MODELING LARGE SHARES OF RENEWABLES IN A GLOBAL ENERGY SYSTEM MODEL

GENeSYS-MOD – An application of the Open-Source Energy Modeling System (OSeMOSYS)

Claudia Kemfert, Konstantin Löffler, Karlo Hainsch, Thorsten Burandt, Pao-Yu Oei

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1. Introduction
2. GENeSYS-MOD: The Global Energy System Model
3. Results
4. Conclusion

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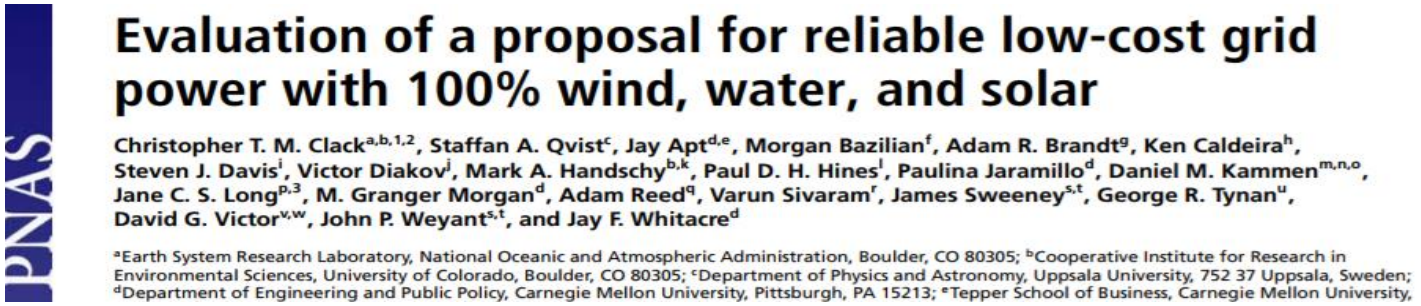
Introduction

1 Current Debate

- Traditionally, energy system model predictions in line with ambitious climate targets relied on fossil fueled power plants equipped with carbon capture and nuclear plants to balance intermittent renewables energy sources.
- The future outlook for conventional energy carriers, however, is now challenged by the availability of low-cost storage technologies and other flexibility options.
- This leads to the recent controversy about the reliability of renewables-based energy:
  - Critical evaluation by Clack et al. (2017):



  - Direct defense by Jacobsen et al. (2017):

1 Classification of Energy System Models

Techno-Economic Optimization Model

- Long-term approach to identify challenges and developments in the broader picture of climate change.
- E.g.:
  - MARKAL/TIMES family of models (NEMS, PRIMES, or MESSAGE)
  - OSeMOSYS, KTH and GENeSYS-MOD, TU Berlin

Macroeconomic Simulation Model

- Designed to replicate the functioning of specific energy markets, without being bound to some predefined, theoretical structural form.
- E.g.:
  - World Energy Model, IEA
  - POLES, University of Grenoble

Techno-Economic Partial Equilibrium Model

- Commonly focus on energy demand and supply markets, allowing for a broader representation of technological aspects.
- Try to bridge the gap between techno-economic and macroeconomic models.
- Improvements of existing optimization models

Computable General Equilibrium Model

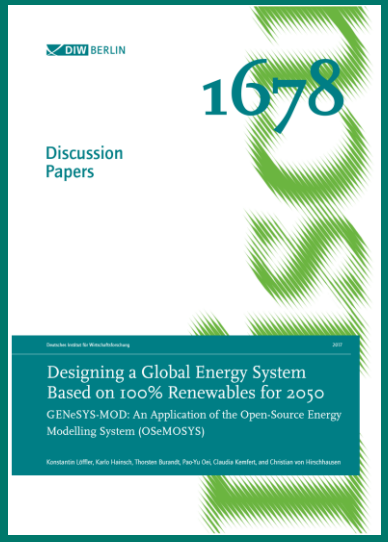
- Assuming a certain market structure, and dynamic of the economy and adding a particular level of technological detail.
- E.g.:
  - EPPA-model, MIT

Introducing:

...a sector-integrated, global, open-source energy system model based on the Open Source Energy Modeling System (OSeMOSYS)

2

GENeSYS-MOD: The Global Energy System Model



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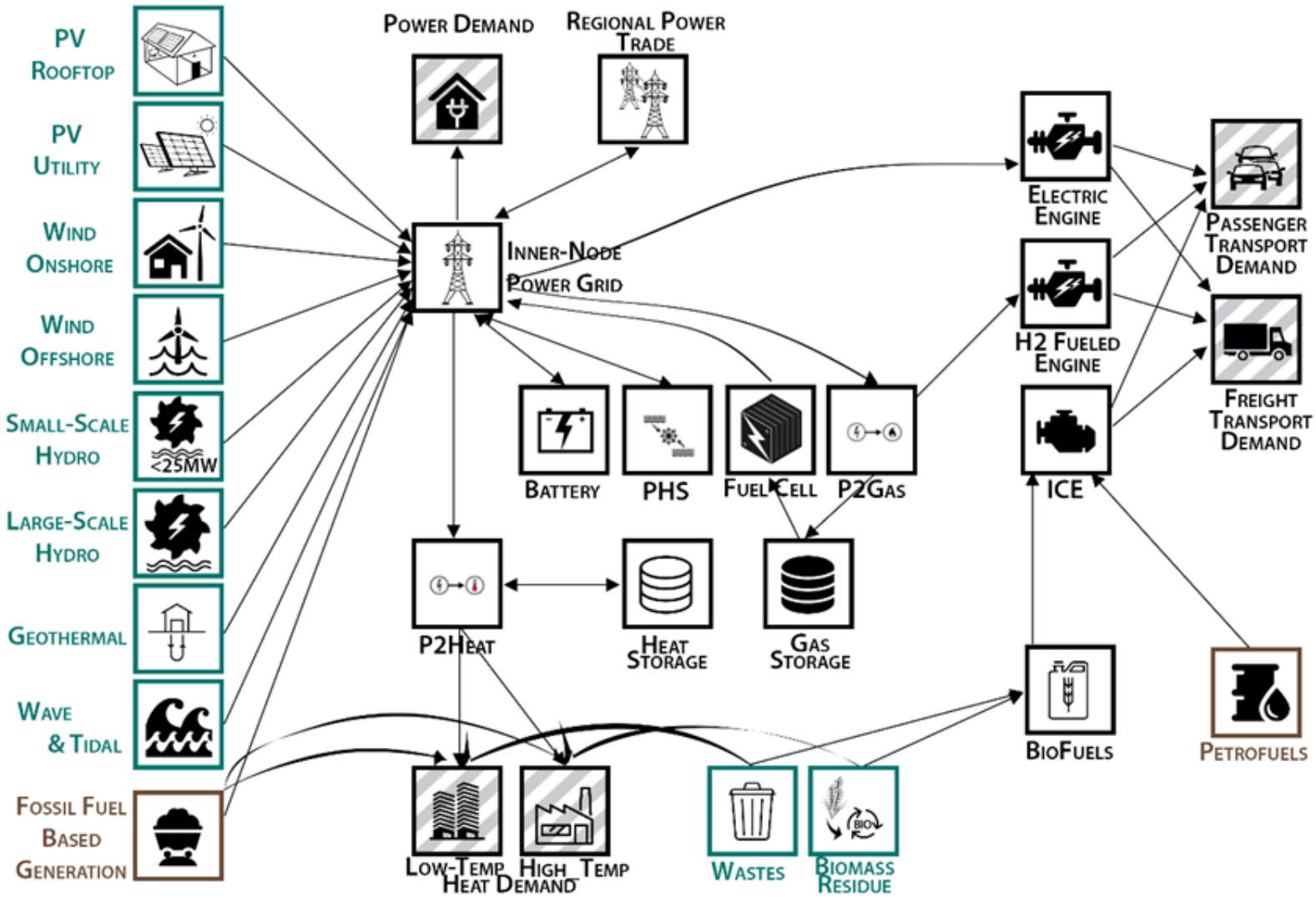
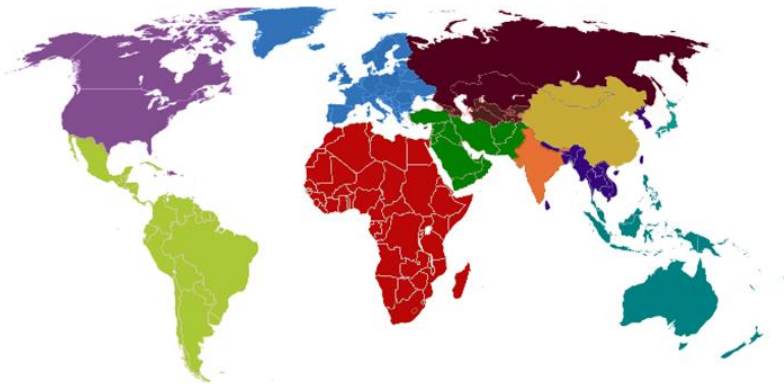
3 Model Design & Technologies



3 Key Data Input for the model

- 10 regions
  - Potentials for Solar and Wind are split up into multiple sub-categories
  - Trading of resources is possible



- Time horizon: 2015 – 2050, in 5 year steps with 2015 as baseline with existing capacities
- Includes the entire energy system with an exogenously set demand for electricity, heat and transport in each region
- Fossil fuel prices are taken from the IEA 450ppm scenario datasets (WEO; 2015)
- The model considers six time slices
  - Three seasons: Winter, Intermediate, Summer
  - Each with a day/night cycle

Scenario Definition: Taking the Paris Agreement seriously

2° Celsius: Looking for the cheapest transition pathway to be in line with the 450ppm climate target

- Global carbon budget of **920** Gt CO_2
- Consistent with the IEA 450ppm scenario setting

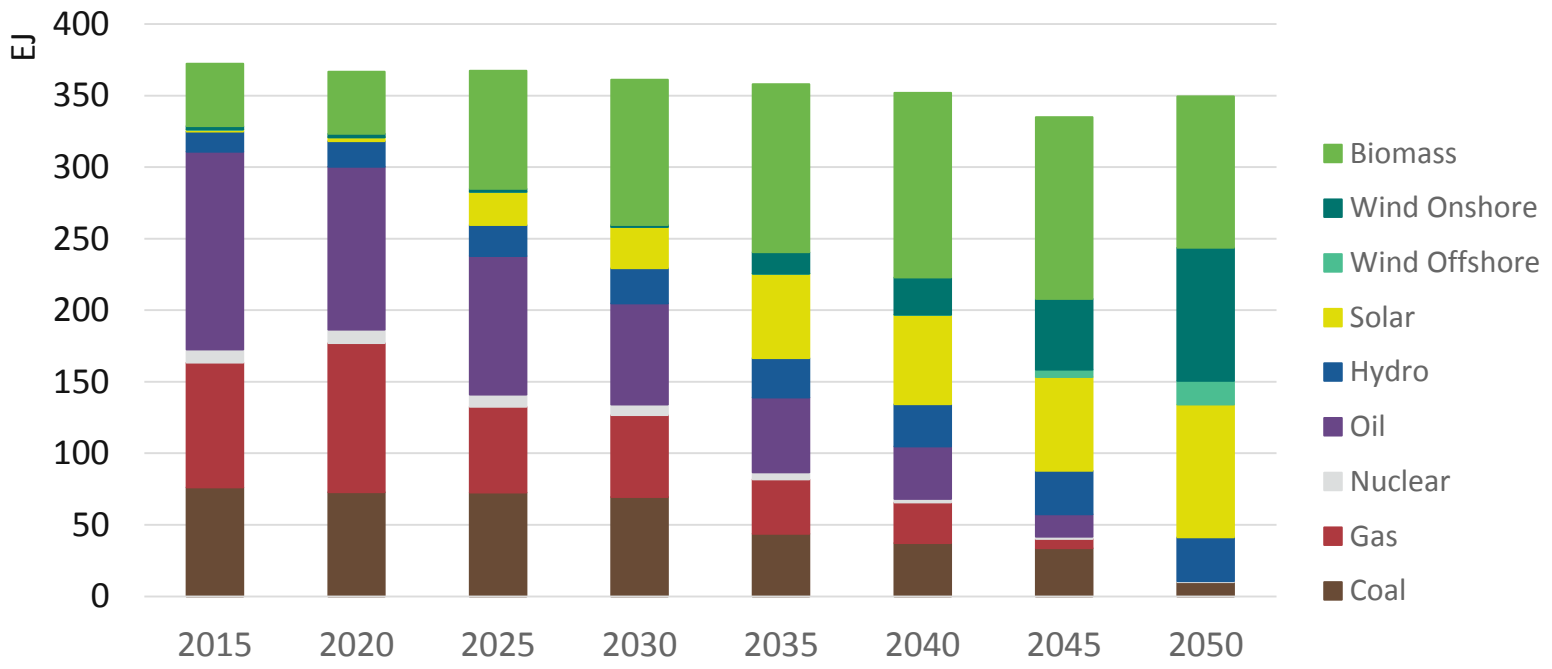
1.5° Celsius: Examine additional costs for reaching the Paris Agreement with an energy system based on 100% Renewable Energy Sources (RES)

- Reduced carbon budget of **650** Gt CO_2
- Constrained to 100% renewable energy in 2050, across all sectors

4

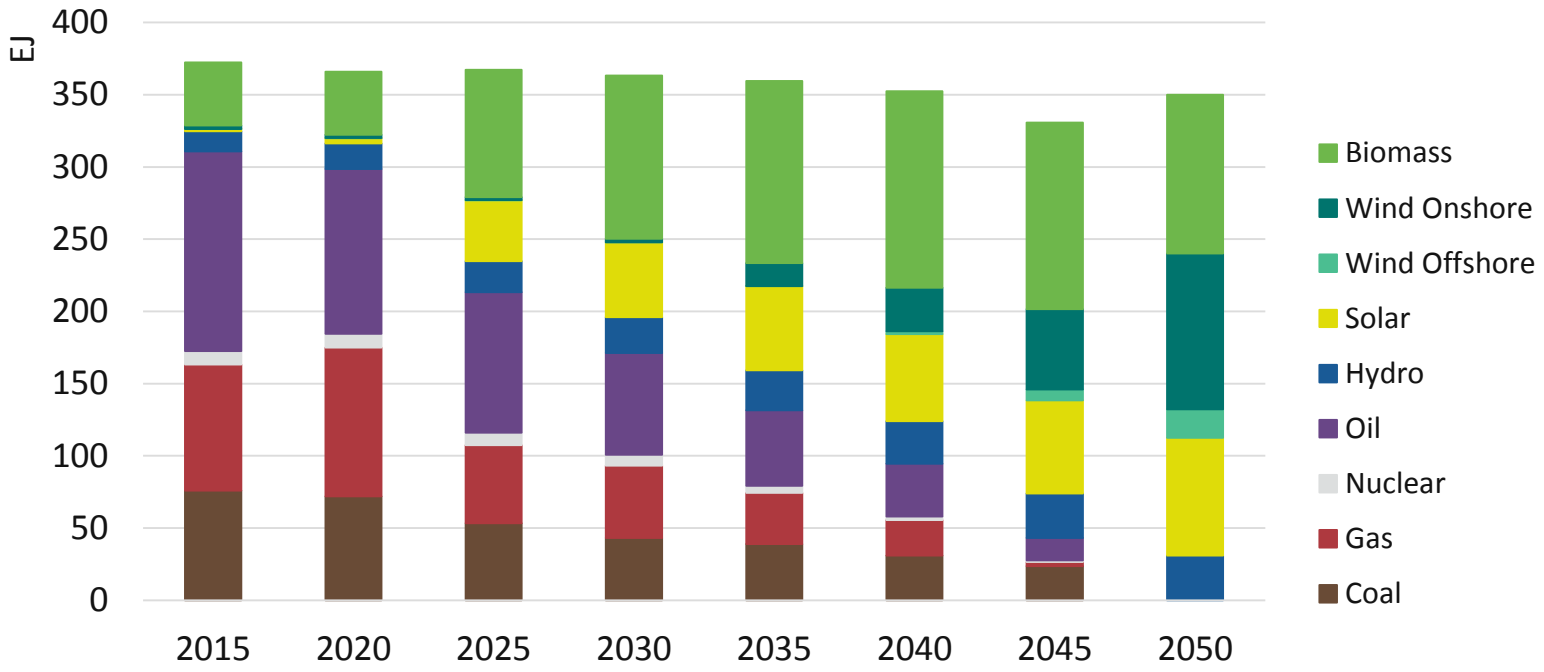
Model Results

4 Resulting Energy Mix [Final Demand – 2° Celsius]



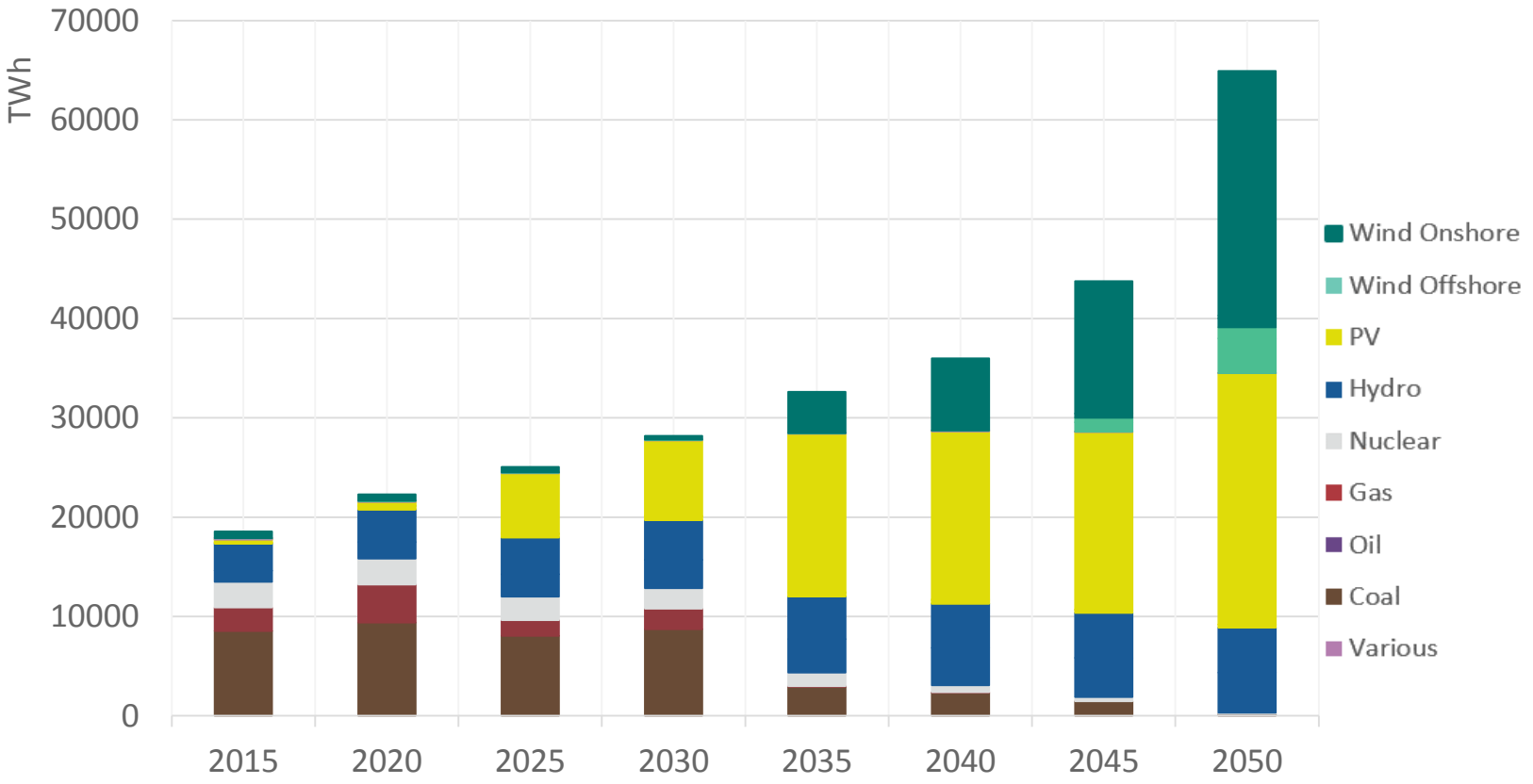
- A gradual movement towards RES can be seen, with cheap solar potentials being utilized first.
- In the 450ppm scenario, ~95% of the energy system is decabonized by 2050.

4 Resulting Energy Mix [Final Demand – 1.5° Celsius]



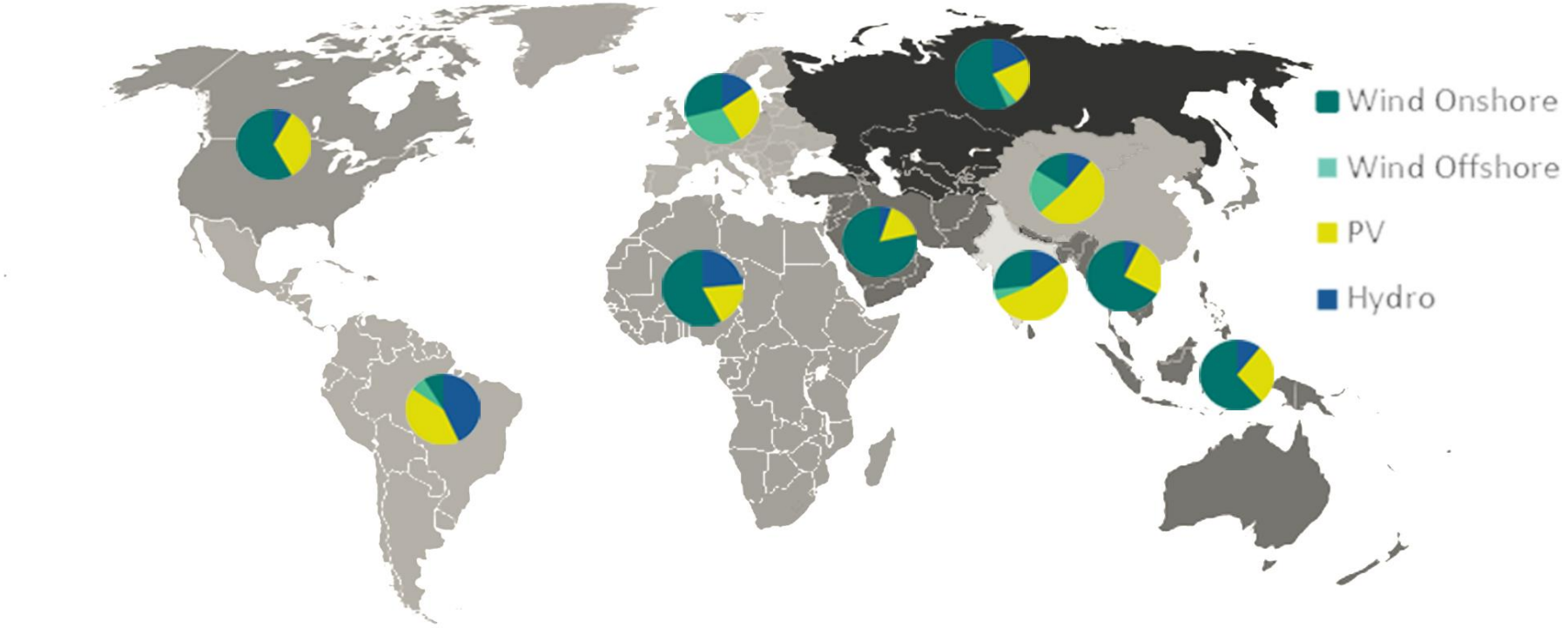
- In the 100% RES scenario, a faster change towards renewables can be observed.
- Also, coal usage is being reduced early on.
- Overall: very little difference between scenarios.

4 Development of Power Generation [2° Celsius]



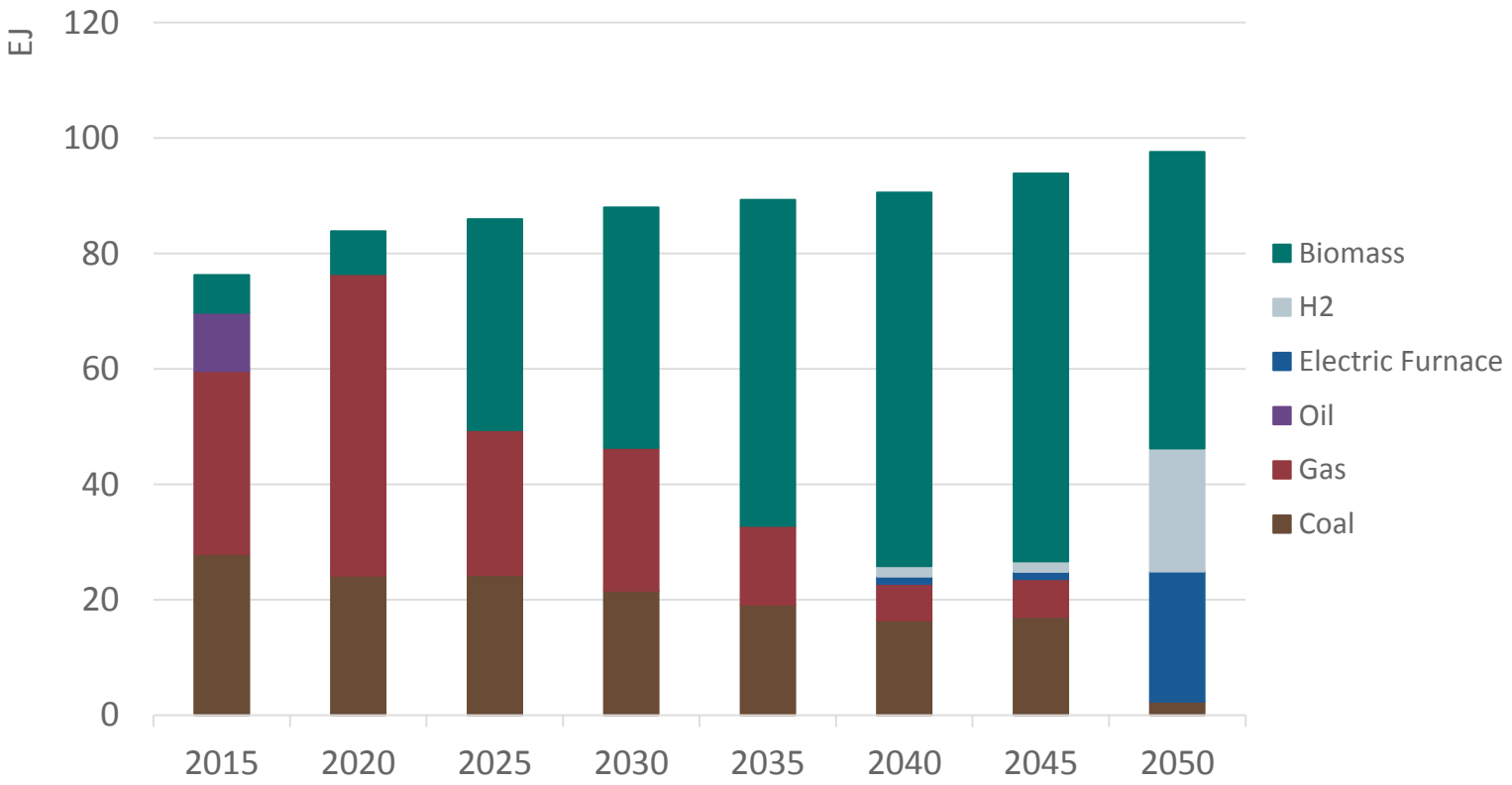
- The power sector is the first to be largely decarbonized, with a tipping point in 2035 in the 450ppm scenario.

4 Power Generation Profiles in 2050 in the 1.5° Celsius Scenario



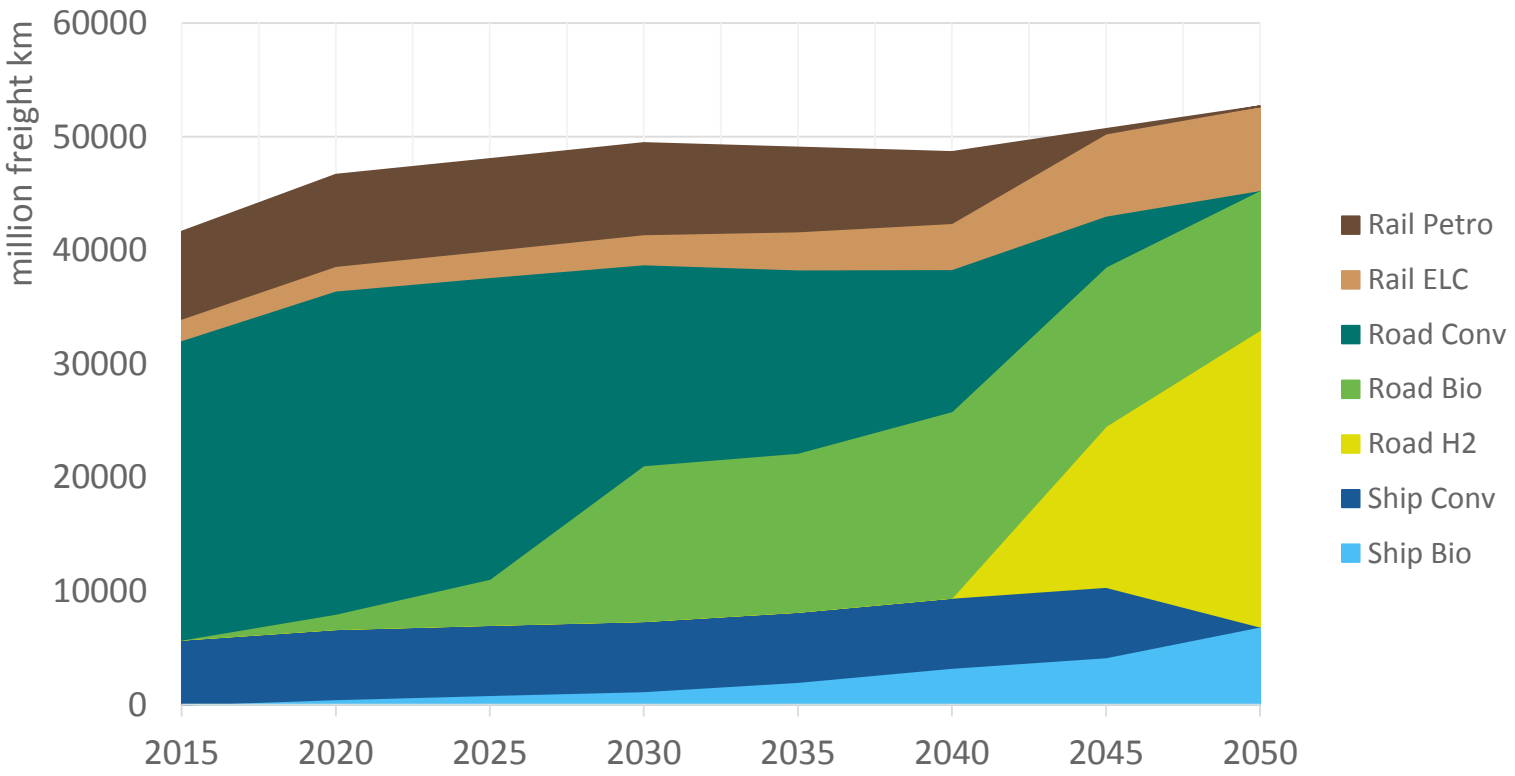
- Different regions and their potentials lead to vastly different generation profiles.

4 Development of high-temperature Heat production [2° Celsius]



- In the heating sector, fossil fuels play a much larger role for a longer time period.

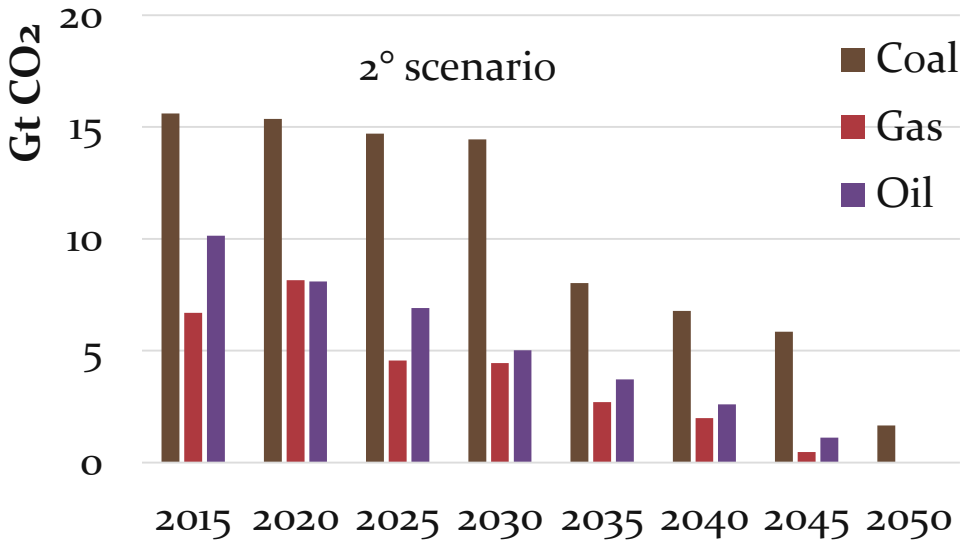
4 Development of Freight Transport 2° Celsius Scenario



- Road-based freight transportation sees an early rise in biofuel-fueled trucks, shifting towards hydrogen in the later modeling periods.

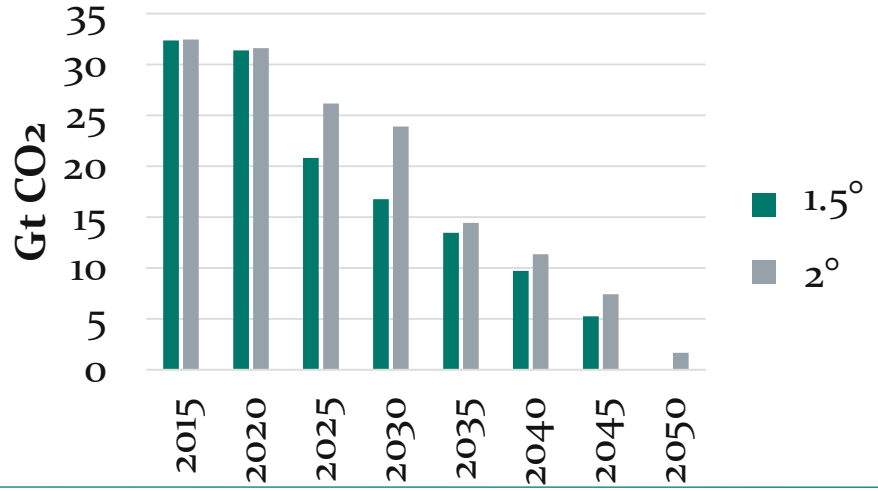
4 CO_2 Emissions

- Coal is making up the largest share of emissions
- Natural gas sees an increased use early on, and a slow decline afterwards.

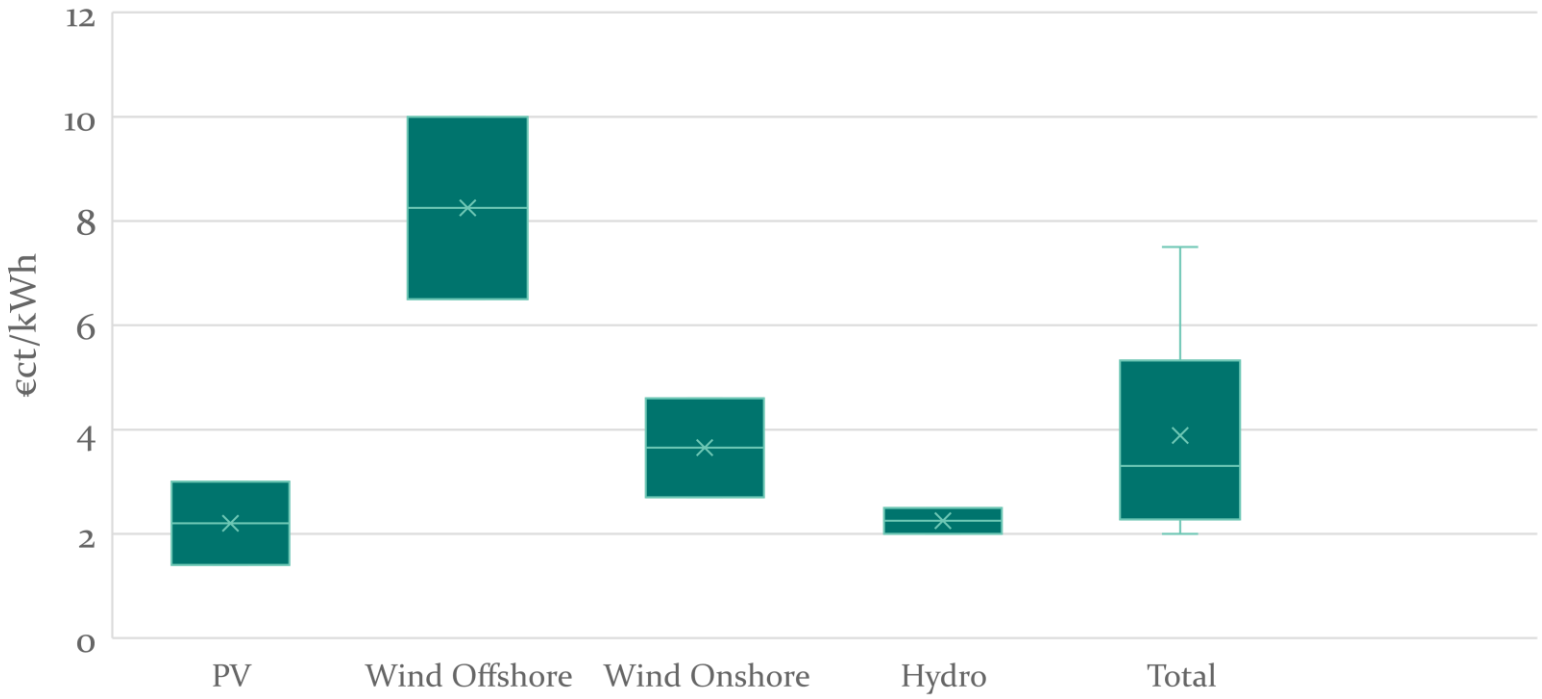


Switching from 2° to 1.5° Celsius

- ~30% less CO_2 has to be emitted in 2025 and 2030
- smaller share of coal in the energy mix, especially in the heating sector
- Only minor cost increases of an energy system for 1.5°



4 Costs of Power Generation in 2050 in the 1.5° Celsius Scenario [€ct/kWh]



- The average costs of electricity generation in 2050 are ~4 **ct/kWh**, showing that, given our results, a system largely based on renewables is economically viable.
- This does, however, does not include any infrastructure or system costs.

4 Key Insigts from Sensitivity Analysis

- Fuel prices: Constant fuel prices, instead of rising prices as projected in IEA WEO 2015, are leading to a higher share of natural gas in the final energy mix
- Storage costs: Halved or doubled storage costs have little to no impact on the optimal energy mix
- PV prices: The prices for PV modules are having a large impact on the share of solar PV in the final energy mix. With double PV prices, offshore wind and biofuel based power generation are becoming the backbone of the energy system

5

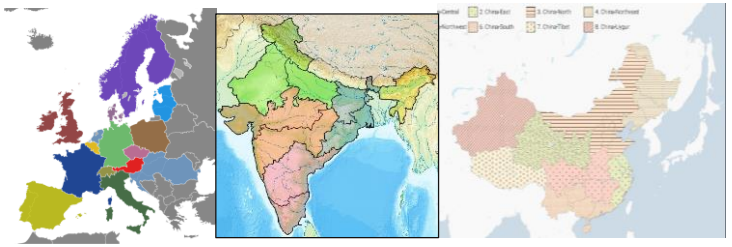
Conclusion

5 Conclusion

- A global energy system largely based on renewable energy sources for the sectors power, heat and transport is technically possible and can be achieved at low cost.
- Energy transformation in the power sector is the easiest and cheapest, and it is thus the first to complete the shift towards renewables.
- A strong sector coupling between both the heat and transportation sectors with the power sector can be observed.
- The main energy carriers utilized in our model results are wind and solar for all sectors, supported by biomass especially in the heating and transport sector.
- Wind is largely used as a resource in northern regions, while the south is dominated by pv coupled with more storage capacities.

5 Further Research

- Modular extension of the existing global model with detailed regions (Europe, India, China, …)



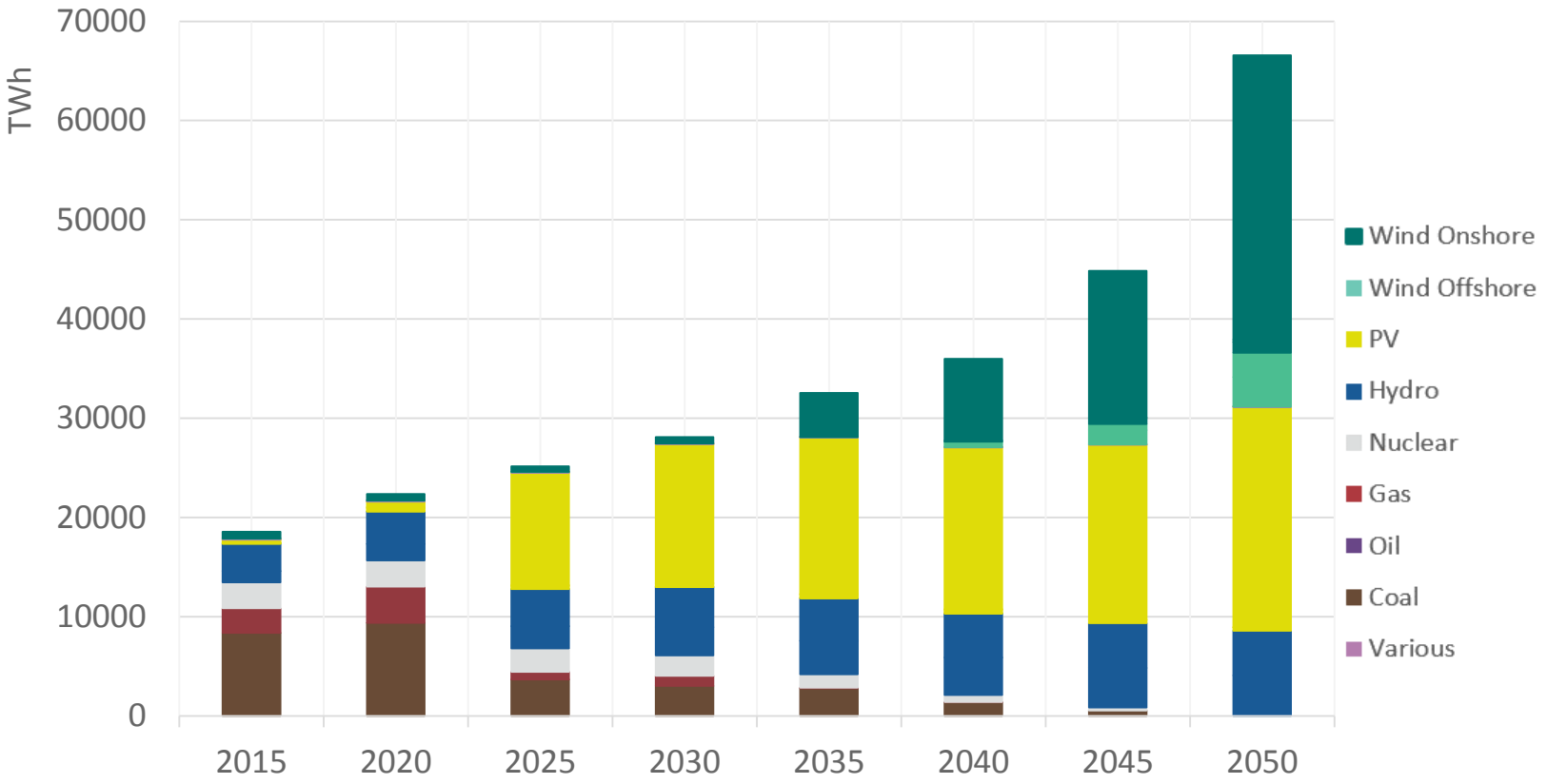
- Improvement of time disaggregation
- Inclusion of infrastructure aspects, such as costs, and endogenous grid expansion
- Publication of the current GAMS version of OSeMOSYS as official part of the OSeMOSYS-framework. Frequent updates and exchange between versions. Support of our GAMS version in the official forums.
- Plans to do joint work on an extension of the storage equations to enable a more detailed storage system.
- Exchange with the IPCC for submitting the results to the scenario database for the 2018 „Special Report on Global Warming of 1.5° C“

Thank you for your attention.

DIW Berlin — Deutsches Institut für Wirtschaftsforschung e.V.
Mohrenstraße 58, 10117 Berlin
www.diw.de

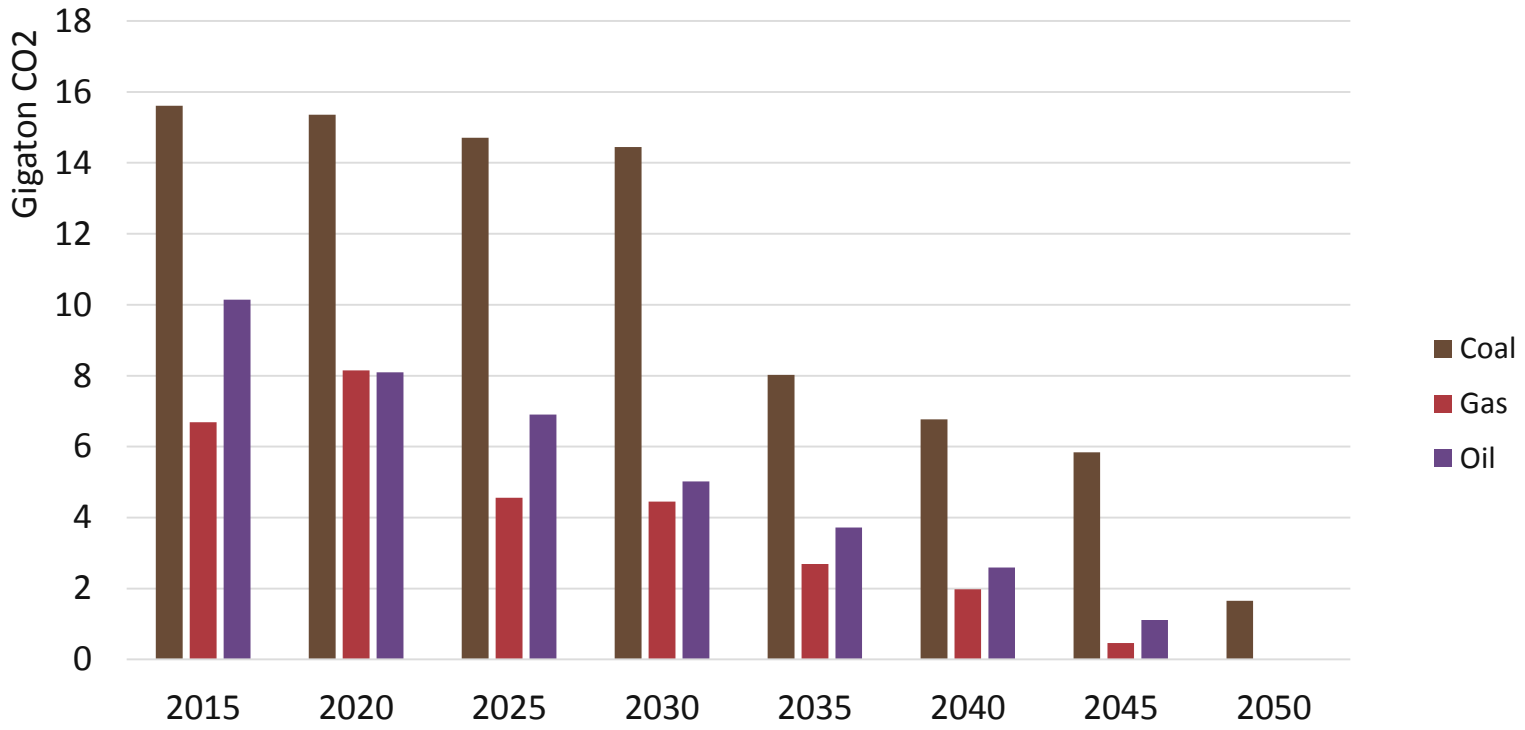
Speaker
Pao-Yu Oei; poei@diw.de

4 Development of Power Generation [1.5° Celsius]



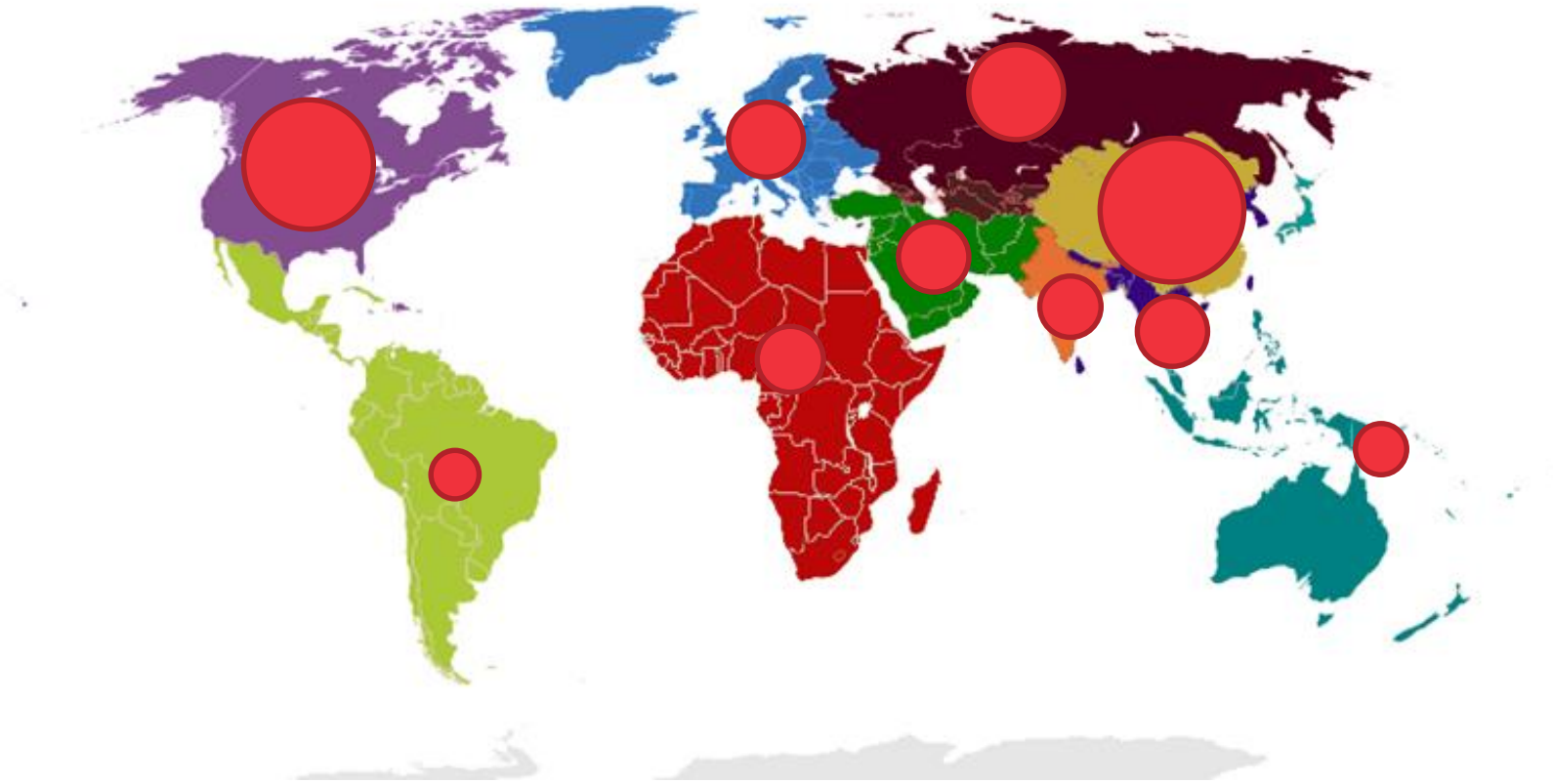
- In the 100% RES scenario, the shift towards renewables in the power sector happens as early as 2025.

4 Emission Pathway [2° Celsius]



- Coal is making up the largest share of emissions and continues to do so, being employed as late as 2050.
- Natural gas sees an increased use early on, and a slow decline afterwards.

4 Share of Total Global CO_2 Emissions from 2015 to 2050 in the 1.5° Celsius Scenario



Data: Own calculations; Image: Own illustration, based on https://upload.wikimedia.org/wikipedia/commons/thumb/0/06/CallingCodesWorld-Labeled.svg/

Economics of Energy and Environmental Policy Journal – Call for Papers
Special Issue: Access to Electricity: Global Experience and Future Directions

Submission Deadline: January 15th , 2018

Pre-submission inquiries welcome.

Please contact Valerie Karplus at vkarplus@mit.edu or EEEP editorial office eeep@iaee.org

- We invite **original**, **unpublished** submissions of 5,000-7,000 words in length (including captions and references).
- Papers should be **technically rigorous in nature** and **accessible to a policy audience** (e.g. very few or no equations).
- Papers on the economics of energy access and its relationship to low carbon agendas are encouraged.
- Country-specific or comparative studies are welcome, with an eye to identifying the potential and limits of any identified best practices.

Journal Rating (2016):
Impact Factor: 1.297
5 Year impact factor: 2.211
Article Influence Score: 1,057

Selected References

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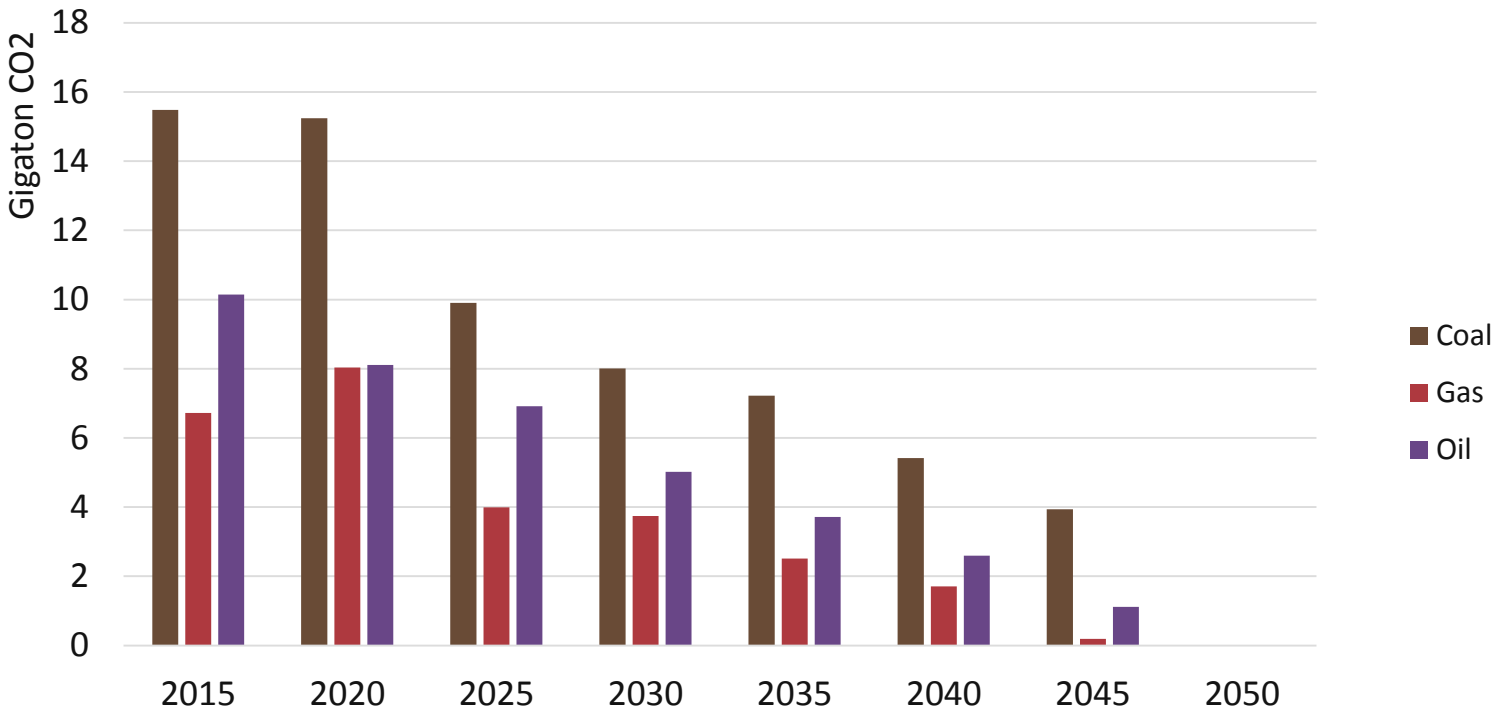
Back-Up Slides

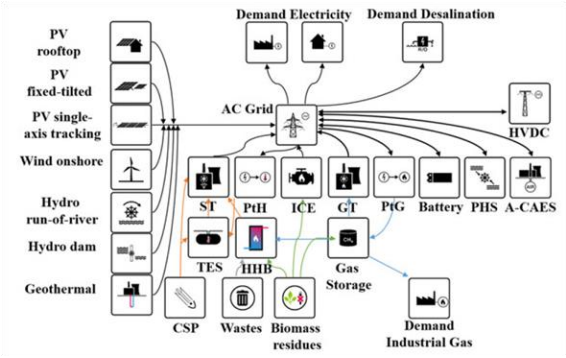
4 Emission Pathway [1.5° Celsius]



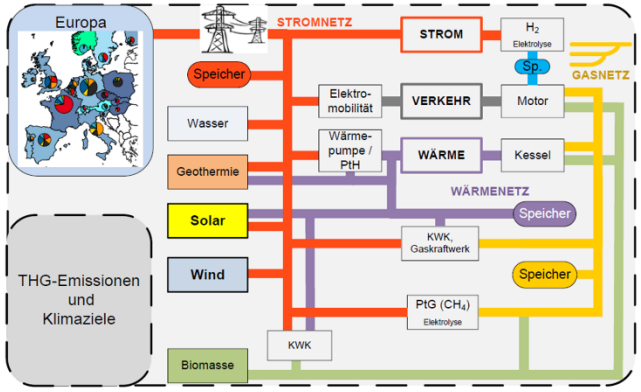
- In the 100% RES scenario, coal emissions are reduced much earlier.
- The emissions in 2050 are zero.

Introduction – Backup

- By offering a modeling framework, energy system models pose powerful tools for scientific research, especially considering the growing debate about decarbonization.
  - Most current work focuses on either sector-specific decarbonization (e.g. electricity), have a limited time-horizon, or only assume low amounts of decarbonization.



Source: Breyer, et al. (2017)



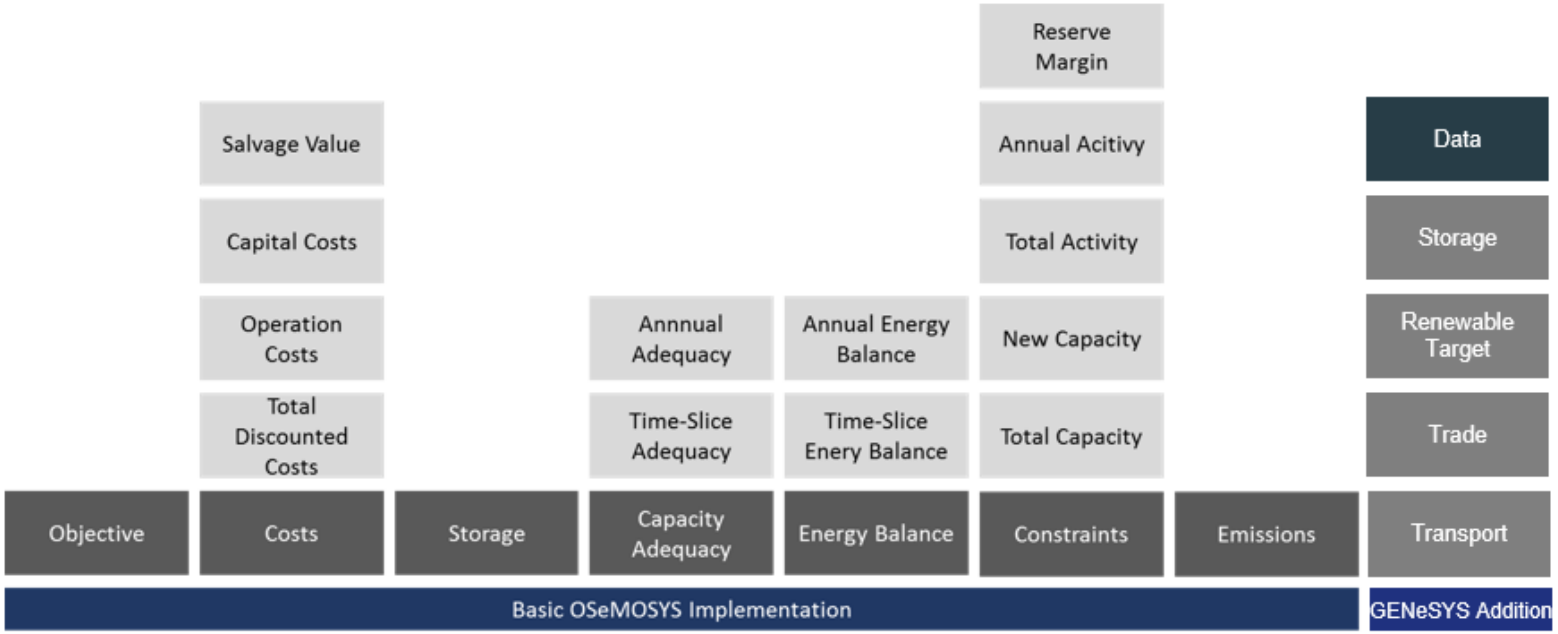
Source: Fraunhofer, et al. (2015)

2 From OSeMOSYS...

- OSeMOSYS:
  - Cost-optimizing Linear Program (LP)
  - Open-source energy systems model
  - Mainly developed by KTH in Stockholm (Howells et al. 2011)

- GENeSYS-MOD...
  - ...offers a fully translated GAMS version of OSeMOSYS.
  - ...enhances the OSeMOSYS framework with multiple additional features.
  - ...is being made publically available to the community with both code and model data.

2 ...to GENeSYS-MOD: Blocks of Functionality



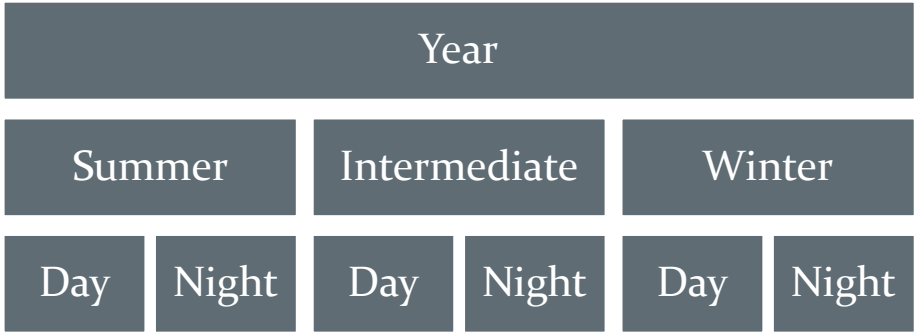
Main improvements of GENeSYS-MOD include:

- a fully reworked trade system
- a new transportation block, introducing a modal split
- endogenous calculation of storage capacities

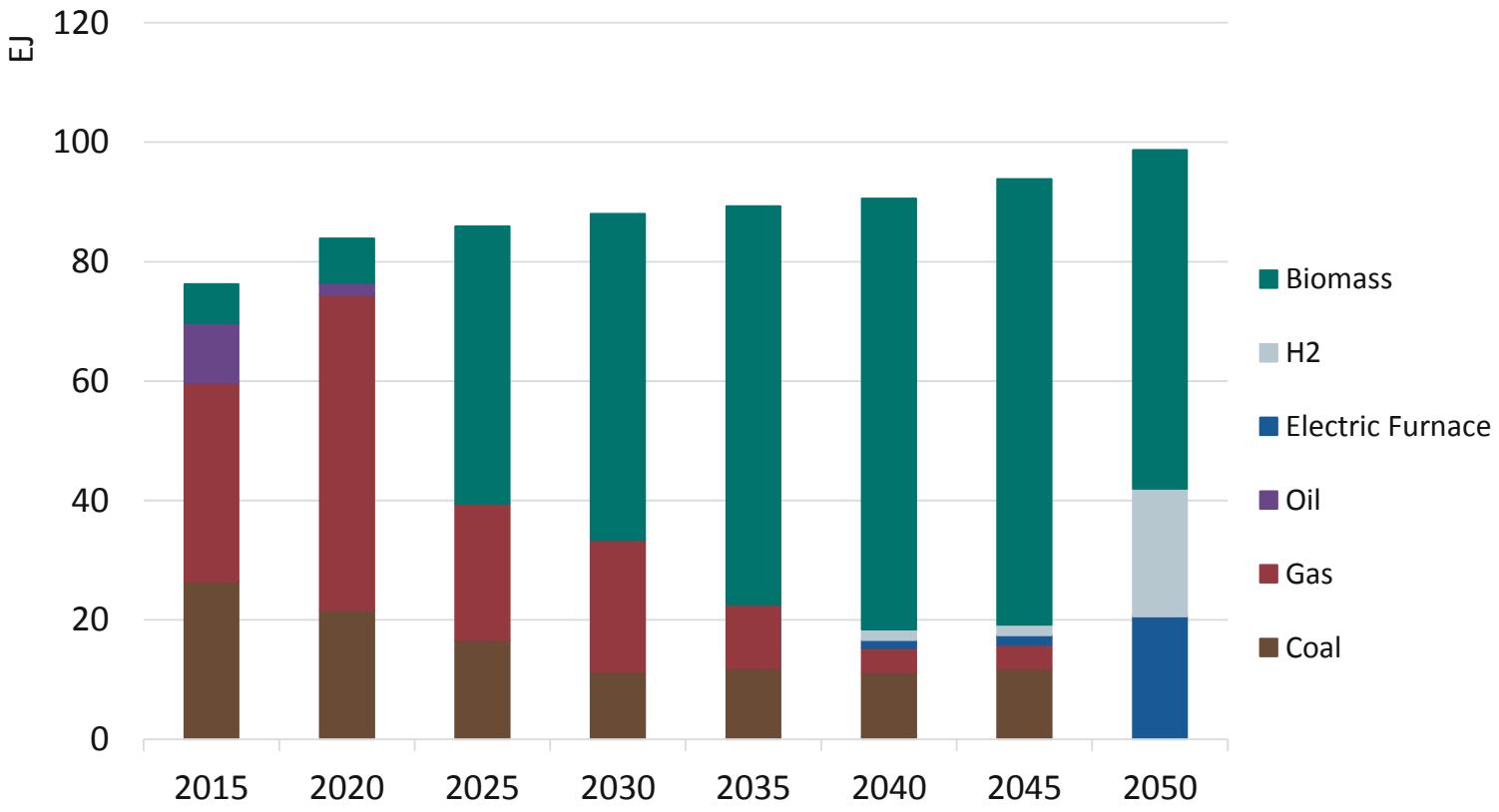
Time disaggregation in our Model

Yearly Disaggregation in Time Slices

Current Time Disaggregation in our Model:

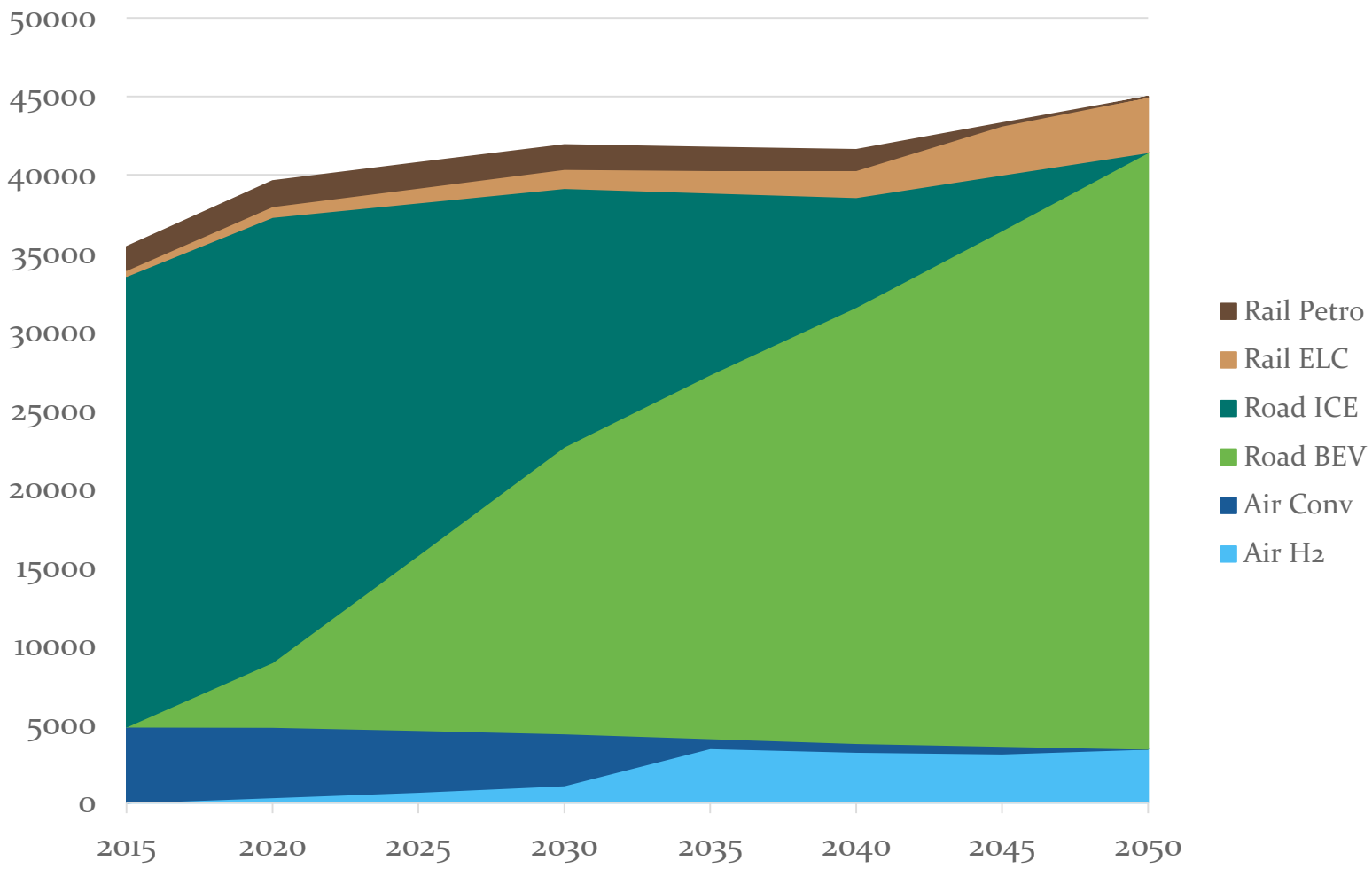


4 Development of high-temperature Heat production [1.5° Celsius]

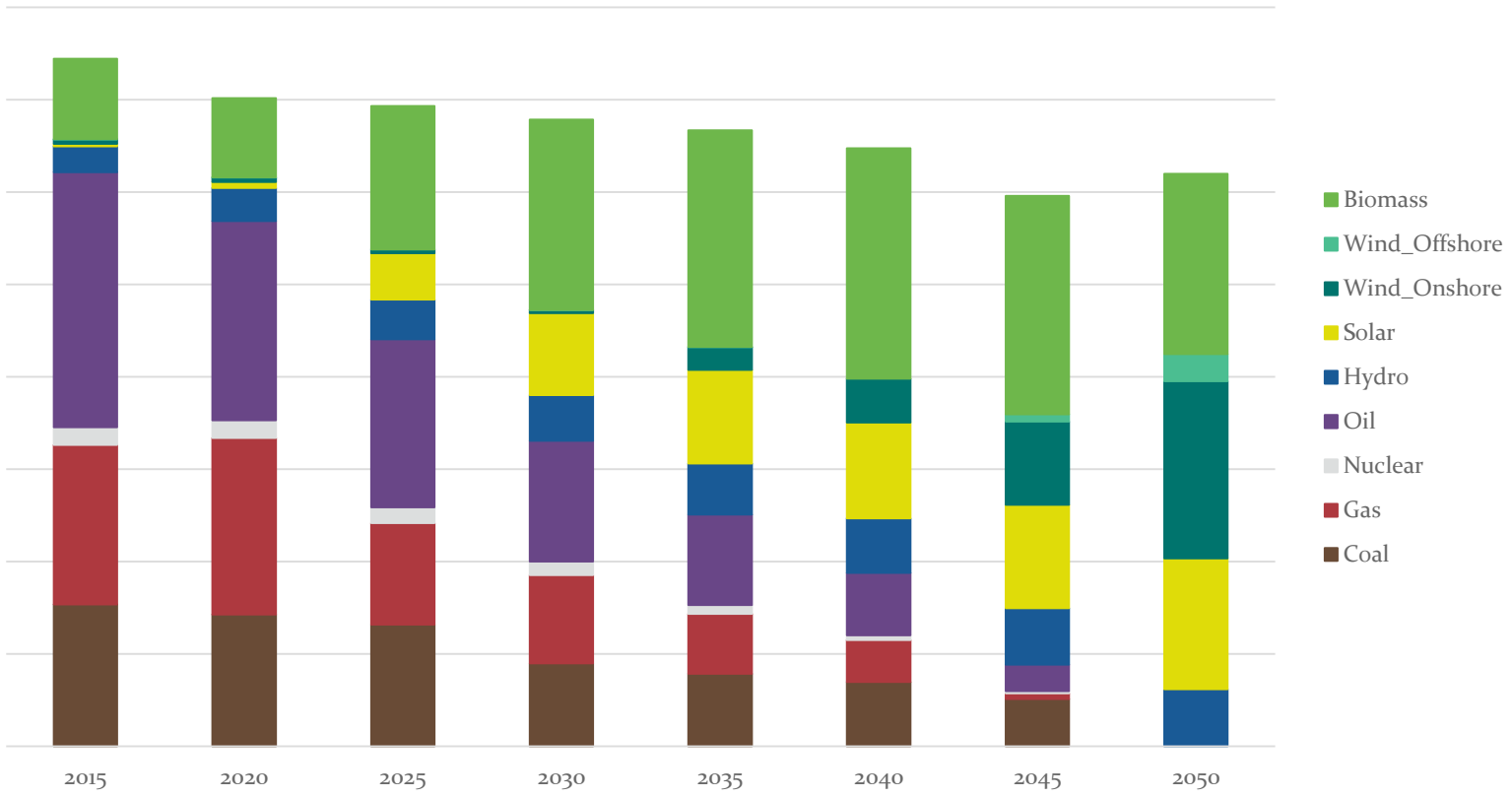


- Especially the high-temperature heat sector is relatively expensive to transform, largely reliant on biomass.

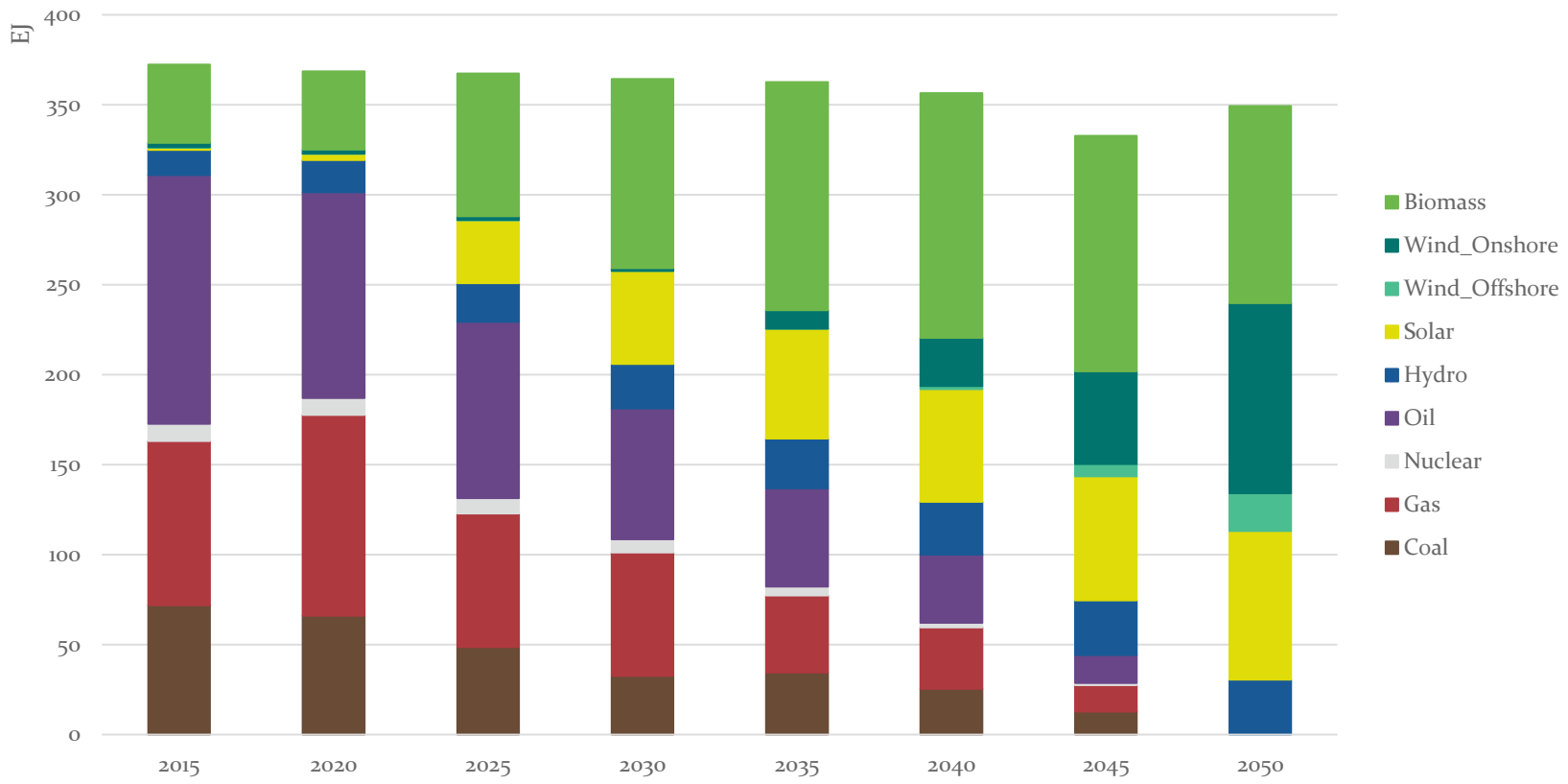
Development of Freight Transport [450ppm Scenario]



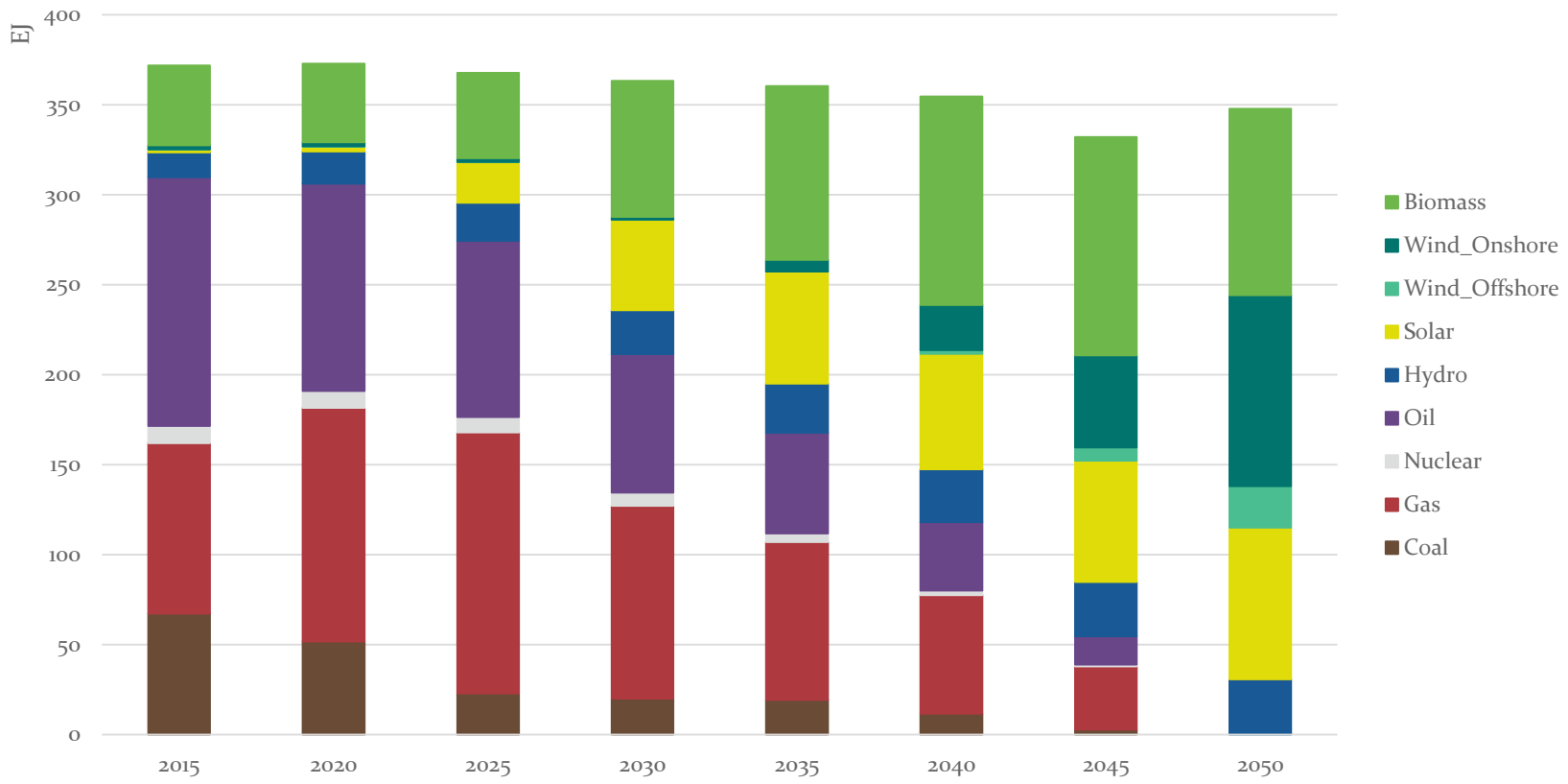
Sensitivity Analysis: Energy Mix – Halved Demand Growth



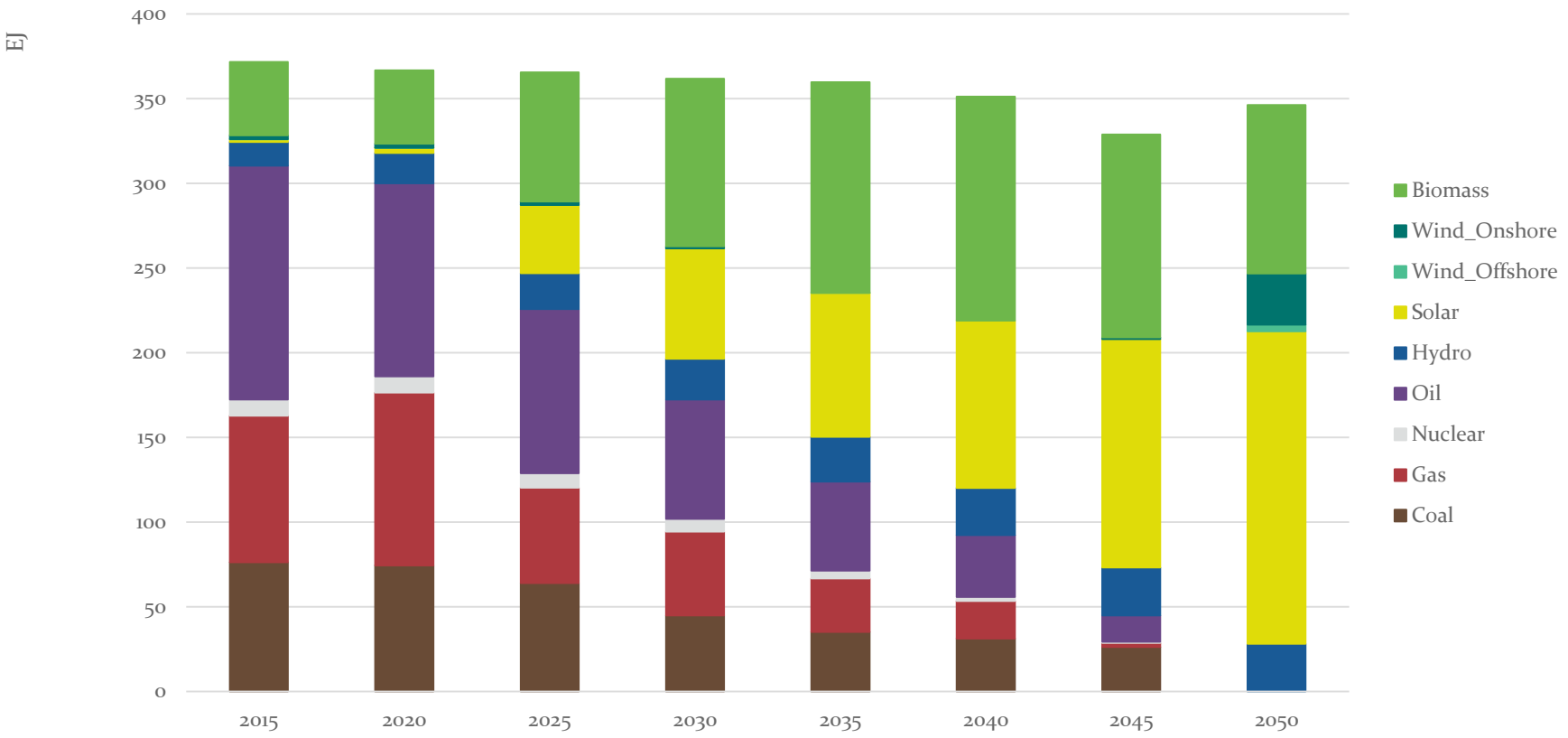
Sensitivity Analysis: Energy Mix – Halved Fuel Price Growth



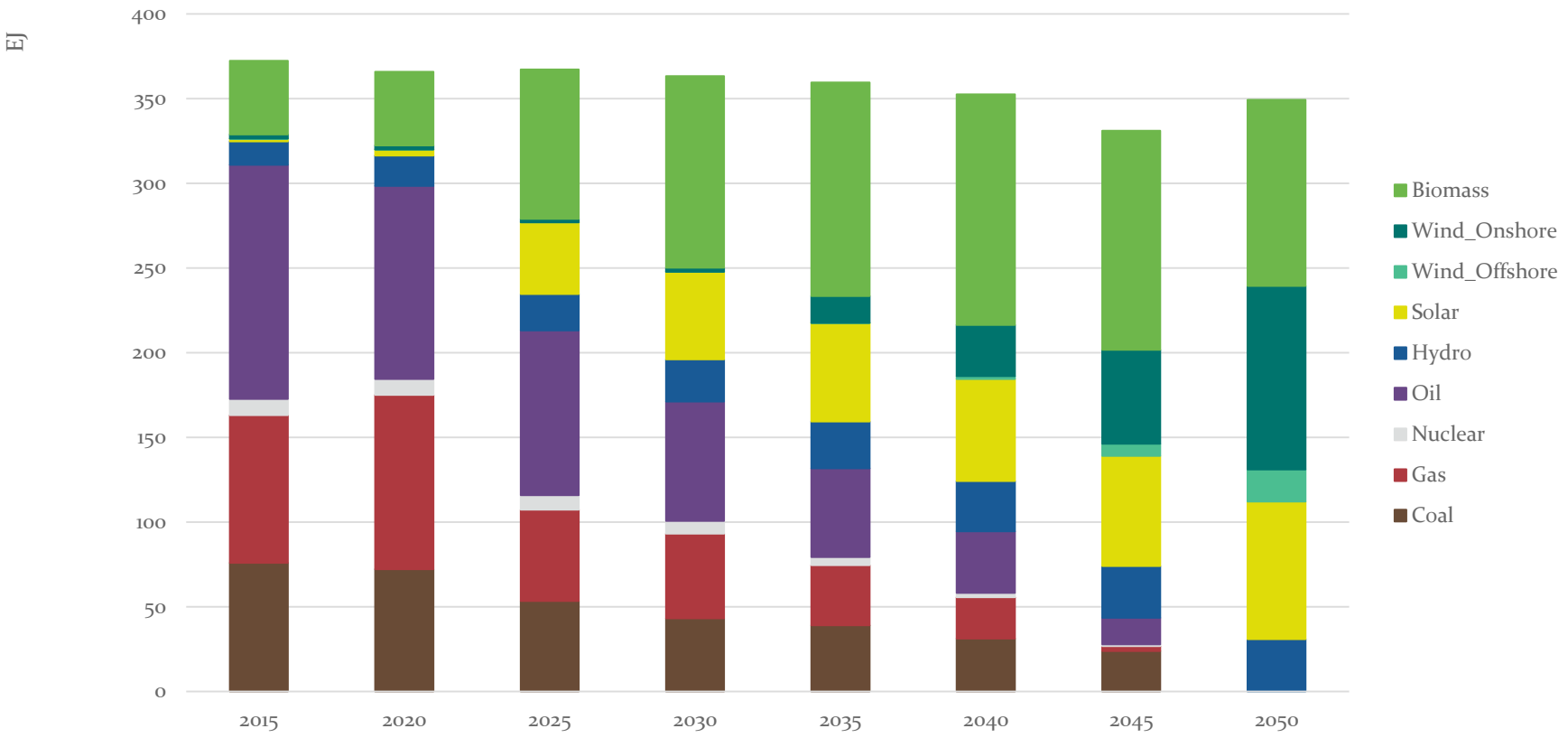
Sensitivity Analysis: Energy Mix – Constant Fuel Prices



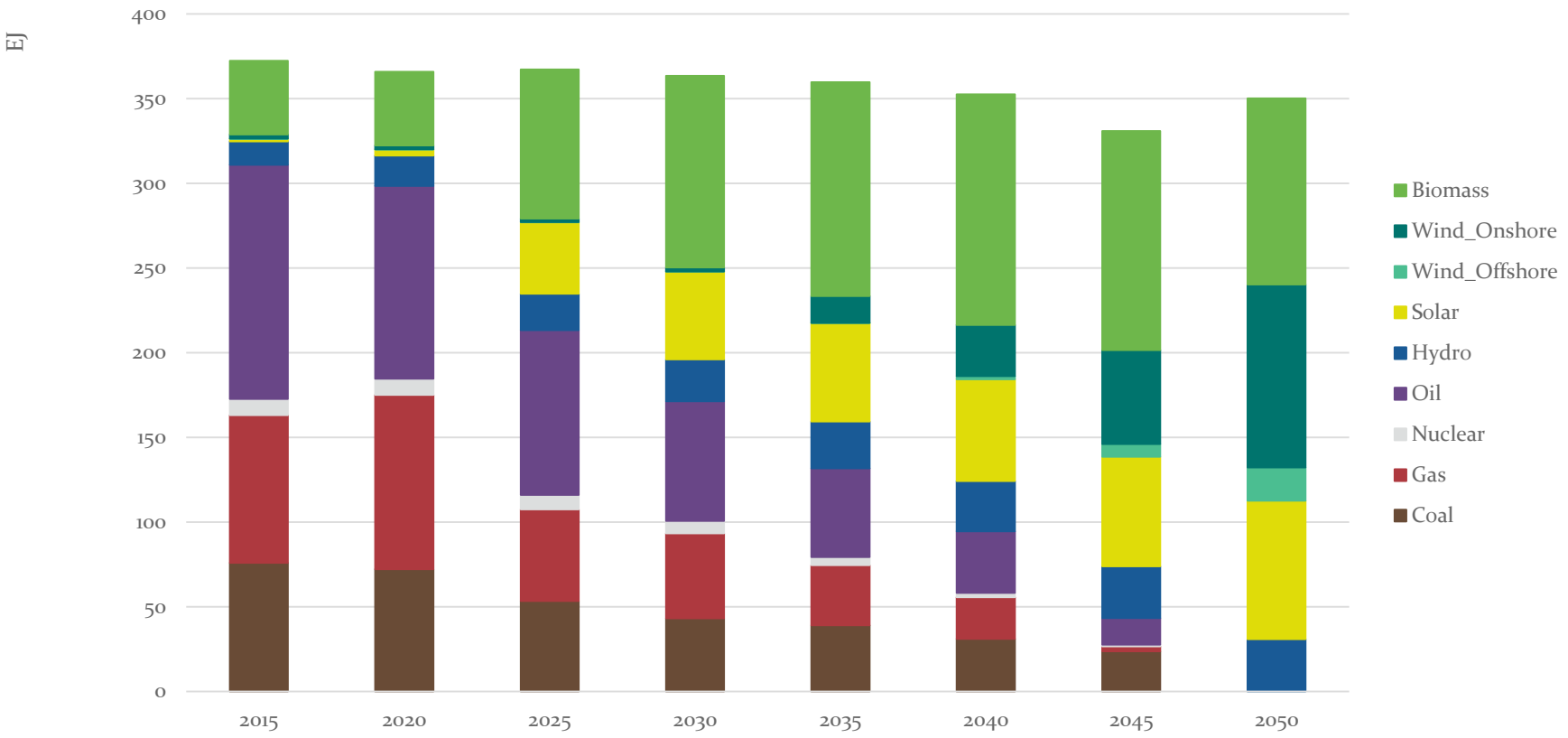
Sensitivity Analysis: Energy Mix – Storage Costs x 0



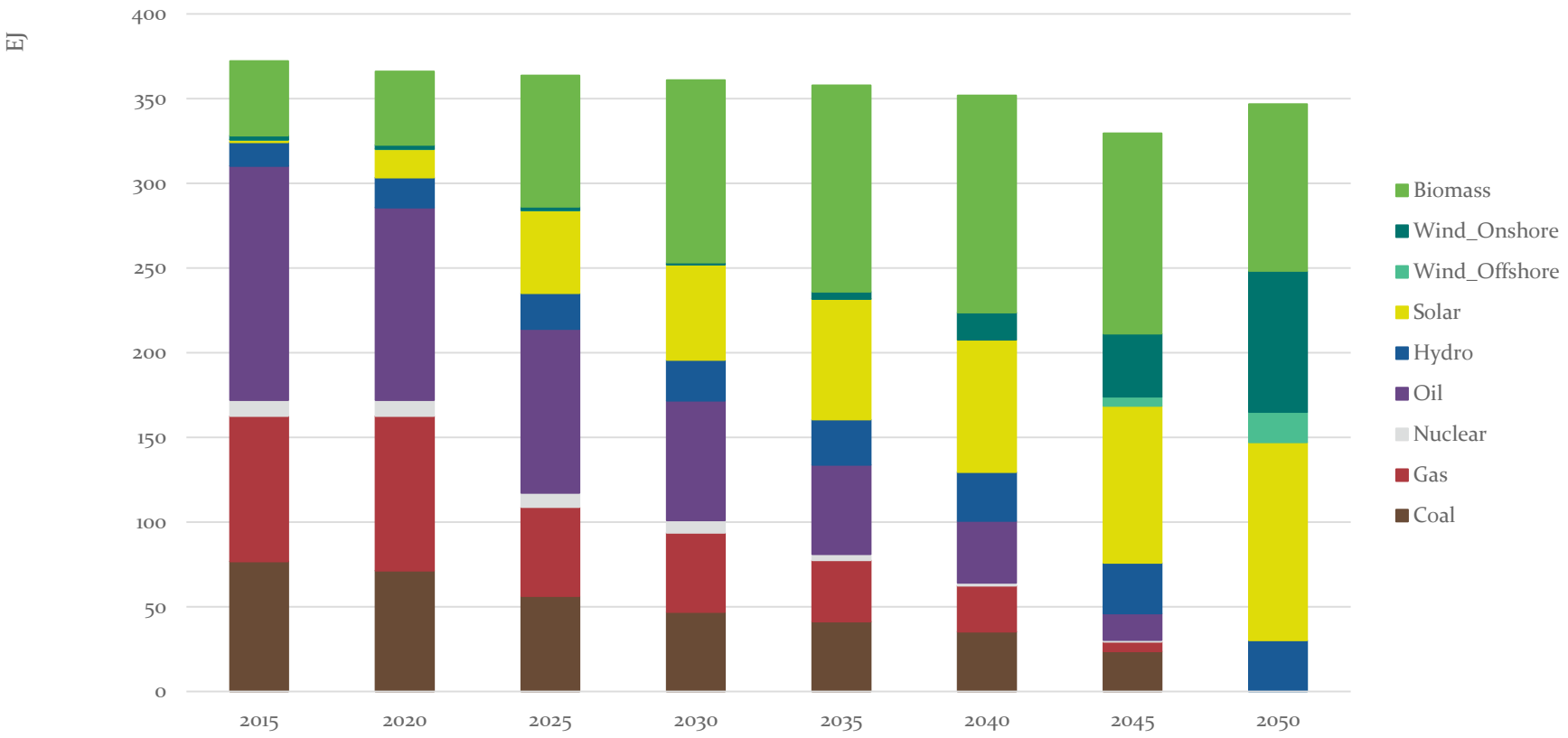
Sensitivity Analysis: Energy Mix – Storage Costs x 0.5



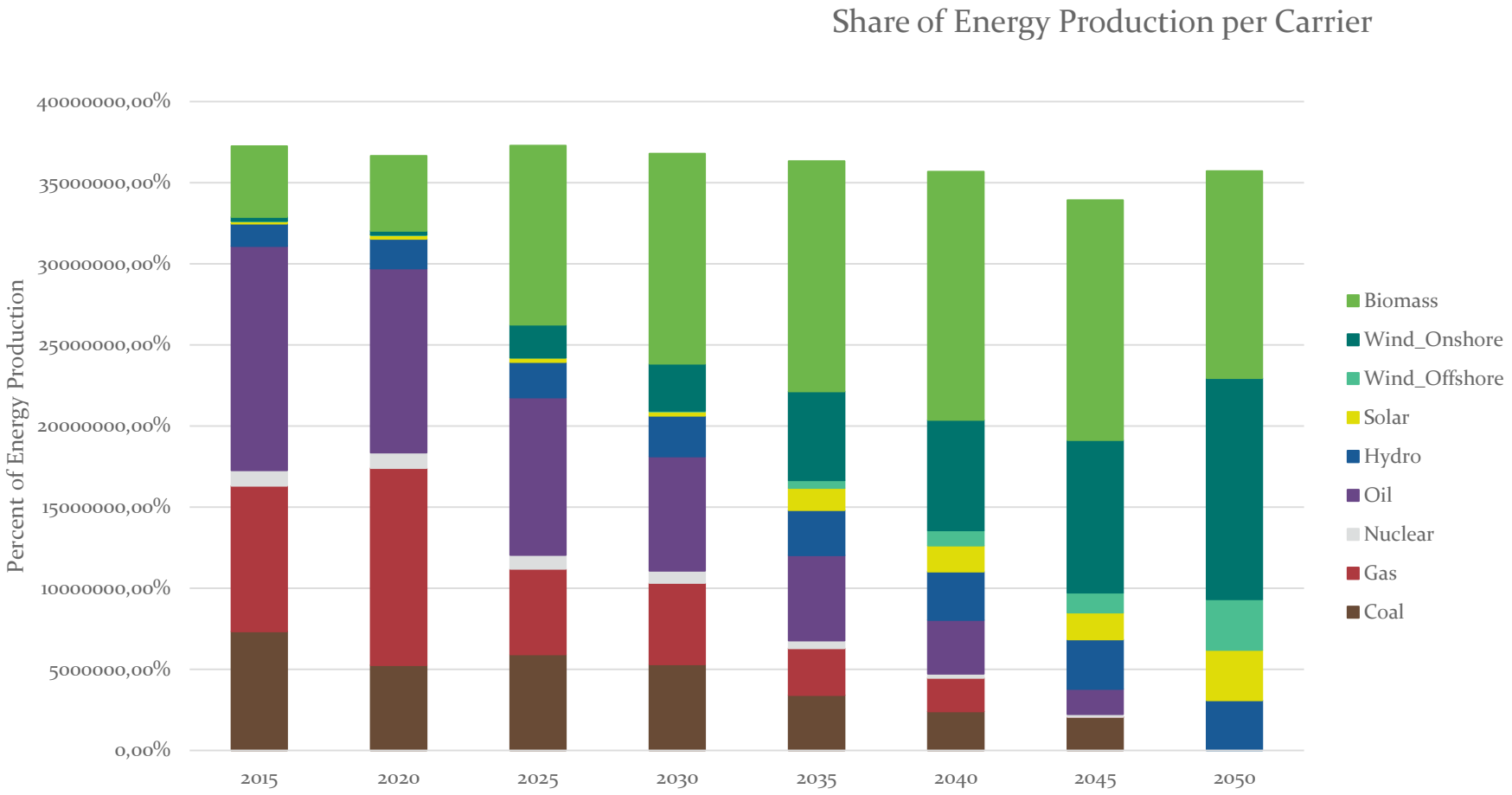
Sensitivity Analysis: Energy Mix – Storage Costs x 2



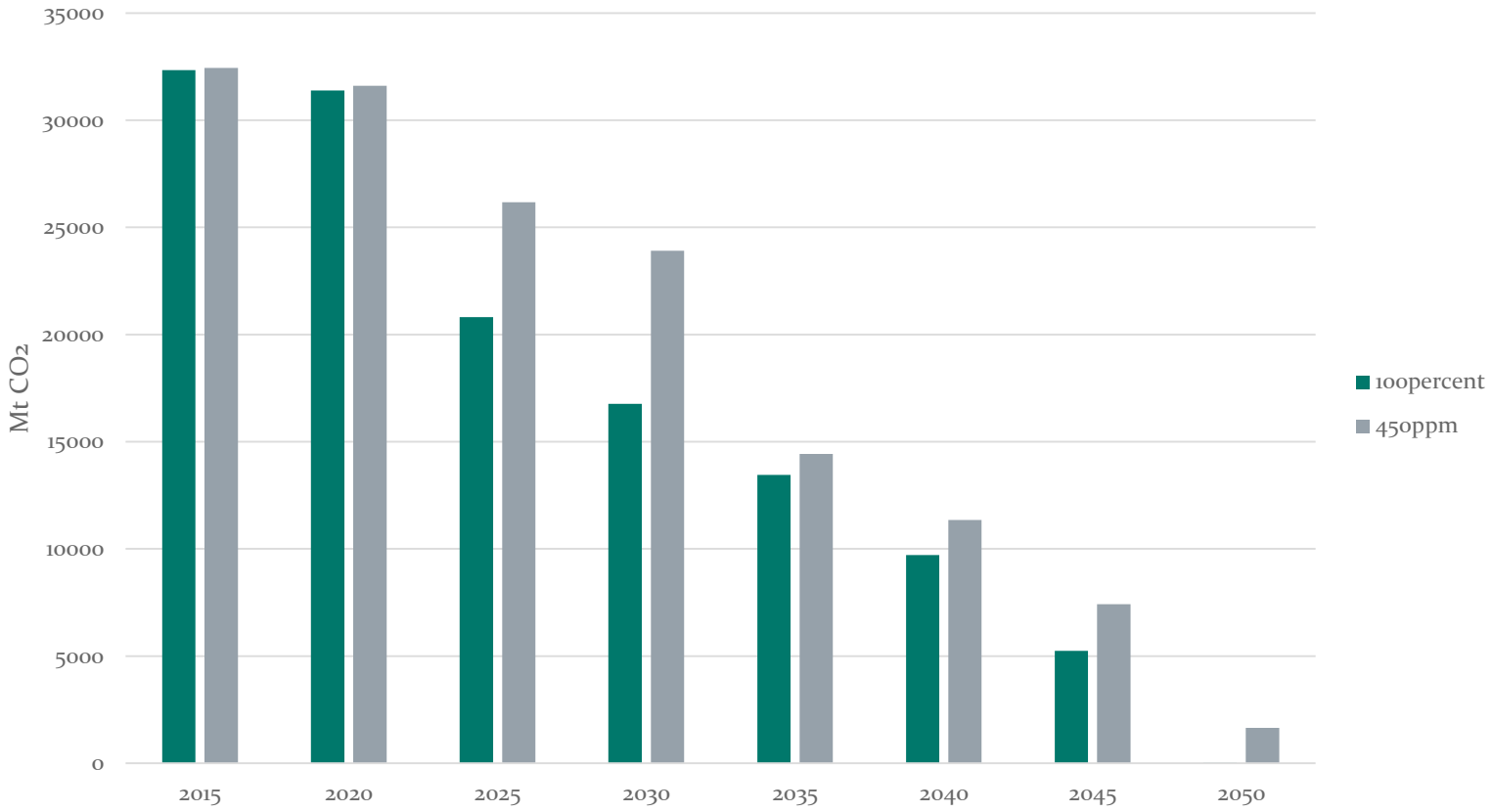
Sensitivity Analysis: Energy Mix – Solar x 0.5



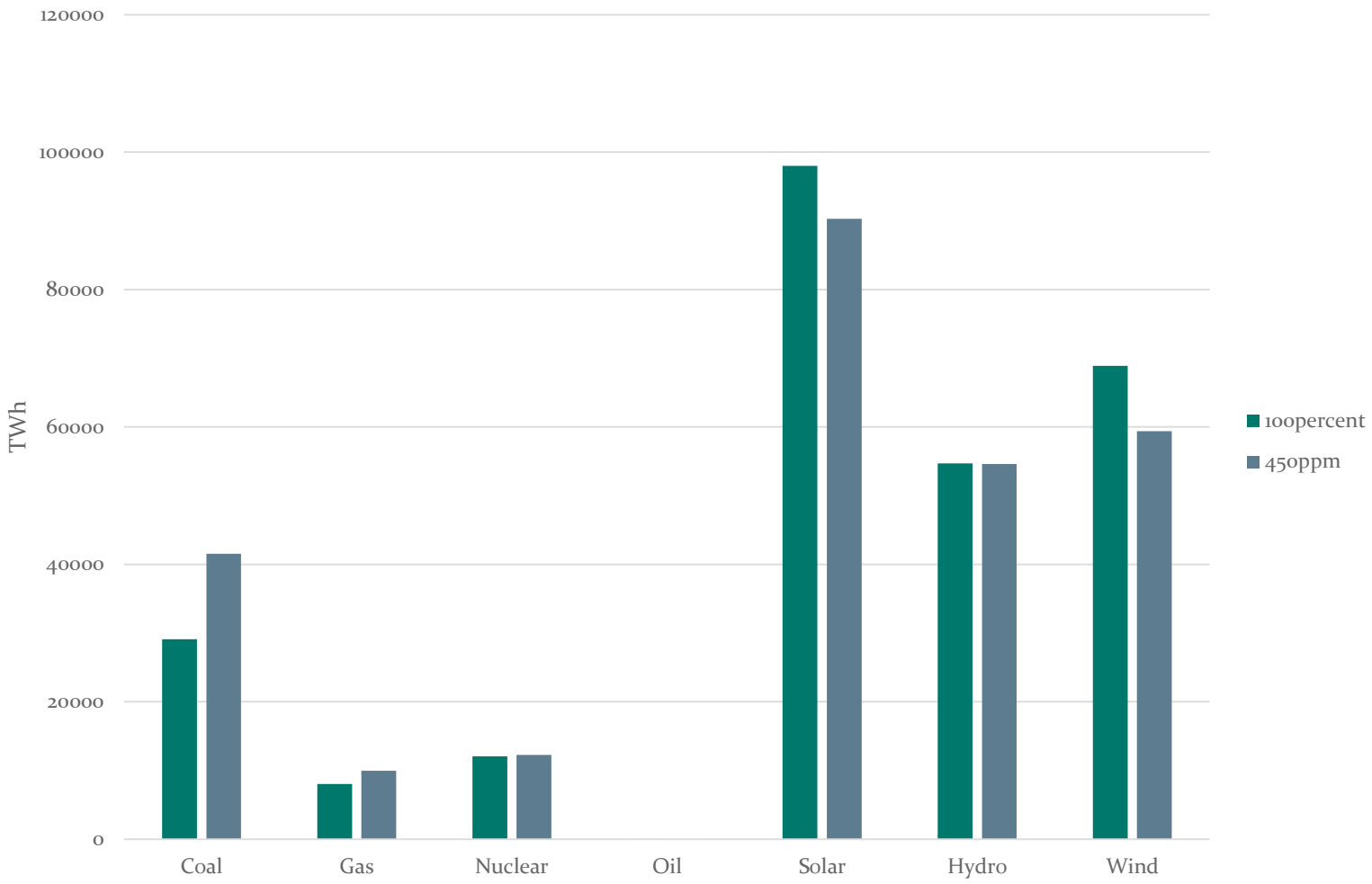
Sensitivity Analysis: Energy Mix - Solar x 2



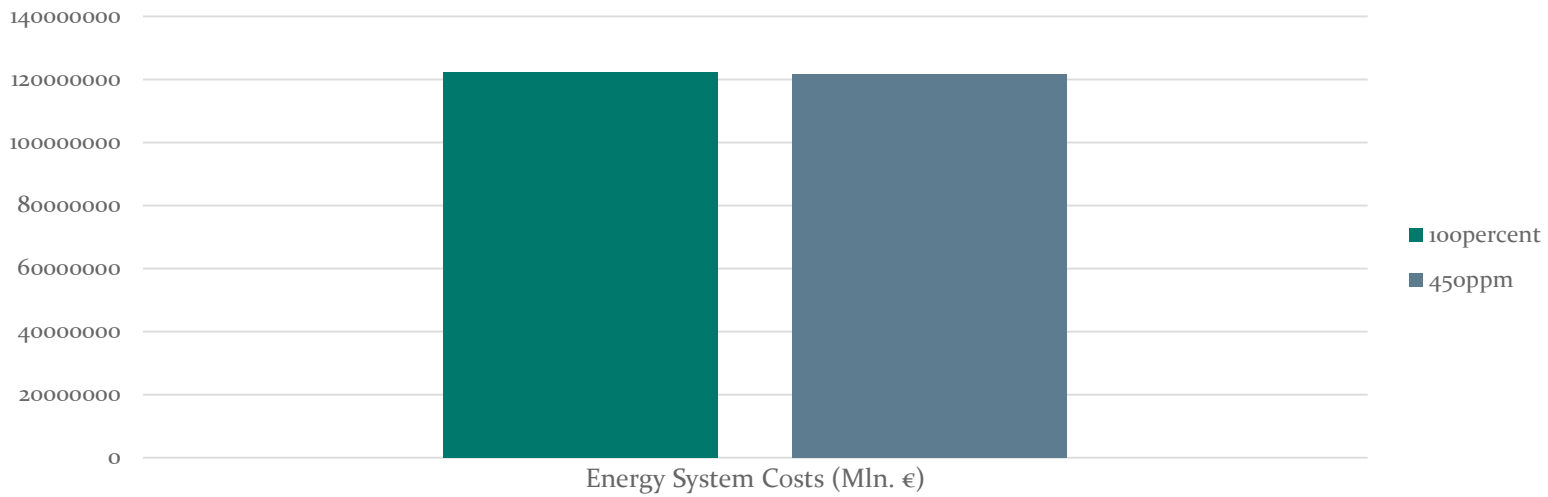
Scenario Comparison - Emissions



Scenario Comparison – Model Period Power Production



Scenario Comparison – Energy System Costs



- The costs of the complete energy system for the 2° scenario are only 0.45% higher than in the 1.5° scenario

Cost Development of Technologies in M€/GW

Technology	2015	2020	2025	2030	2035	2040	2045	2050
CSP	4100	3800	3500	3200	2900	2600	2300	2000
PV	1000	800	650	550	490	440	400	380
Geothermal	5263	4903	4542	4182	3821	3461	3100	2740
Solarthermal	5263	4903	4542	4182	3821	3461	3100	2740
Wind onsh.	1400	1250	1095	1035	1000	975	950	925
Wind offsh.	3300	3106	2911	2717	2522	2328	2134	1939
Lion Battery	1500	1300	1300	1000	1000	800	800	700
Heatpump	1300	1286	1271	1257	1243	1229	1214	1200