Analysis of the required global energy system transformations and the associated macroeconomic implications in order to meet ambitious decarbonization targets.
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Motivation

• The Paris agreement in December 2015 codified aspiration to hold the increase in global average temperature to well-below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C.

• Such ambitious climate policies would significantly reduce the risks of climate change and, therefore, they can be considered safer guardrails.

• According to the report of IPCC (2014), the cumulative CO₂ emissions from 2011 to limit warming to less than 2°C and 1.5°C at different levels of probability are as below:

<table>
<thead>
<tr>
<th>Net warming/Probability</th>
<th>1.5°C</th>
<th>2°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 66%</td>
<td>400 GtCO₂</td>
<td>1000 GtCO₂</td>
</tr>
<tr>
<td>&gt; 50%</td>
<td>500-600 GtCO₂</td>
<td>1300-1400 GtCO₂</td>
</tr>
<tr>
<td>&gt; 33%</td>
<td>700-900 GtCO₂</td>
<td>1500-1700 GtCO₂</td>
</tr>
</tbody>
</table>

• Despite the presence of climate policy measures in some world regions, progress in the implementation of concrete world-wide decarbonization policies has been slow. Therefore, it is essential to study how a further delay of cooperative action closes the window for achieving the targets.

Objectives

- This study identifies the feasible solution space for achieving the described decarbonization targets.
- It investigates in a systematic manner the required global energy system transformations and behavioral changes in order to meet the feasible targets.
- For a comprehensive analysis, macroeconomic implications of the implemented mitigation policies are taken into account.
- To emphasize on the urgency of reaching a more practical global climate agreements, impacts of a further delay in taking emission reduction action are evaluated.
Methodology: TIAM-MACRO

- Adapted by Kypreos and Lehtila (2013) to link multi-regional TIMES models (e.g., TIAM) with the MACRO model.

Analysis of the required global energy system transformations and the associated macroeconomic implications in order to meet ambitious decarbonization targets
Scenario definition

- Based on our current knowledge of future technological and economic development, the feasibility of the decarbonisation targets can be summarized here:

<table>
<thead>
<tr>
<th>Start year (Delay action)</th>
<th>1.5°C</th>
<th>2°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>66%</td>
<td>50%</td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2040</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Accordingly, following scenarios can be considered:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>• No major CO₂ reduction policy</td>
</tr>
</tbody>
</table>
| WB2DS    | • Carbon budget: 1000GtCO₂; insuring the 2°C target with a probability of more than 66%  
          • Start year: 2020 |
| 2DS      | • Carbon budget: 1400GtCO₂; insuring 2°C with a probability of more than 50%  
          • Start year: 2020 |
| 2DS-D    | • Carbon budget: 1400GtCO₂; insuring 2°C with a probability of more than 50%  
          • Start year: 2030 |
The fuel mix in the decarbonisation scenarios in 2100 is substantially different from the current mix, with the share of renewables increasing from 14% in 2020 to 58% in the 2DS, 63% in the 2DS-D and 65% in the WB2DS.

While fossil-fuels remain the leading energy carrier in the Base scenario, reliance on fossil fuels in the decarbonisation scenarios dramatically falls from 81% in 2020 to 11% in the WB2DS, 12% in the 2DS-D and 15% in the 2DS.
Final Energy Consumption by energy carrier and sector

- Fossil fuels dominate in the Base scenario dominate the final energy carriers, final energy consumptions in the 2DS and WB2DS reflect the significant role of electrification of end-use sectors. The share of electricity and heat in cumulative final energy consumption increases from 24% in the Base to 43% in the 2DS and 47% in the WB2DS.

- The cumulative final energy consumption in the 2DS is 18% and in WB2DS is 22% lower than the Base. Major efficiency improvements and service-demand reductions are experienced in the Industry sector.
Coal remains the leading source of electricity in the base scenario, in the 2DS scenario conventional coal power plants are almost completely phased-out by 2040.

Bio-CCS 13% share turns the global electricity mix into a source of negative carbon emissions over the period of 2050-2100.

The rapid deployment of variable renewable electricity (VRE) sources in the 2DS scenario, reaching a share of 43% in 2100, will need to be enabled by increasing system flexibility.
Changes in the electricity generation between the WB2DS and the 2DS

- Initially the WB2DS leads to a lower generation from fossil fuels without CCS, compensated mainly by other renewables, gas with CCS and biomass with CCS.

- More stringent carbon budget constraint, lead to less fossil fuel with CCS and more biomass with CCS especially after 2070. This is due the fact that remaining CO₂ emissions from fossil-fuel CCS technologies make them less attractive than the biomass with CCS.

- After 2040, the increasing electricity demand in the WB2DS scenario is mainly covered by other renewables, nuclear and biomass with CCS.
Critical role of bioenergy

More stringent carbon budget constraint increases the need for bioenergy with CCS. Recognizing its key mitigation role and constrained availability of sustainable biomass, the development of integrated systems to support highly efficient production and consumption of biomass will be crucial.
While in the 2DS, the energy system reaches carbon neutrality by almost 2080, in the 2DS-D and the WB2DS it happens 10 years earlier in 2070.

In the 2DS, 51% and in the WB2DS, 69% of the total CO2 budget is expected to be used up by 2030. This denotes the importance of short-term measures.
In all scenarios renewables dominates the other measures. Hence, renewables can be considered as the backbone in the transition to a decarbonized energy system.

Energy-service demand reduction seems to be necessary for reaching ambitious climate policies.
Investment needs in the power sector

- Renewables (excluding biomass CCS) with a share of around 67% of the cumulative investments in the period of 2020-2100, dominate in all the decarbonization scenarios the future investments in the power sector.

- Investments in fossil CCS and biomass CCS represent around 16% of the cumulative investments, while nuclear account for around 13%.

- Compared to the 2DS case, cumulative investments over the period 2020-2100 increase by 14% in the WB2DS and 6% in the 2DS-D.
Macroeconomic implications of the decarbonization scenarios

- GWP losses are notably higher in the 2DS-D (5.4% in 2100) than in the 2DS (4.6% in 2100), once more highlighting the importance of early action.
Conclusions

• Based on our current knowledge of technological and economic developments, reaching the decarbonization targets seems to be barely feasible and implies huge macroeconomic impacts.

• Renewables (excluding bioenergy) will be the backbone of the decarbonized energy systems. However, rapid deployment of variable renewable electricity (VRE) sources will need to be enabled by increased system flexibility.

• The availability of sustainable bioenergy supply sources, and carbon storage sites are two key factors for Bioenergy with CCS.

• Decarbonizing power generation and allowing electricity to substitute fossil fuels in inflexible energy sectors (e.g., mobility) is recognized as a cost-effective mitigation strategy.

• Delaying action by 10 years will imply considerably higher direct and general equilibrium costs.
Vielen Dank!

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Main model assumptions
The delay leads in the early years to higher CO₂ emissions compared to the 2DS, which are being offset by lower emissions in the period after 2040 to stay within the same carbon budget limit as in the 2DS.

Higher carbon budget in the WB2DS leads to lower emissions in the whole time horizon, starting from 2020.

Delaying action by 10 years will lead to around 50% higher marginal abatement costs by 2100.

More ambitious carbon budget constraint in the WB2DS will double the marginal abatement costs by 2100.
Electricification of final consumption and decarbonization of the power sector

- Decarbonizing power generation and allowing electricity to substitute fossil fuels in inflexible energy uses (e.g. mobility) is a cost-effective decarbonisation strategy.
- Delaying action implies more rapid decarbonization of the power sector and higher contribution of the electricity in the final energy consumption.
Estimates for renewables global potential over the century

Analysis of the required global energy system transformations and the associated macroeconomic implications in order to meet ambitious decarbonization targets
Realizable potential of renewables

- The realized potential for each renewable type is calculated based on following two points:

1. The whole estimated potentials can be reby the end of the century.

2. The realized potentials until 2050 are given according to the following studies:

- IEA Technology Roadmap Solar PV (2014)
- IEA Technology Roadmap Solar Thermal (2014)
- IEA Technology Roadmap Geothermal (2012)
- IEA Technology Roadmap Hydro (2012)

* Here only geothermal for power production is considered.
Analysis of the required global energy system transformations and the associated macroeconomic implications in order to meet ambitious decarbonization targets.
### CO₂ storage potential (Gt) (optional)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>Best estimate</td>
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<tr>
<td>Coal beds</td>
<td>3.5-200</td>
<td>150-250</td>
<td>176</td>
<td>267</td>
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<tr>
<td>Saline Aquifers</td>
<td>1000-10000</td>
<td>200-200000</td>
<td>9530</td>
<td>240</td>
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<tr>
<td>Oil &amp; Gas Fields</td>
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<td></td>
<td></td>
<td>1153</td>
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<tr>
<td>Depleted</td>
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<tr>
<td>Gas</td>
<td>675-900</td>
<td>500-1000</td>
<td>700</td>
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<td>672</td>
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<td>Including undiscovered reserves</td>
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<td>-</td>
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</tr>
<tr>
<td>Oil</td>
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<td></td>
<td></td>
<td>149</td>
</tr>
</tbody>
</table>

- For this study we used the ‘best estimate’ of ecofys (Hendriks et al., 2004).
- Due Public resistance against onshore storages, they are excluded.
- The assumed cumulative CO₂ storage is thus 748 Gt.

![Pie chart](chart.png)

**Legend:**
- Enhanced Oil Recovery (offshore)
- Depl oil fields (offshore)
- Depl gas fields (offshore)
- Enhanced Coalbed Meth recov <1000 m
- Enhanced Coalbed Meth recov >1000 m
- Deep saline aquifers (offshore)
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