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Dynamic calculations of climate impact of long-term energy scenarios

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IVL Swedish Environmental Research Institute has made dynamic analyses of four power production scenarios taking into account that emissions from construction of a power plant occur prior to the operation of the plant. The aim of the study was to analyse dynamic emissions of greenhouse gases for selected Nordic electricity scenarios and compare how emission profiles vary in time. This approach gives an indication of the climate benefits and impacts of energy technologies in the short and long term. The methodology may also be used to evaluate which parts of the life-cycle of different technologies that require further development to reduce short and long term climate impact. Calculations have been made both on emissions and on the climate impact using radiative forcing. The study included the four NEPP scenarios Reference, Green Policy, Regional Policy and Climate Market.

Emissions vary during the life-cycle of a power plant

Energy conversion technologies emit greenhouse gases (GHG) during construction (upstream) and operation (downstream). Furthermore, there are also emissions related to the extraction, refining and transport of fuels as well as from auxiliary energy needs. These emissions are also classified as upstream emissions. In order to reduce the GHG emissions from 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 to 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.

Dynamic approach for climate impact assessment

Assessment of climate impact of different energy scenarios is often only considering the downstream emissions. For accurate environmental impact assessments it is important to include emissions from the whole lifecycle. In this study we brought the environmental impact assessment one step further to include the timing of the emissions as well. A time-resolution of one year was used. Accordingly, we divided the life-cycle emissions into emissions from the construction phase and the operation phase. An extensive review of existing life-cycle assessments (LCA) was made to determine the emissions from the different phases. There is extensive data on operational emissions that do not vary significantly between different sources, whereas the emissions from the construction phase vary substantially, see Figure 1.

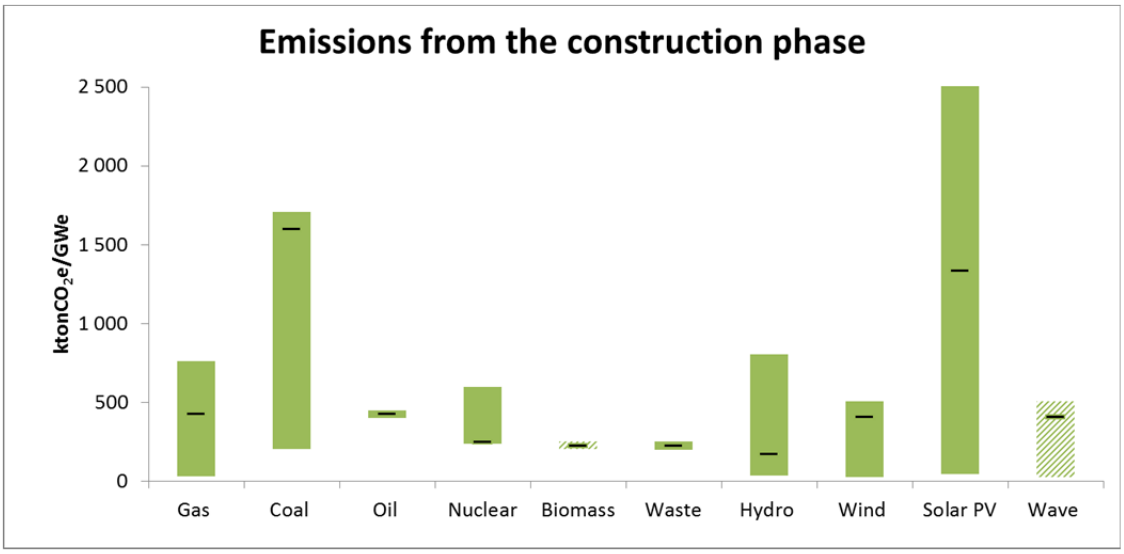

Figure 1. LCA-data from construction phase of various electricity production technologies. Dashed bars indicate poor data availability and that assumptions had to be made (biomass was assumed to have the same performance as waste and wave was compared to wind). The values chosen as default values in our calculations are marked with black lines. Note that these were chosen because they were considered to most accurately represent Nordic conditions. We are aware that there are large variations.

The emissions from the construction of the power plant are based on installed capacity. These emissions are assumed to evenly spread out during the construction of the power plant. The upstream operational emissions and downstream emissions are assumed to be spread out during the whole lifetime of the power plant and occur only if the power plant is operated and are consequently based on the power production in each scenario.

Investments in new capacity give rise to emission peaks

The results of the dynamic calculations of GHG emissions for all four NEPP scenarios are shown in Figure 2, where the curves represent GHG emissions per TWh to allow for comparisons between the scenarios in which the total power production varies. There are emission peaks in periods with large investments in new production capacity. For example large investments in new solar PV around the year 2030 give rise to emission peaks in the Green Policy scenario. In traditional LCA, these emission peaks would be spread out during the whole life-cycle and therefore probably be hidden by the operational emissions.

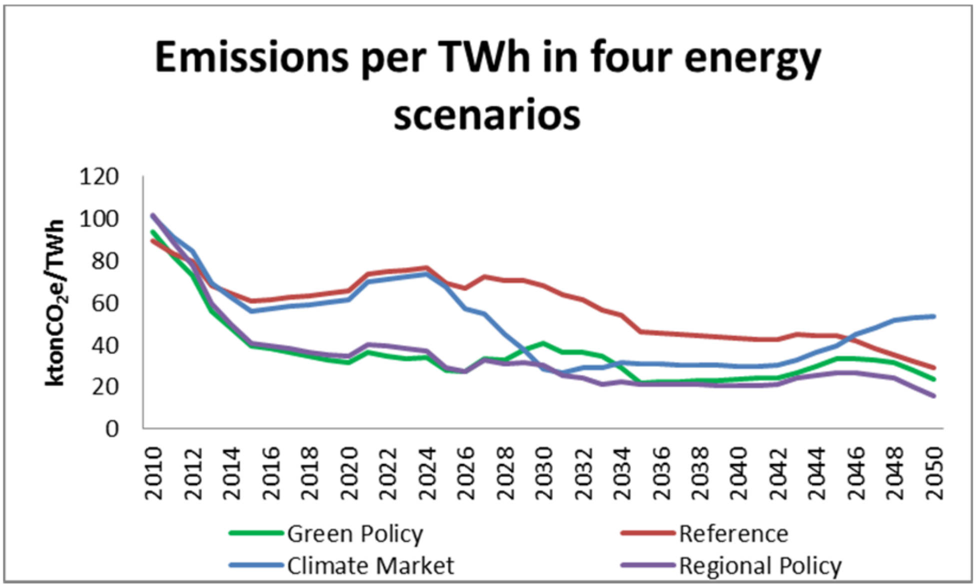

Figure 2. GHG emissions in four NEPP scenarios for the power sector.

The difference using traditional LCA methodology and the dynamic approach is illustrated in Figure 3, for the Green Policy scenario. The emissions are postponed with the traditional approach since the construction emissions are spread out during the whole life-cycle. The accumulated emissions are not equal until later in the century because investments occur during the whole period up to 2050 (with traditional LCA some of these emissions would occur after 2050). We also find that the combustion emissions dominate in all scenarios and that the total life-cycle emissions are around 20-50% higher than the combustion emissions.

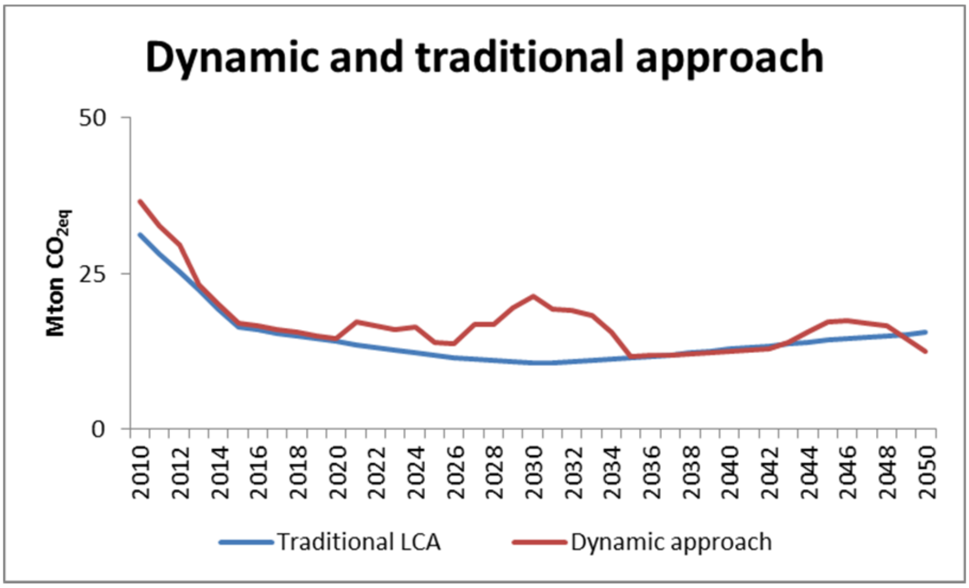

Figure 3. GHG emissions in the Green Policy scenario in the case of traditional LCA (whole life-cycle) and with the dynamic approach.

Inertia affects climate impact

For the climate it is crucial when the GHG emissions appear. The GHG emissions in the different scenarios are therefore used to calculate radiative forcing based on an IVL model. The model calculates the global average surface temperature change due to emissions scenarios. The model takes into account the inertia of the climate system, i.e. that it takes time before a change in atmospheric concentrations of GHG lead to a temperature change. The resulting change in temperature, both per year and accumulated, is shown in 4. The Regional Policy scenario gives rise to the lowest long term emissions and climate impact closely followed by the Green Policy scenario that shows slightly lower emissions in the medium term. Due to the inertia of the climate system it takes around 10 years before the climate impact of the Regional Policy scenario is lower than the Green Policy scenario.

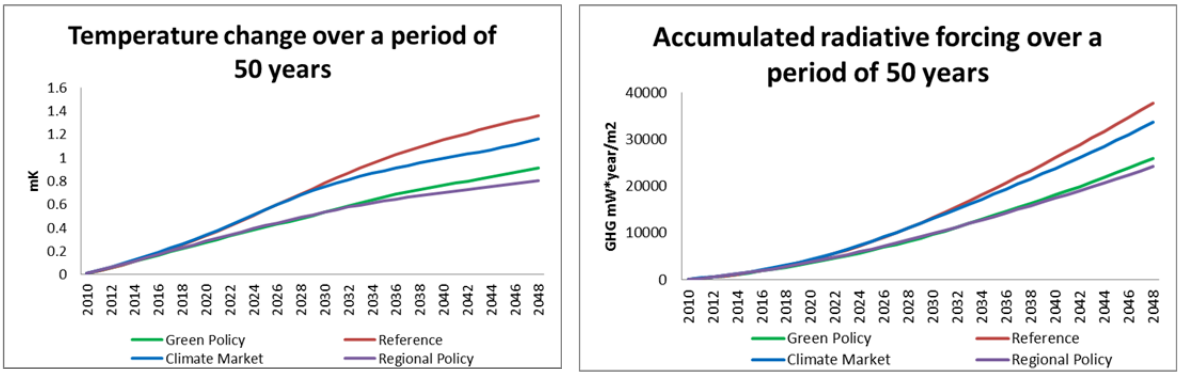

Figure 4. Temperature change and accumulated radiative forcing caused by the GHG emissions from the power production in the four studied NEPP scenarios. The calculations are based on emissions per produced electricity to allow for comparison.

Conclusions

The combustion emissions dominate in all the studied scenarios and the total life-cycle emissions are 20-50% higher than the combustion emissions. Power production technologies show different life-cycle performance. Emissions from renewable technologies dominate during the construction phase whereas the operational emissions are low. For fossil fuels, the emissions from combustion dominate.

By taking into account the timing of emissions, it is obvious that emission peaks occur during periods with high investments or re-investments. Traditional LCA will underestimate the emissions and climate impact in the short term and overestimate the long term impact. The timing of the emissions is important for the actual climate impact. If urgent climate mitigation is needed, it is therefore important to prioritise action with both short and long term emission reduction.

The emissions from the construction of technologies need to be further investigated as various LCA's show diverging results. The calculations shown in this synthesis report are based on values considered most relevant for Nordic conditions. More detailed analyses are needed for example regarding solar PV's in Nordic conditions.