Chair of Energy Systems
TUM School of Engineering and Design
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Scenario-based Evaluation of the Utilization of Waste and Biogenic Residues for Sector Coupling via Polygeneration

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Motivation

In order to create a completely defossilized energy transition, alternative carbon sources have to be established instead of the currently used fossil resources. These include not only the substitutes themselves, but in particular the technologies that enable their use for applications, such as the chemical industry or as drop-in fuel. However, according to current estimates, biomass and biogenic residues alone cannot cover the expected demand for carbon in the German energy system until 2050 [1]. The use of gasification-based plants to include other residual materials such as plastic fractions is already being discussed, with research focusing in particular on the technologies needed to supply synthesis gas. Coupling to the power sector, for example through power integration or power generation, is also being investigated. Gasification, however, enables much more than single- or co-generation of electricity and/or heat. For example, the concept of polygeneration promises a flexible shift between system services for the power grid and the provision of synthesis gas for various chemical applications. To evaluate how alternative technologies can act in a possible future energy system, a common method is energy system optimization. However, this work is focused on the calculation of different scenarios of the German energy system in 2050 in order to evaluate the influence of changing boundary conditions regarding the feedstock on the use of polygeneration plants.

Methods

The energy system model, implemented as described in [2], is based on energy and mass balances with an hourly time resolution. Figure 1 shows a simplified scheme of the used energy system model, where all the boxes can be seen as a placeholder for a whole group of technologies. Various types of demands (heat, mobility and chemicals) must be satisfied additional to the conventional power demand. All the data used is based either on existing literature or on own process simulations in case of the gasification-based process routes. A more detailed explanation of the data basis in general is given by the authors in [3] and for the process simulation in [4].

The optimization objective is to minimize the total system cost in order to emulate a market-driven behavior of the economy. Results can thus be interpreted as the most cost-efficient way of fulfilling all the assumed energetical and material demands in a fictive 2050 energy system.

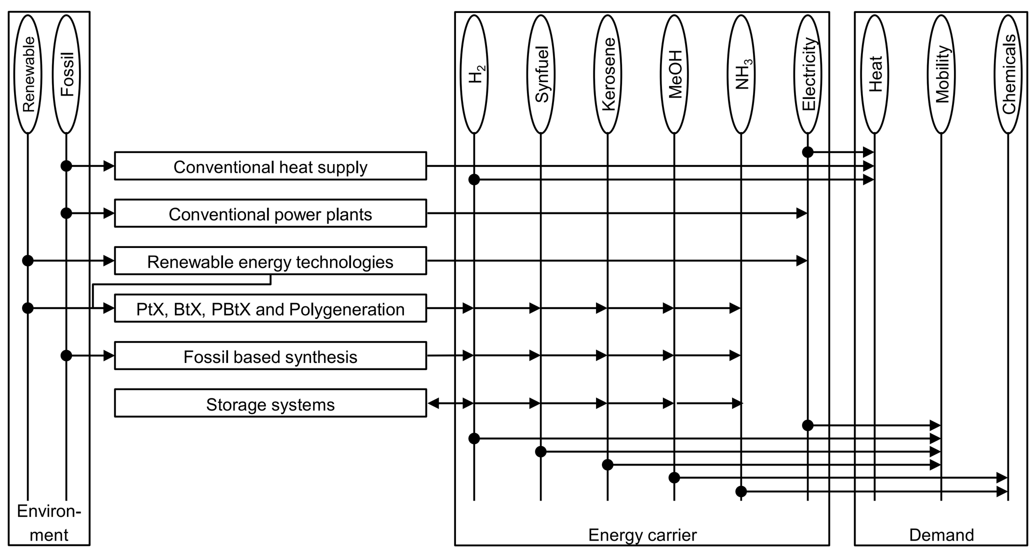

Figure 1: Simplified diagram of the used energy system model.

Sector Coupling

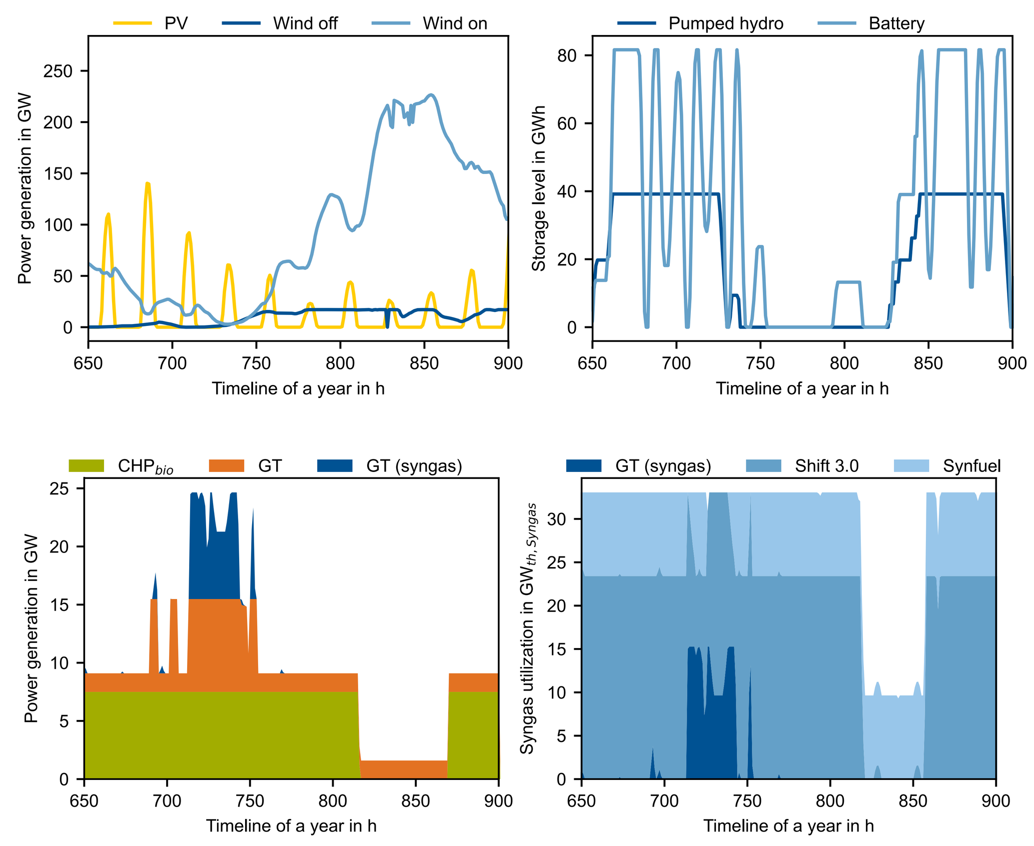

Figure 2: Peak load coverage by syngas gas turbines in times of low photovoltaic and wind availability [3].

Providing flexibility for the power grid is one of the key challenges for future (100% renewable) energy systems. It is necessary to bridge periods without significant generation from wind and solar radiation as well as to provide negative power in times of very high generation.
Polygeneration plants can be used for both problems. Figure 2 shows an example of a period with prolonged undersupply from wind and PV and consequently empty storages. Figure 3, in contrast, shows a time slice with above-average generation from renewable technologies.
In both cases, the polygeneration plant steps in to either generate electricity via syngas gas turbines or to skip the water gas shift reaction during the gas conditioning by hydrogen integration and thus offer negative control power.
In both examples the total gasifier load is kept almost constant. Thus, the flexibility is provided solely by the downstream application of the raw gas.

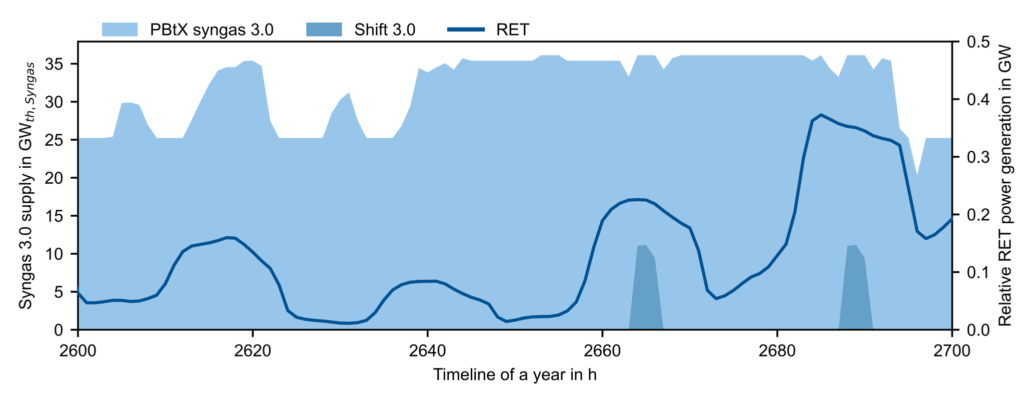

Figure 3: Share of PBtX syngas supply in times of high renewable power generation [3].

Base Case Results

As expected, the energy system is primarily based on photovoltaics and wind turbines. In addition, smaller capacities of hydropower, biomass CHPs and gas turbines are used for base and peak load coverage. Despite the higher costs of polygeneration plants, due to the synergies, significant shares of H_2 and diesel are generated via this.
The feedstock demand in an optimal system exceeds the current, sustainable availability of biomass with more than 500 TWh, showing the demand for waste utilization.

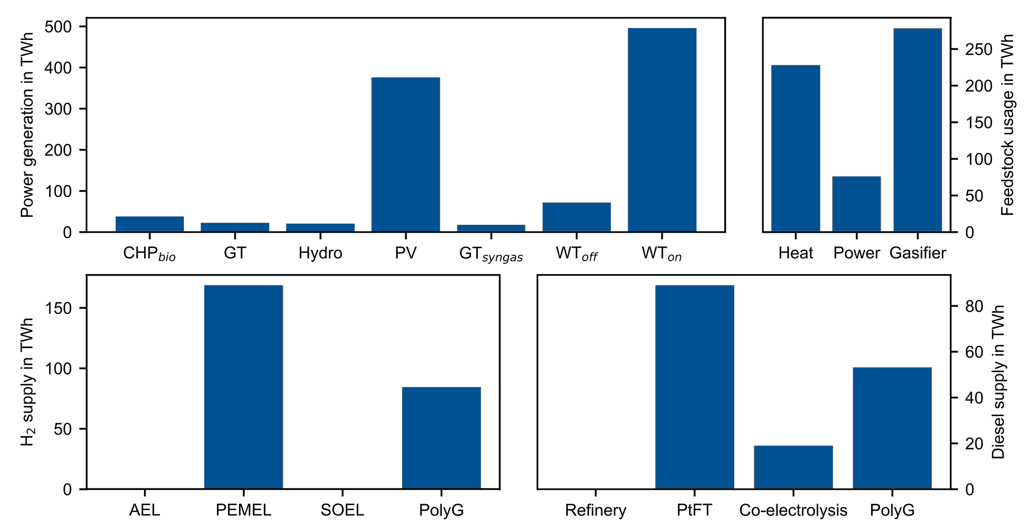

Figure 4: Base case technology portfolio and feedstock utilization [3].

Sensitivity Analysis

A sensitivity analysis shows that the model is not overly sensitive to any of the inputs CO_2 emission costs, feedstock costs, or feedstock potential. The behavior is trivially expectable as seen in Table 1.
Only the feedstock utilization shows a plateau at CO_2 costs between 50 and 100 €/t. This is due to a jump in the installed capacities of PV, wind turbines and battery storage.

Table 1: Peak load coverage by syngas gas turbines in times of low photovoltaic and wind availability [3].

	Increasing CO_2 certificate costs			Increasing feedstock costs
Overall system costs	↑			↑
CO_2 emissions	↓			↑
Power generation	↑			↑
Feedstock utilization	0-50 €/t ↑	50-100 €/t →	100-175 €/t ↑	↓

Conclusion

The results show that while power generation in 2050 is almost entirely based on PV and wind, the use of polygeneration plants provides a great deal of flexibility for the overall energy system. This flexibility provided by a polygeneration plant allows for a significantly less costly energy system while meeting all greenhouse gas emission targets. One reason is the considerably lower demand for battery storage, which ultimately means not only lower investment costs, but also a significantly lower use of rare metals.

One of the key findings is that taking away this polygeneration flexibility results in an increase in overall system cost by 3%. The reduced flexibility in the electricity sector must also be covered by alternatives, which results in a not neglectable increase regarding battery storage, as well as a 50% increase in carbon capture capacities to meet the systems carbon demand. In summary, this demonstrates the ability of polygeneration, based on different feedstock, to supply multiple sectors in parallel and provide substantial flexibility to the system.

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[1] Fachagentur Nachwachsende Rohstoffe e. V. (2021): Basisdaten Bioenergie Deutschland 2021
[2] Miehling, S.; Lambert, J.; Hanel, A.; Fendt, S.; Herrmann, S.; Spliethoff, H. (2022): Energy System Optimization using (Mixed Integer) Linear Programming. (submitted). In: MethodsX.
[3] Hanel, A.; Dossow, M.; Fendt, S.; Spliethoff, H. (2022): Optimized Use of Polygeneration Plants in a Highly Coupled Energy System Model. In: 35th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2022). Copenhagen.
[4] Dossow, M.; Dieterich, V.; Hanel, A.; Spliethoff, H.; Fendt, S. (2021): Improving carbon efficiency for an advanced Biomass-to-Liquid process using hydrogen and oxygen from electrolysis. In: Renewable and Sustainable Energy Reviews