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NEPP-PM: Scrutiny of Myhrvold & Caldeira (2012): Methods to compare climate influence of alternative technologies

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On the transition from coal to low carbon electricity and its climate impact

In order to reduce the greenhouse gas (GHG) emissions from the energy supply there is a need to develop and deploy low or zero carbon-supply options. For renewable power plants the main GHG emissions occur during plant construction. For fossil-fuel based power plants, in contrast, the emissions from operation dominate. Increased GHG emissions in the near term, leading to an increase in their atmospheric concentrations and radiative forcing, may produce undesirable climate effects in the near-term (e.g., change in global atmospheric and oceanic temperatures) since accelerated rates of global warming mean ecosystems and humans have less time to adapt. In order to assess the climate impact related to the transition from coal based to more low carbon electricity it thus seems important to take into consideration the time aspect i.e., when the GHG emissions (and associated temperature change) appear.

Methods to compare climate influence of alternative energy technologies

Myhrvold and Caldeira (2012) propose assessing the relative climate benefits of alternative energy technologies for policy purposes by comparing the change in global mean temperature that each alternative energy technology would produce under various schedules of deployment (a temperature change metric). Alvarez et al. (2012), on the other hand, propose comparing a time-integrated approximation to the radiative forcing produced by each alternative (a cumulative radiative forcing metric).

To convert radiative forcing to global temperature changes, assumptions must be made regarding e.g., time constaints, sensitivities, and feedbacks in the climate system, all of which introduce uncertainty to the results. The cumulative radiative forcing approach in Alvarez et al., (2012) extend the global warming potential (GWP) metric recommended by the IPCC (Forster et al., 2007) to enable consideration of the time-dependent climate influence of fuel-technology choices being made now, without prejudging which impacts on climate are important. However as argued in Caldeira and Myhrvold (2012) the metric proposed by Alvarez et al., (2012) may fail to measure differences that could be important to policy choices between energy technologies since it does not to the same extent take climate system characteristics into account.

Both the model used by Myhrvold and Caldeira (2012) and IVL (in the associated project) calculate the global average surface temperature change due to emissions scenarios in three steps: i) atmospheric concentrations are calculated based on emissions of GHG; ii) radiative forcing is calculated based on concentrations ; and iii) temperature change is calculated based on radiative forcing. Both models can illustrate the inertia of the climate system, i.e. that it takes time before a change in atmospheric concentrations of GHG leads to a temperature change.

The main differences between the models are the descriptions of the ocean and the climate sensitivity. These parameters influence the temperature response from a given emission scenario in terms of the amplitude and temporal dependency. Myhrvold and Caldeira (2012) assume a 4 km thick ocean slab with diffusive vertical heat transfer. In contrast, the IVL-model describes the ocean as a 75 meters thick slab of water which is well mixed so heat transfer occurs instantly and uniformly. Secondly, Myhrvold and Caldeira (2012) apply a climate sensitivity parameter, λ of 1.35, while IVL uses λ= 1.0. We haven't compared the two models regarding their temperature response. It's likely that these model differences affect the amplitude and time dependency, but we cannot determine if this has any significant effect on the conclusions by Myhrvold and Caldeira (2012). The results by Myhrvold and Caldeira (2012) show that it takes up to 15 years or more before the effects of reduced GHG emissions are clearly visible as a temperature change. This is consistent with simulations by the IVL-model on other emission scenarios.

Analysing the transition from coal to low carbon electricity

Myhrvold and Caldeira (2012) find, in their analysis of the energy system transitions, that the replacement of traditional coal based electricity production by alternatives energy sources as natural gas and renewable energy sources may lead to climate benefits first in the second half of this century. Myhrvold and Caldeira (2012) select coal-fired power plants as the basis for comparison because replacing plants of this kind delivers the greatest climate benefits since this technology emits the most GHG per unit electricity generated.

An insight from Myhrvold and Caldeira (2012) is that delaying the transition of the electricity sector delays long-term climate benefits of alternative energy sources while accelerating the transition decreases the emissions from coal use but increases the rate of emissions from the construction of new power plants. The climate impact depends on the time dependant difference in emissions between the alternative energy technology and the technology that is replaced. The effect of the corresponding climate change need to be further studied (i.e., the impact of a short term increase of the temperature compared to an increase in the future). In general slow climate change is better than a rapid change.

The transition from coal to gas

Myhrvold and Caldeira (2012) (that include carbon dioxide, CO_2, methane, CH_4, and nitrous oxide, N_2O) find that natural gas will not be able to provide substantial climate benefits in the second half of this century but also indicate that two years would be needed before the warming (due to the replacement by natural gas) is equal to what would have occurred without the transition from coal.

A substitution of coal based electricity by natural gas will besides to reduce the CO_2 emissions and potentially increase the emissions of CH_4, also reduce the emissions of black carbon (BC) particles as well as the emissions of sulfur dioxide (SO_2, a sulfate aerosol precursor). The latter will lead to an increased warming (Wigley, 2011). Thus in order to estimate the climate impact of a transition from coal to gas in the electricity sector all these factors should be taken into consideration.

Wigley (2011) show that the effects of larger CH_4 leakage and the reduction in SO_2 emissions related to the substitution of gas for coal for electricity production on a global scale may results in increased rather than decreased global warming (as in the case of including only CO_2 emissions) for many decades (depending on the leakage rate). This is in line with Hayhoe et al. (2002) and Howarth et al. (2011) even if Hayhoe et al. (2002) found CH_4 emissions to cause cooling due to an assumed smaller leakage from gas production. With leakage rates of up to 5% Wigley (2011) finds that the transition from coal to gas based electricity leads to a reduction of the global mean temperature in the second half of this century. The impact on the global-mean temperature depends on the substitution rate of coal.

Alvarez et al., (2012) that only study CO_2 and CH_4 emissions related to the transition from coal to natural gas, find that the use of natural gas instead of coal for electric power plants can reduce radiative forcing immediately (compared to after a few year as in Myhrvold and Caldeira, 2012). This may be due to different emissions scenarios or the fact that Myhrvold and Caldeira(2012) use temperature change as a metric for assessing climate impacts while Alvarez use radiative forcing. Alvarez et al., (2012) also indicate that the SO_2 emission factor seems to be decreasing implying that the net benefits of fuel-switching will occur much sooner than projected by Wigley (2011). Both Wigley (2011) and Alvarez et al., (2012) conclude that CH_4 leakage rates for natural gas production need to be limited in order to maximize the climate benefits of natural gas. Myhrvold and Caldeira (2012) on the other hand do not specifically discuss the importance of methane leakage.

Whether natural gas may provide substantial climate benefits in the second half of this century (as claimed by Myhrvold and Caldeira, 2012) depends on what is meant by substantial. According to Alvarez et al., (2012) it seems like in order to delay the climate benefits for natural gas beyond the second half of this century a rather large methane leakage is needed.

The transition from coal to renewable energy

Myhrvold and Caldeira (2012) base their analyses on the assumption that lower GHG emission power plants typically require greater upfront emission to build than coal based. In the literature however the estimations for the emissions related to the construction phase for different power plants differ substantially between different studies (see Figure 1). This is the case also for coal based electricity and one limitation with the study by Myhrvold and Caldeira (2012) is that they in the analysis only include one emission estimate for coal based power (indicated in the Figure). Myhrvold and Caldeira do not present any sensitivity analysis regarding their chosen value for construction of a coal based power plant. In the future it is also likely that the emission from the construction phase will probably decrease as a result of increased need to reduce GHG emissions in total. Our literature review indicates that it is not obvious that lower GHG emission power plants have higher emissions from the construction phase than coal based (thought the differences could be somewhat changed if the comparison was made per GWh instead of GW). Thus, further LCA-analysis comparing the energy technologies using the same assumptions are needed in order to draw any firm conclusions.

It appears as Myhrvold and Caldeira (2012) assume that the existing coal based power plants at the start of the transition is new but that they are not burdened with any emissions from the construction phase – which is a somewhat strange assumption. The impact of this depends on how large these emissions are compared to the emissions from the construction of renewable power plants. The emissions associated with the construction of coal based power plants are included in our analysis. The result for carbon capture and storage (CCS) has not been studied explicitly as it is not an important option in the NEPP scenarios included in this analysis.

Myhrvold and Caldeira (2012) also take the potential warming from waste heat related to the energy conversion in the electricity production into account and finds that the effects may compose a substantial fraction of total climate forcing from e.g., solar PV, solar thermal, and nuclear (but is assumed to be zero for wind and hydroelectric). The magnitude of the warming from waste heat has not been assessed here. The estimated values for transmission lines and losses connected to electricity transfer in Myhrvold and Caldeira has not been assessed either since existing LCA studies in general do not cover this kind of data. In particular not data for long-distance transmission lines that bring power generated from wind or solar to the end users. Myhrvold and Caldeira (2012) also state that the uncertainty in the transmission line impact is small compared with the variation between LCA data for the emissions from construction/production.

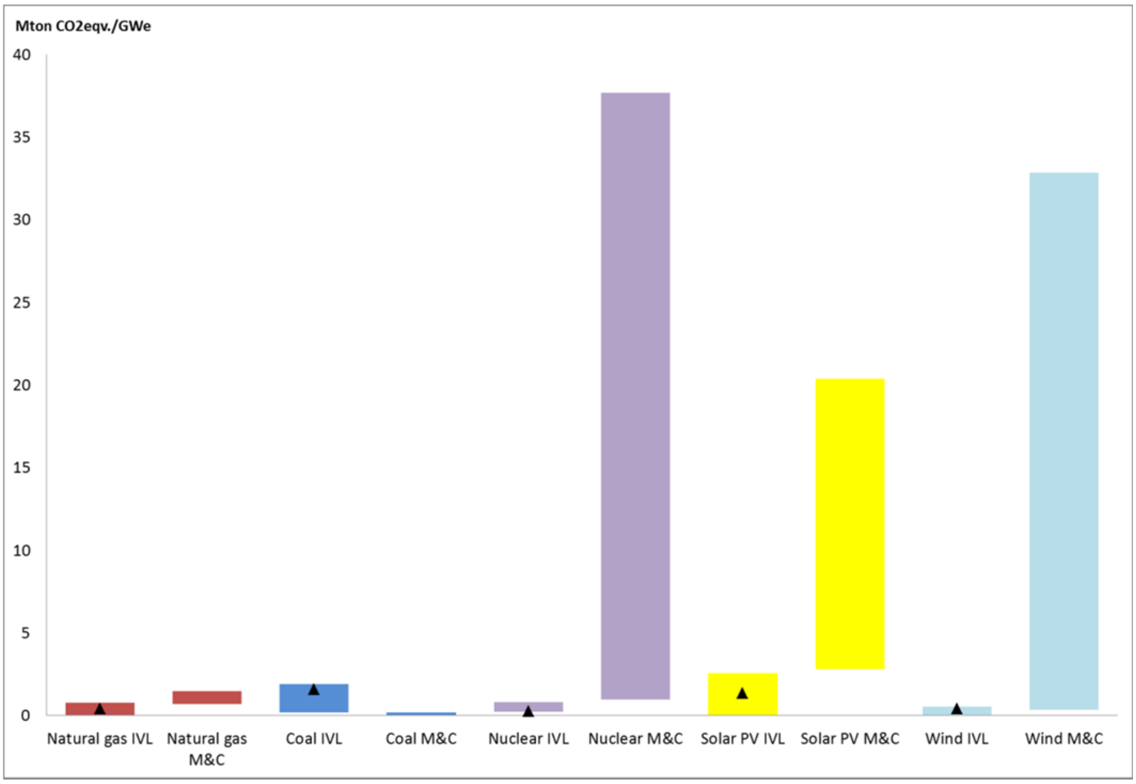

Figure 1. The total GHG emissions (including CO_2, N_2O and CH_4) from the construction of power plants based on different energy sources for a range of different sources. M&C illustrate the values used in Myhrvold and Calderia (2012), representing low and high end of their interval except for the coal case (where they only include one value). IVL represents the interval found in this analysis and the values chosen for the further analysis within the NEPP project is indicated with the black triangle. Solar PV is solar photovoltaic. Biomass based power is not included due to the lack of data and hydro power is not included either.

A large-scale deployment of renewable power technologies offers opportunities for technological advances that may reduce the associated GHG emissions. The sensitivity analyses in Myhrvold and Caldeira (2012) fail to analyse the impact of a substantial technology improvement already at the start of the transition, leading to a lower GHG emission value than the lower bound in that study. Our literature review for example finds lower GHG emission values than the lower bound in Myhrvold and Caldeira (2012) for most technologies.

Myhrvold and Caldeira study each alternative power option individually and in order to compare we produce similar graphs based on our data and assumptions (see Figure 2 and Figure 3). For example, in the case of solar photovoltaic and wind we unlike Myhrvold and Caldeira also include emissions due to maintenance. Since Myhrvold and Caldeira (2012) do not include biomass based power and since there were an unexpected lack of insufficient data for the GHG emissions from the construction of biomass based power this technology is not included. Hydro power is also excluded.

Figure 2 illustrates that the transition to renewable energy sources could, given that the technologies have relatively low GHG emissions from the construction phase, have more or less the same climate impact as the phasing out of coal based power at the same pace.

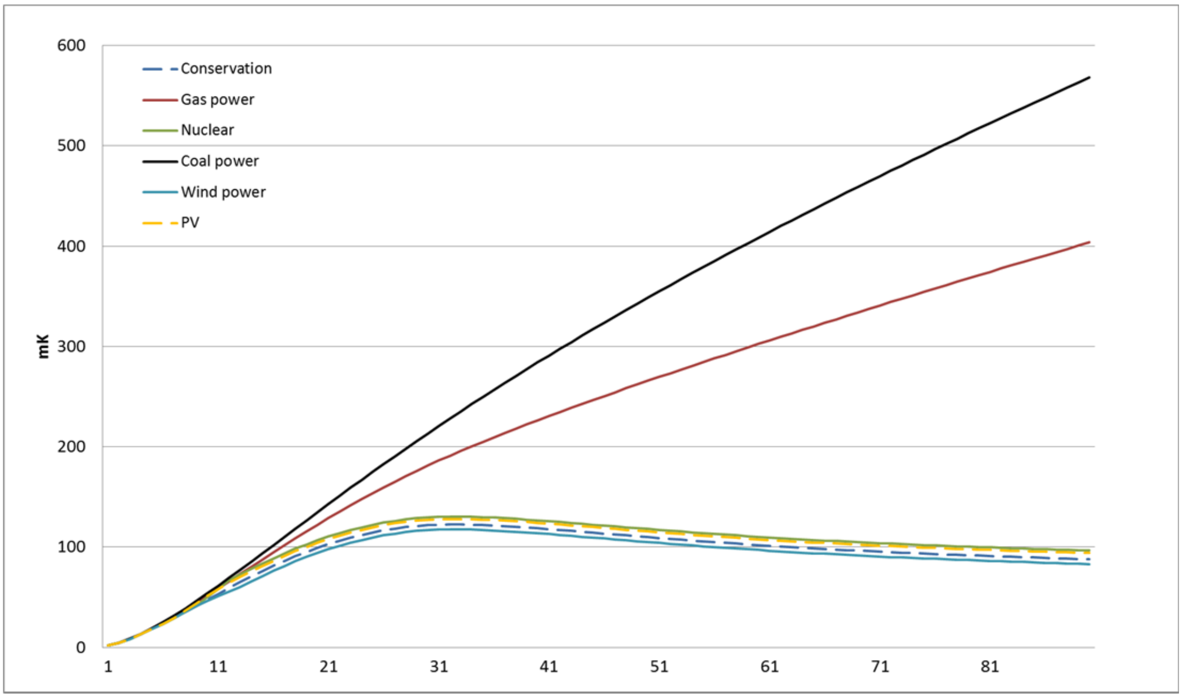

Figure 2. The temperature increases predicted to occur during a 30 year transition from 1 GWe of coal based power to natural gas, nuclear power, solar photovoltaic (PV), and wind power. The solid black lines represent the warming resulting from continued coal use with no alternative technology and the dashed dark blue line illustrates the temperature increase predicted to occur if coal were phased out at the same rate as the other energy sources are introduced. Note: Conservation, Nuclear, Wind and PV show almost identical values. To prevent the curves from overlapping completely, we slightly adjusted the values.

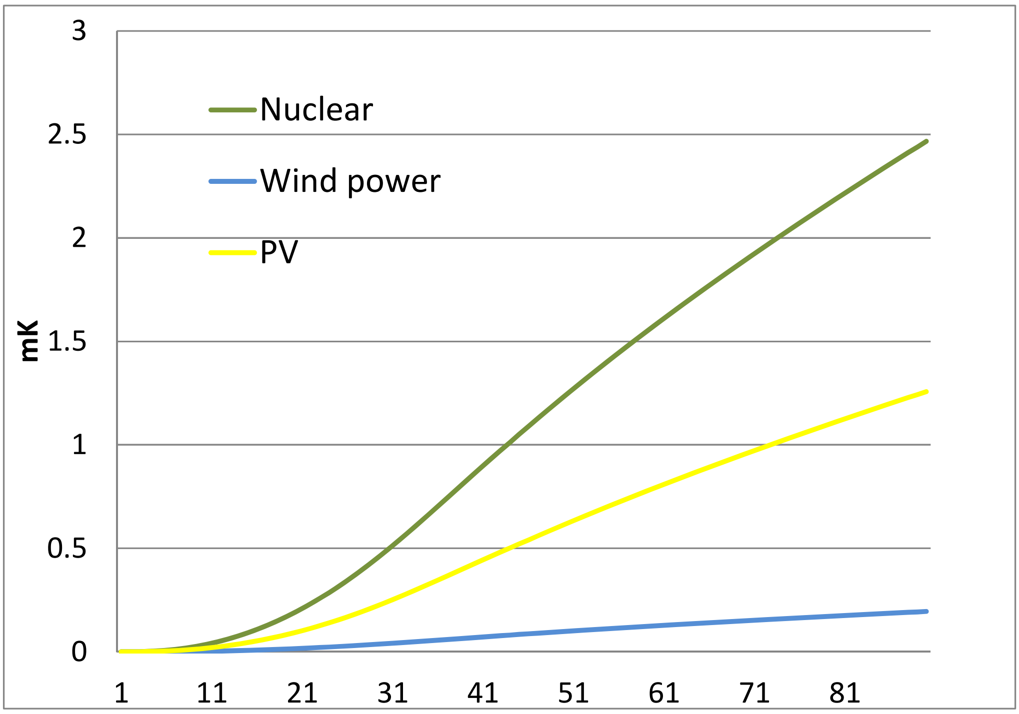

Figure 3. The temperature increases predicted to occur during a 30 year transition from 1 GWe of coal based power to nuclear power, solar photovoltaic (PV), and wind power (when only the impact from the different energy technologies are displayed, in order to clarify the difference between the different non-fossil fuel options).

Conclusions

Even with the introduction of renewable based power the climate impact will not be reduced immediately. This depends on the following aspects. (i) The climate impact of the replaced fossil fuels will not cease immediately. (According to Myhrvold and Caldiera (2012) the phasing out of coal based power without any replacement technology will also result in a continued temperature change throughout the century. (ii) The introduction of renewable fuels is also associated with GHG emissions due to the construction phase. Some of the renewable energy sources (as wind power) though have the potential to have more or less the same climate impact as the phasing out of coal (given that the GHG emissions from the construction are at the lower range). (iii) The inertia of the climate system which imply that it takes time (15 years or more) before the reduced total GHG emissions from the lower GHG emission supply options result in a significant temperature decrease as compared to the coal reference scenario.

This review indicates that it is not clear that lower GHG emission power plants have higher emissions from the construction phase than coal based. However, further LCA-analysis comparing the energy technologies using the same assumptions are needed in order to draw any firm conclusions regarding that. This review finds that the transition from coal to renewable energy may reduce the climate impact already in the midterm (roughly 15-35 years, based on Figure 2 in Myhrvold and Caldiera, 2012, with the potential exception of hydropower which have not been studied further). It is still important to limit the GHG emissions from the construction of renewable energy and other alternative power options in order to increase the climate benefit in the near term. The extent of the climate benefit due to a transition from coal to low carbon electricity and when it appears depends on the GHG emissions from the construction phase and other assumptions. With this climate impact perspective co-firing of biomass and coal in existing coal based power plants seems like a promising option as a complement to the introduction of renewable fuels since it does not require the construction of completely new power plants. It would be interesting to further study the climate impact of co-firing.

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