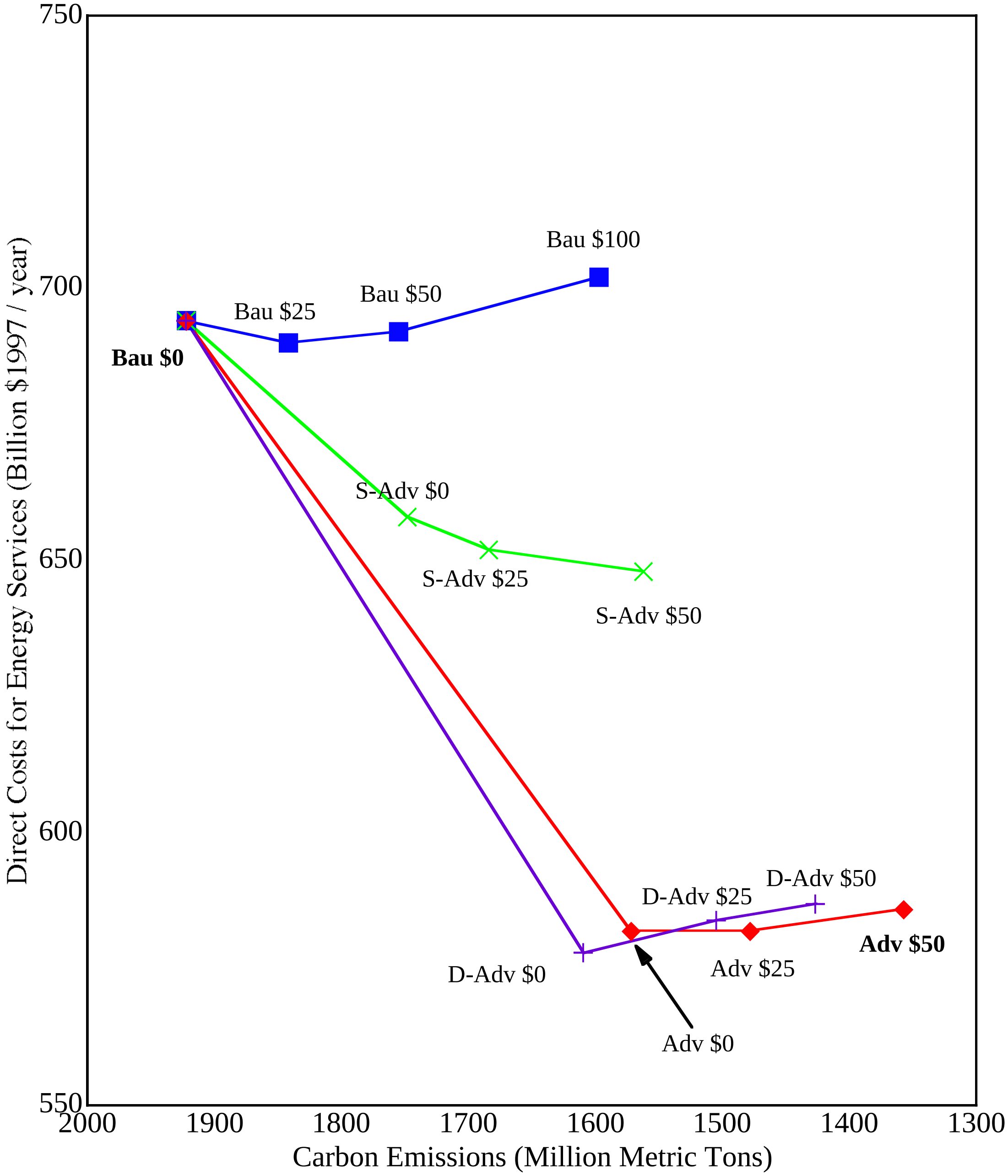
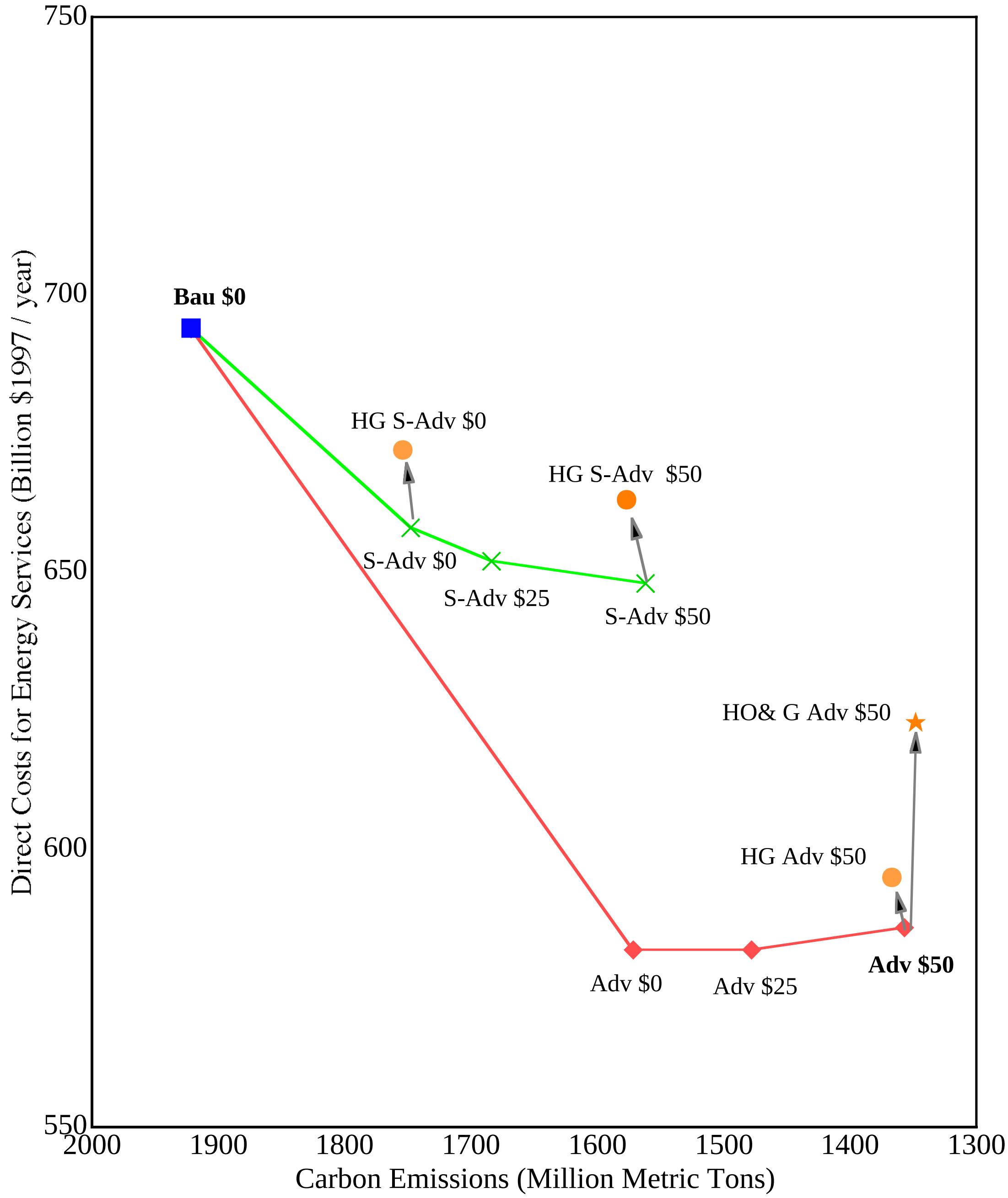
Figure 4. CEF 2020 Direct Costs and Carbon Emissions (Business As Usual, Supply-only Advanced, Demand-only Advanced, & Advanced policy implementations)



Source: http://enduse.lbl.gov/projects/cef.html

Figure 5. High Fuel Price Sensitivities Relative to Supply-only Advanced and Advanced Forecasts, CEF 2020 Direct Costs and Carbon Emissions



Source: http://enduse.lbl.gov/projects/cef.html