Stranded Assets, and the Role of Biomass and Hydrogen in the European Energy Transition

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Introduction

The European Union (EU) plays a crucial role in the decarbonization of energy systems and the transition towards renewable energy sources (RES). For instance, with the Renewable Energy Directive 2009/28/EC[1], the member states of the EU agreed to provide National Renewable Energy Action Plans while defining renewable energy targets for 2020. Also, the Regulation (EU) 2018/842[2] sets a binding target for greenhouse gas (GHG) reductions until 2030. These targets lead to coal (hard and lignite coal) and other fossil fuels being phased-out across several European countries. Still, additional capacities of fossil-fueled power generation are being built (Caldecott and McDaniels 2014; Europe Beyond Coal 2019). In turn, higher shares of RES led to decreasing capacity factors of, especially, natural gas-fired power generation. This can be observed in several member states of the EU, for example, in Germany, Italy, or the Netherlands. There, additional capacities of gas-fired power plants increased by around 10% between 2010 and 2015, while the annual capacity factor dropped from 50% to approximately 35%. In general, stranded assets pose a high financial risk. As assessment by the Carbon Tracker Initiative (2015) concludes that globally, projects with a value of 2 trillion US$ of capital expenditures are in danger of ending stranded. This was also highlighted by a recent study by Mercure et al. (2018). In their study, they show that a substantial fraction of the global fossil fuel industry may end stranded, presenting a total wealth loss of 1-4 trillion US$. In general, a trend can be identified, where, driven by climate goals, high shares (50-80\%) of fossil fuels could become stranded, a phenomenon also known as "carbon bubble" (McGlade and Ekins 2015).

Nonetheless, the quick ramping possibilities and fuel flexibility of gas-fired power plants can help to achieve renewable targets of the EU, when using biogas, synthetic methane, or hydrogen instead of natural gas. In this regard, the objective of this study is to use a multi-sectoral energy optimization model to look at the role of these fuels in the EU energy transition. The paper focuses on addressing questions related to: How much of the current or future gas infrastructure is needed for a successful European energy transition and what options can help minimize stranded assets. Firstly, the use of biomass, biogas, and biofuels in different sectors will be analyzed. This is of particular importance, as biomass in Europe is generally a scarce resource with limited potential[3]. This potential is even projected to decrease in the next decades until 2050 (Elbersen et al. 2012). In this context, the value of hydrogen in different sectors will also be assessed. Secondly, an analysis of stranded or unused capacity will be performed for the pathways. Lastly, with hydrogen, biogas, and methanized synthetic gas, we approach the different sectors, the needed gas infrastructure will be analyzed.

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See footnotes at end of text.

Methodology, Data, and Key Assumptions

The study is carried out by using the open-source energy system model *GENeSYS-MOD (Global energy system model)*, built on the *Open Source Energy Modeling System (OSeMOSYS)* (Howells et al. 2011; Welsch et al. 2012). In general, *GENeSYS-MOD* is a linear cost-optimizing model encompassing the sectors electricity, heat (industrial, commercial), and transport (passenger, freight with different modal types) (Löffler et al. 2017). Also, different sector-coupling technologies (Power-To-X, Storages, Methanation, etc.) allow for

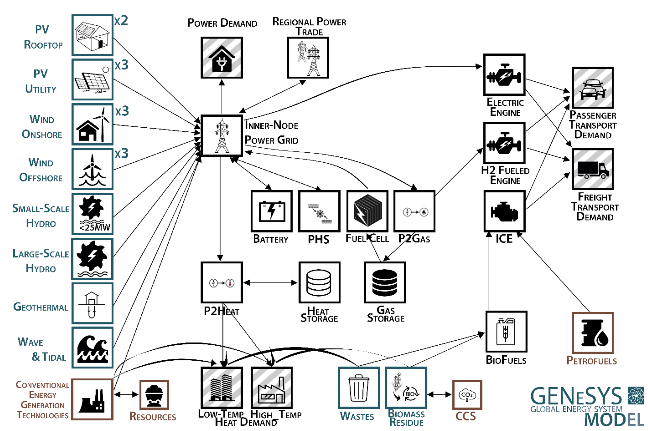

Figure 1: Overview of the technology options included in GENeSYS-MOD

a technology-oriented, integrated assessment of points in the future low-carbon transformation. The model calculates the optimal investments into capacity addition and generation for energy-producing, demanding, or transforming technologies, and thus the resulting energy mix. The objective function of the model minimizes the net-present value of the calculated energy system for the whole model period.

GENeSYS-MOD can be viewed as a network-flow cost-optimization model (Howells et al. 2011). In the network, nodes represent Technologies, and arcs represent Fuels. Examples for Technologies are production entities like wind or solar power generation units, conversion technologies like heat pumps, storages, or vehicles. In general, Fuels represent energy carriers like electricity or fossil fuels, but also more abstract units like passenger-kilometers for vehicles or areas of land are classified as Fuels. Also, Technologies may require different Fuels and can have more than one output Fuel[4]. Efficiencies of the technologies are accounted for and allow the modeling of energy losses due to conversion. Figure 1 gives a general overview of the different technologies in *GENeSYS-MOD* and the connections between them. The model allows for yearly investment and has perfect foresight over the total modeled period (2015-2050) with the base-year fixed to real values.

The general mathematical model formulation can be found in Howells et al. (2011) with the recent modifications presented in Löffler et al. (2017) and Burandt et al. (2018).

Input data, scenarios and key assumptions

For this study, Europe is presented in 17 nodes, each representing a country or geographic region. The model covers the EU-28 countries as well as non-EU Balkan states. Final demands for electricity, passenger & freight transport, and heat are given exogenously via scenario assumptions based on the four European energy transition pathways defined in the Horizon 2020 Project SET-Nav (Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation), see Crespo del Granado (2019)

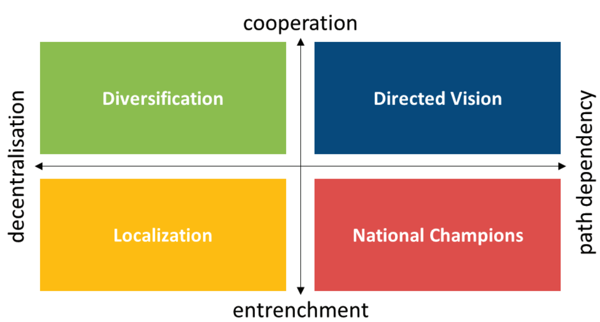

Figure 2: Overview of the scenarios.

The scenarios storylines are based on the level of cooperation and the level of centralization, as depicted in Figure 2. The *Diversification* pathway is characterized by heterogeneous actors and a high degree of cooperation and digitalization. The *Localization* pathway shares the same level of centralization and digitalization, but a local resistance to big infrastructure projects and exploitation of local (renewable) resources leads to a more entrenched scenario. From a European Union perspective, the *Directed Vision* pathway reflects a scenario with a strong policy framework, a shared vision, and a by the EU directed vision. Lastly, *National Champions* depicts a future energy system with strong local utilities, regulatory capture, and generally low transition costs. This scenario features the same focus on locally available potentials as *Localization*.

The model data is based on Burandt et al. (2018). Compared to the version of the model presented in Hainsch et al. (2018) and Löffler et al. (2017), several new additions have been made. Firstly, to better represent the need for flexibility options, ramping, together with ramping costs, has been added to the model alongside with a new time resolution of the model. The model now uses a reduced hourly time-series based on the algorithm presented by Gerbaulet & Lorenz (2017).

Also, the preexisting structure of high-temperature and low-temperature heat as depicted in has been altered. The new structure features four different temperature ranges with a more distinct differentiation in industrial (0-100°C, 100-1000°C, and >1000°C) and residential heating (0-100°C). For this new representation, a large variety of new technologies has been implemented.

Furthermore, a natural gas and LNG infrastructure has been added. Liquefaction and regasification plants have been added alongside gas pipelines and the possibility of LNG imports. Additionally, new vehicle-types using LNG were included in the model.

Results

This section presents key results of this study. The scenarios were abbreviated in the following figures as follows: *Diversification – DIV, Localization – LOC, Directed Vision – DIR, National Champions – NAT.*

Utilization of biomass and biofuels per sector

The resulting sectoral usage of biomass, biofuels, and biogas is shown in Figure 3. Whereas the picture for the utilization of solid biomass in 2020 looks uniform across the different scenarios, the usage per sector differs between the scenarios from 2040 on. The

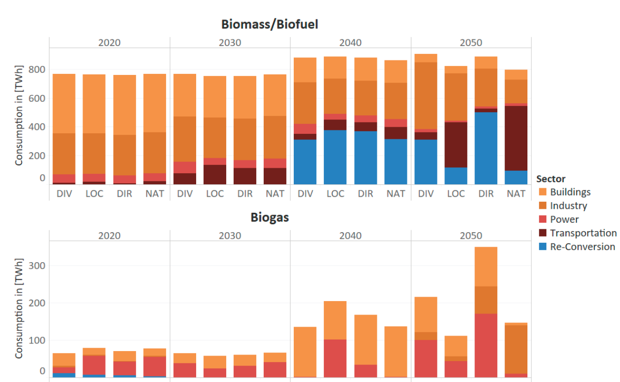

Figure 3: Consumption of biomass, biofuels, and biogas in different sectors.

trade of biomass is very limited in the entrenchment scenarios (*Localization* and *National Champions*), which have a significant effect on the utilization of biomass in the different scenarios.

The re-conversion of biomass into bio-methane is one of the most significant differences in 2050. Also, the amount and usage of bio-methane vary per scenario and sector. The scenarios with a high share of cooperation (*Diversification* and *Directed Vision*) see higher utilization of bio-methane in general and especially in the power sector. On the other side, the scenarios with less cooperation see higher use of biofuels in the transportation sector. Overall, biomass poses a flexible and versatile option for decarbonization in many areas. The final usage of biomass highly depends on the degree of cooperation in the low-carbon transformation.

Role of hydrogen

Contrary to the observations in the bio-energy sector, the use of hydrogen is not depended on the level of cooperation, but more on the degree of centralization.

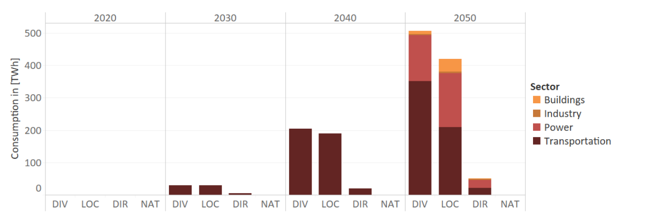

Figure 4: Consumption of Hydrogen and synthetic methane per sector and scenario.

As seen in Figure 4, the scenarios with a high level of decentralization, *Diversification,* and *Localization*, pose the most consumption of Hydrogen. A cost-optimal use of the limited amount of hydrogen occurs in the transportation sector. Fuel-Cell Electric Vehicles (FCEV) pose a reliable alternative to purely electric Battery Electric Vehicles (BEV) especially in the later stages of the model runs. Especially with higher production of hydrogen, FCEV becomes, even more, cost-competitive compared to BEV or conventional cars fuels with biofuels.

In 2050, in the scenarios with large hydrogen production, hydrogen will also be used in the power sector (as methanized synthetic gas) as well as heating fuel in the buildings sector. Again, depending on the underlying assumptions and boundary conditions, hydrogen together with biomass pose to be very versatile fuels in future energy systems; especially providing flexibility in the power system as synthetic or bio-methane. Without sectoral emission targets, an introduction of those alternative gas-based energy carriers in the power sector allows for other sectors to emit more CO_2. This is especially important for the high-temperature industry sector (e.g., steel-making, glass-melting, etc.) as this sector is generally more challenging to decarbonize or electrify.

Gas infrastructure

Regarding the gas infrastructure developments, in the coming decades (2020 and 2030), natural gas is a backbone of the energy system with a high degree of usage in the power, industry and buildings sectors. But in all scenarios, a uniform decrease in this usage can be observed in Figure 5.

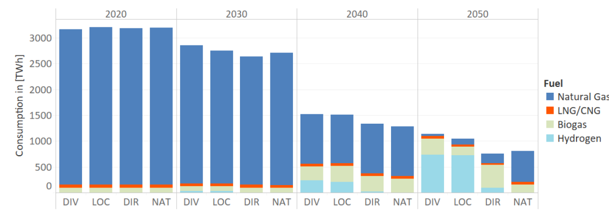

Figure 5: Total consumption of gas-based energy carriers.

Although the need for natural gas continues to decrease from 2030 until 2040, the overall consumption of gas-based energy carriers stays nearly stable from 2040 until 2050 for *Diversification* and *Localization*. As seen in previous figures, this is the result of the utilization of hydrogen in these sectors. In the *Directed Vision* scenario, also outlined in an earlier section, biogas plays a significant role in the energy system. Still, the sectoral usage of gas-based fuels changes in different sectors, compare Figure 5. Regarding the needed future gas infrastructure, it can be seen that from a total consumption of roughly 3000 TWh in 2020, only one-third is consumed in 2050. This implies that, apart from the currently existing infrastructure, no new additions are needed.

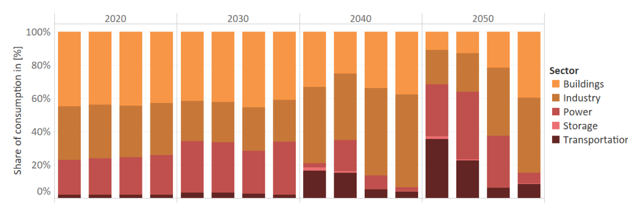

Figure 6: Sectoral shares of usage of gas-based energy carriers and their deviations (including Hydrogen and LNG/CNG).

Whereas gas-based fuels are mostly used for heating in 2020 and 2030, differences between the scenarios become clear in the last years of the modeling period.

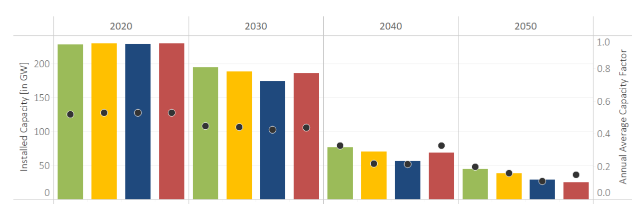

Figure 7: Installed capacities in GW and share of unused capacity in the power sector.

Only the *National Champions* and *Directed Vision* scenarios have similar shares of usage in all sectors compared to the current energy system. Here the most significant shares of gas-based fuels are still used for heating in the buildings or industrial sector.

Lastly, looking at the installed capacity of Open Cycle Gas Turbines, Closed Cycle Gas Turbines, and Steam Engines in the power sector, the previous trend of decreasing usage of gas-based energy carriers can also be observed here. The overall utilization of gas-based power plants stays nearly constant from 2020 until 2030. In 2040, the installed capacities, as well as the average use of gas-fired power plants, varies between the scenarios. In the later years, the gas-fired power plants are used alongside batteries and other sector-coupling technologies to balance large amounts of variable renewable energy sources in the power system. The scenarios with more decentralization, see comparably higher capacities and higher capacity factors in 2050, as more renewables in the power system in the case of Diversification or limited trading possibilities in the Localization scenario need more gas-fired utilities to balance the power system. As the results suggest, large amounts of capacity are unused, starting in 2040. In light of the current plans (grid operators) to install even more gas-fired power plants, the issue of the risk of these newly constructed assets being stranded is highlighted.

Overall, the investments into new gas-fired power plants need to be carefully considered by policymakers in the near future. Although gas-fired power plants are needed for providing flexibility alongside storages in 2050, the majority may still be stranded or operating with an extreme low-capacity factor. As proposed and analyzed in this study, there is a possibility to reuse the existing infrastructure for cleaner gas-based fuels, like hydrogen, synthetic methane, or biogas. Also, gas-fired combined-heat-and-power plants fueled by those energy carriers play an important role in reducing the emissions of the heating, and partly the industrial, sector. Refitting existing turbines with heat-recovery systems may thus decrease the risk of assets ending stranded.

Summary

Overall, a decrease in natural gas-based energy in all sectors is projected under ambitious decarbonization scenarios. Generally, the danger of assets being stranded (most notably gas-fired power plants) increases with each additional power plant being planned and commissioned. Hence, *GENeSYS-MOD* sees a decrease in the total usage of natural gas in the power sector. This is contrary to the current plans of many countries to increase the power production from natural gas.

Nevertheless, gas-fired power plants are needed in the future energy system (mostly utilizing biogas or hydrogen) for balancing a high RES share in the power system. The results note the importance of the flexibility and versatility of gas-based energy carriers in general. In most scenarios, hydrogen or bio-gas play a significant role in the future energy system either allowing for decarbonization of non-electricity sectors or providing balancing options for variable renewable energy sources in the power sector. This importance is even likely to increase in some of the scenarios beyond 2050. Meaning that in order to sustain a low utilization of the gas infrastructure, capacity markets beyond electricity should be considered. The business model for the future gas infrastructure requires gas capacity markets to reward and price the value of flexibility it provides to the power system; this will hinder the possibility of stranded assets.

Due to the regional disparity in the availability of renewable energy source (to produce hydrogen from excess energy in, e.g., the peak sun hours) and biomass, the level of international cooperation is an essential factor for future energy systems. The importance of trading in either power, solid biomass, or gas-based energy carriers will be a crucial factor for future energy systems.

Footnotes

[1] See https://eur-lex.europa.eu/eli/dir/2009/28/oj, last accessed 29.07.2019.

[2] See https://eur-lex.europa.eu/eli/reg/2018/842/oj, last accessed 29.07.2019.

[3] This study omits energy crops as possible option for biofuels.

[4] Therefore, co-generation of heat and electricity as well as co-firing with biomass can be implemented without introducing new technologies to the model.

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