Solar Power & NEMS

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Abstract: Using a sequence of counter-factual scenarios, this paper examines the National Energy Modeling System's (NEMS) robustness to changes in solar power modeling and conducts a sensitivity analysis of those changes. This paper isolates some of the ranges in which NEMS can adequately model changes to solar variables and other ranges where the system becomes unable to continue making unique estimates. Knowledge of these limits will be useful in future versions of the model as well in NEMS' role as a policy tool.

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Background

Solar power capacity and investment continues to expand each year, and the future energy consumption in the economy will be directly influenced by this growth. Along with other renewable and low carbon sources, solar power will strengthen its increasing role in the energy security and environmental policies of the United States.

Solar power's role as a low-emission alternative to traditional fossil fuel sources makes it one option for the future mitigation of greenhouse gas emissions. Additionally, solar power also could potentially displace international oil and gas imports that come from countries that currently pose a potential security threats to US interests. Energy security, national defense, and environmental degradation could all impose significant costs and demand large governmental resources in the future; mitigating future costs by diverting some of those potential outlays into solar power could make economic sense, even if solar power is not cost competitive under current market conditions; decisions to subsidize the industry further could provide returns on investment beyond recovered revenue from the electricity market. Thus, analysis and modeling of solar power is particularly relevant to the formulation of both environmental policy and foreign relations; adequate modeling and policy choices based on solar power's viability could be very beneficial for these ends.

Further, the future of solar power in the US is changing rapidly. The private sector's role in solar production is changing, increasing the value of a robust forecasting model for solar power. General Electric[1] and LG[2] have both recently announced and reaffirmed significant monetary commitments to the solar industry, creating potentially drastic changes to both solar technology and physical installations. Further developments in the private sector require further robustness checks on the

[1] "**GE Expands Solar Business as Immelt Seeks to Mirror Wind Growth**" http://www.bloomberg.com/news/2010-10-12/ge-expands-solar-business-as-immelt-seeks-to-mirror-wind-growth.html

[2] "**Bring it on: GE and LG enter the solar game**" http://venturebeat.com/2010/10/13/bring-it-on-ge-and-lg-enter-the-solar-game/

models and policy tools currently in place to ensure that accurate forecasts are attained. This will help to understand the continued evolution of the national electric grid and also identify issues of future concerns that could result from adding large levels of intermittent energy sources that might not need to be addressed if alternative energies had a lower level of usage. Thus, rigorous testing and strengthening of those models used for national policy will provide value for making optimal policy regarding this growing industry.

One of the primary long-run tools used in energy policy and analysis is the Energy Information Administration's (EIA) National Energy Modeling System (NEMS). Official NEMS runs conducted by the EIA are used in consideration of future energy policy and legislation, and thus the model is potentially significant in the allocation of resources and investment in the coming years and decades. Examining the role and robustness of solar modeling in NEMS should provide guidance on how best to proceed with future solar (and other renewable) energy policy, and contribute to sound economic, environmental, and defense policy.

NEMS employs a large-scale modular structure, modeling every significant aspect of the energy in the economy; it is updated annually and provides the official energy forecasts of the energy economy. The forecast window of the 2010 base case is 2035, and the model examines everything from the international markets for fuel sources to the expansion of electric capacity at the regional level. The model simulates multiple market equilibria simultaneously, thus allow for significant feedback and substitutions that occur in the real-world energy markets. Solar power is modeled in the Renewable Fuels Module (RFM), but also feeds into both the Electricity Market Module (EMM) and the Petroleum Market Module (PMM). The RFM interacts with these modules in order to capture the substitution effects that occur between solar power and other fuel sources in the electricity market, as well as the decision to build new capacity in the Electricity Capacity Planning (ECP) subroutine, as well as distribution and grid efficiency gains that come from distributed generations at residential and commercial sites. NEMS' large scope and its role in policy make it central to the future of solar power and other alternative energies in the US.

Objectives & Methodology

Using NEMS, this paper will examine the manner in which solar power is incorporated into NEMS, conduct sensitivity analyses of the solar elements in the model, and identify some key assumptions in NEMS that could be improved or revised. This analysis is done by conducting a series of test runs of the 2010 system first by replicating the publically available 2010 Annual Energy Outlook (AEO 2010).[3] The baseline assumptions are then relaxed and input values altered to test the system's sensitivity to changes of specific variables. These sensitivities are then examined and interpreted. Strengths and weaknesses are assessed, and recommendations for areas of improvement in future models are suggested.

Scenarios Considered

This paper is primarily reports two distinct scenarios were room for improvement was found. The first scenario looks at the sensitivity to changes in the efficacy of solar photovoltaic cells in the capture of solar energy, while the second looks at changing the capital costs of solar thermal and solar photovoltaic from their baseline estimates.

Under the PV efficacy scenario, a series of different efficiency parameter values were considered. The solar efficacies were examined under both optimistic assumptions (increasing the

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[3] http://www.eia.doe.gov/oiaf/aeo/

efficiency from baseline by 50%, 100%, 200%, and 300%) and pessimistic assumptions (reducing the efficacy 3/4ths and half of the previous levels). These results were calculated primarily with the electricity capacity planning unit turned off, thus isolating the effect on solar electric generation without expanded capacity so as to check the robustness of the efficacy parameter itself, rather than the average efficacy of all units installed under a large regime.

Under the Capital Cost Scenario, the dollars per kilowatt hour of capacity were altered to see the responsiveness of installations and capacity that resulted. Several optimistic scenarios were tested (capital costs reduced to 50%, 33%, 25%, and 20% of total) as well as a pessimistic case (capital costs increased to 200% of baseline). These results will focus primarily on the end-use generators, as their results proved to be the most significant.[4]

Scenario 1 – Changing the Efficacy of Solar PV and the Per-Unit Generation Response

Changing the efficiency parameter resulted in two very different results. The optimistic projections changed per-unit generation in line with what would be expected from such increases, while the pessimistic scenarios proved to be difficult for NEMS to model.

The results from improving the efficacy of solar PV proved to be somewhat robust to what would have been expected, with generation improving in roughly a linear fashion (i.e. double the efficiency, double generation) with only slight deviations the linear trend.[5] In running optimistic projections of PV solar efficiency on a per-unit basis, NEMS acquits itself quit well.

[4] Data tables and graphs of the results can be found in the appendix. Run outputs are available upon request from the authors.
[5] Differences from a straight linear projection were all +/- 1% of the expected value. These slight differences occur due to changes between convergence cycles, whereby slight differences would crop up. This is the result of the

However, the two pessimistic scenarios proved to have quite a different response. Reducing the efficiency of the solar panels to 75% of their projected path resulted in no change from the baseline, while reducing them to 50% of their baseline efficiency resulting in a slight dip from the baseline case over the first 4 years of the estimation before returning to the baseline outputs from 2015 to the end of the sample. In effect, NEMS proves incapable of modeling the next 25 years with large decreases in the general efficiency of the baseline projects of improved efficiency. While able to handle the lower levels of efficiency for a few years, the model stops solving and merely prints the results found in the baseline case. Even turning off the portion of the model that decides whether to change capacity from baseline (which is equivalent to a "command" of installing those units predicted in the baseline), the model still is unable to solve the pessimistic scenario. Thus, any policy model runs that would look at more pessimistic future for solar technology must be careful to make sure that Solar PV is not returning to its baseline level of output per installed unit.

Scenario 2 – Changing the Cost of Capital of Solar PV & Solar Thermal Installations

The results from changing the capital costs of solar technology proved somewhat mixed. While small deviations from the baseline appear to be robust to changes, larger shifts in the underlying data appear to encounter some cap or default value that is not the baseline scenario. Policy scenarios that produce results similar to these values should be viewed skeptically, as they appear to be the result of the program being unable to calculate values based on the changed inputs.[6] This observation is especially important for large jumps in manufacturing or installation advances that significantly change the cost of solar capital.

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large size and multiple moving parts of the model, and not some reflection of poor specification, as the feedbacks from generation would interact in moderately non-linear ways with the rest of the model.

[6] Note that the model logs do note that there is a problem with the values in those year, though the main model diagnostics imply that there was no problem achieving convergence.

In the narrow range around the baseline specifications, the results come back quite robust. Small changes in the capital cost see small changes in both the net summer capacity for the electricity sector as well as for the end-use generation. However, over a certain level, further changes in the capital cost generate identical "override" values in both optimistic and the pessimistic cases. In other words, once the model becomes incapable of solving for the new values, it will spit out the higher level of solar capacity even *though the capital is more expensive*. Thus, any runs that return values in the range of those results found in the appendix should be considered a failed run (with respect to solar power), even if the NEMS run reports convergence in each year and identifies the run as successful.

Conclusions

This paper has presented two specific areas where the solar components of NEMS should be viewed skeptically when modeling large changes from the baseline scenarios. Especially of note is that NEMS seems to have more trouble handling changes to solar that are more pessimistic than the baseline scenarios, having much more capability in the optimistic direction. While NEMS is an extremely robust, powerful, and useful analytical tool for examining and implementing energy policy in the US, some of the solar equations in the RFM could stand refinement. Specifically, advances in solar technology or in the market for solar production that are the result of increased private or public research could might not be able to be accurately modeled by NEMS in the 2010 archived version. Large gains in solar efficiency or large negative shocks in the markets for solar capital production may prohibit NEMS from making valid estimates. If the US does pursue policy with to reduce GHG or security issues by increased solar usage, NEMS will need to further refine the RFM to adequately analyze potential technological advances.

Appendix

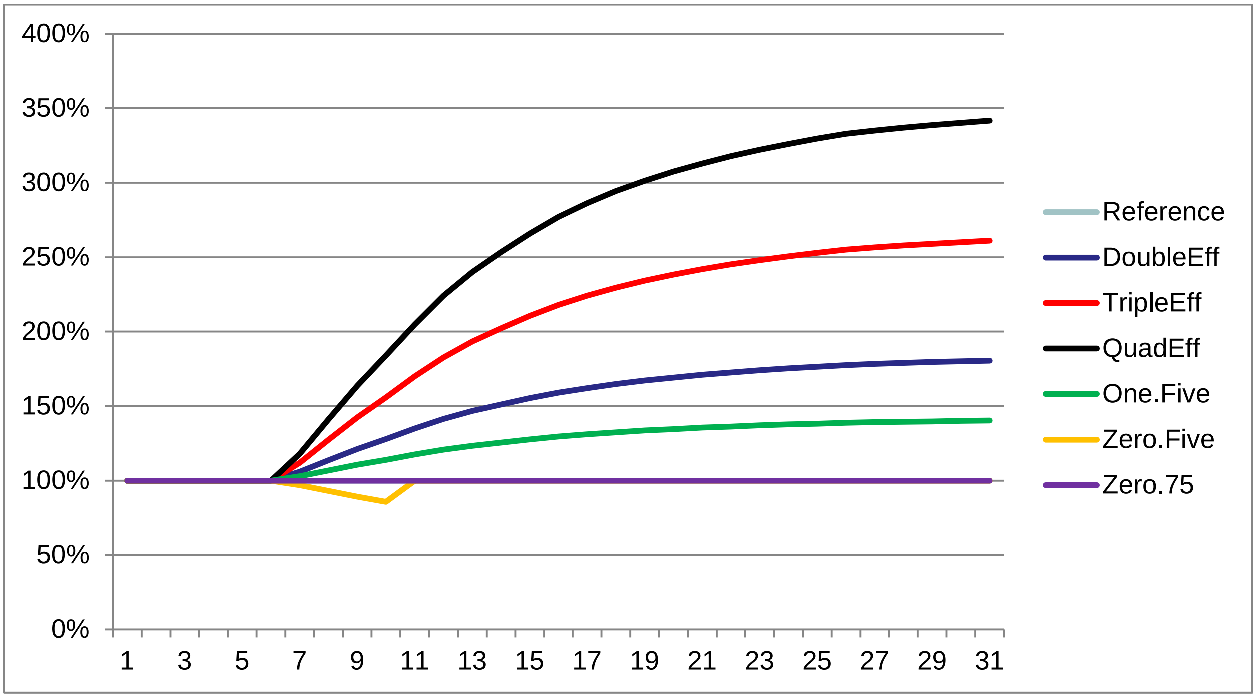
Table 1 – Key inputs to the Solar submodule:

Model Variables and Parameters	Units	Value
Fixed O&M cost for solar thermal technology	Mills/kW	34.691
Fixed O&M cost for photovoltaic technology	Mills/kW	7.138
Investment policy incentive as a fraction of capital cost	Percent	10% permanent tax credit; 30% tax credit until 2016
Capital cost of solar thermal technology	$/kW	2867
Capital cost of photovoltaic technology	$/kW	3513
Variable O&M cost for solar thermal technology	Mills/kWh	0
Variable O&M cost for photovoltaic technology	Mills/kWh	0
Capacity constraints for photovoltaic technology in EMM region n in year y	MW	1,000 each region/year
Capacity constraints for solar thermal technology in EMM region n in year y	MW	1,000 each region/year

Table 2 – Scenario 1: Solar PV Generation relative to baseline:

	Generation (Percent of baseline)					
Efficiency Change	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Half	100%	100%	100%	100%	100%	100%
3/4th	100%	100%	100%	100%	100%	100%
Reference	100%	100%	100%	100%	100%	100%
+50%	100%	117%	129%	135%	139%	140%
Double	100%	135%	159%	171%	178%	181%
Triple	100%	170%	218%	242%	255%	261%
Quadruple	100%	205%	277%	313%	333%	342%

Graph 1 – Scenario 1: Solar PV Generation relative to baseline:



Graph 2 – Scenario 1: Growth from 2010, scaled by change to baseline number

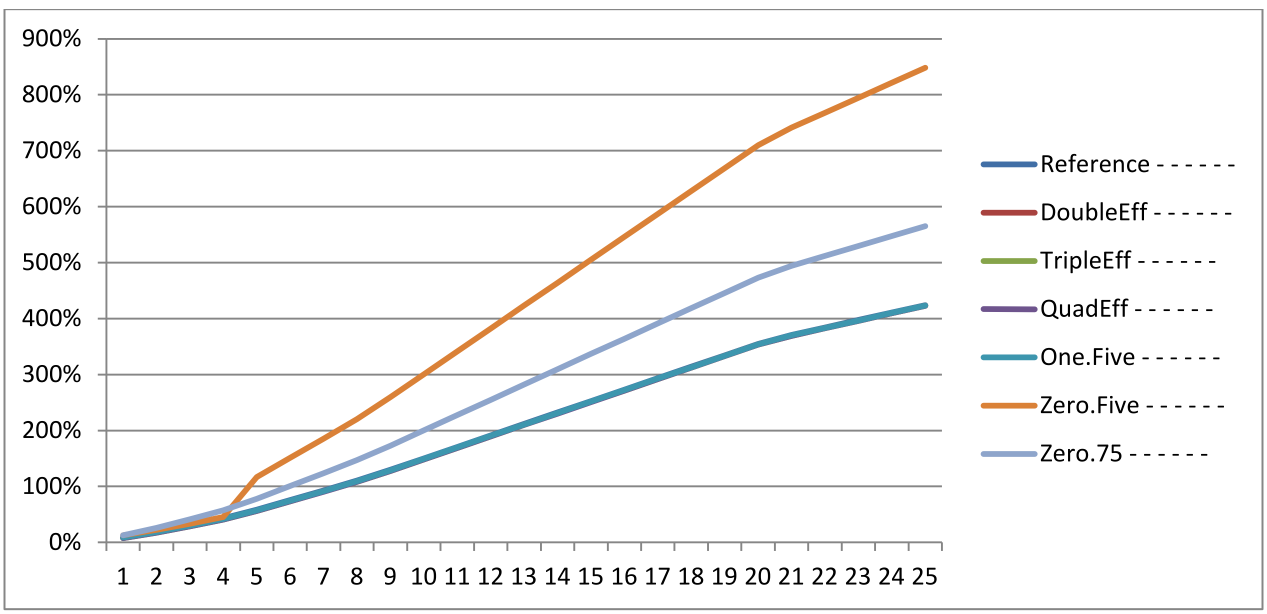


Table 3 – Scenario 2: Total Solar Generation (bKWH) with Changed Capital Costs:

Generation (billion kilowatthours)						
Capital Costs from baseline	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
1/5th	3.23	13.86	17.69	18.73	22.61	29.68
1/4th	3.23	13.87	17.69	18.71	22.60	29.68
1/3rd	3.23	13.86	17.69	18.72	22.61	29.66
1/2nd	3.23	13.77	16.21	16.82	18.52	21.66
Reference	3.23	13.12	16.12	16.73	18.43	21.58
Double	3.23	13.87	17.69	18.74	22.63	29.71

Graph 3 – Scenario 2: Total Solar Generation (bKWH) with Changed Capital Costs: