Energy Transformation & Intermittency in System Dynamic Models

(Open-Source) Modellierung

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Motivation und zentrale Fragestellung

WILIAM (Within Limit Integrated Assessment Model) [2] is a global Integrated Assessment Model (IAM) that combines economic, social, demographic, environmental and energy related aspects into one system dynamics model. It aims to enhance the existing MEDEAS IAM to provide policy-makers and relevant other stakeholders with an open source, well-documented model to assess the feasibility, effectiveness, costs and impacts of different sustainability policy options.

The Austrian Energy Agency is responsible for developing the energy transformation module, which calculates the primary energy required to satisfy the final energy demand. Challenges include

- implementing an allocation algorithm in system dynamics that endogenously decides which transformation technology is being used based on endogenous and exogenous variables (e.g. Prices, Policies)
- adequately representing intermittency effects on annual energy balances at high shares of variable renewable energy sources (vRES)

Methodische Vorgangsweise

WILIAM is developed in the Horizon 2020 project LOCOMOTION[2]. Starting point for the development of WILIAM is MEDEAS, which was developed in the predecessor project. Both models share the same general methodological approach:

- System dynamics simulation
- Input-Output modelling (in the economic module)
- Time horizon 2050 with annual resolution
- Multiregional approach (MEDEAS: Nested approach with three levels “World”, “EU”, “Country”; WILIAM: 8 regions + EU countries in parallel)
- Implemented in VENSIM and translated to Python
- Open source philosophy

However, WILIAM aims to improve MEDEAS by adding new modules (e.g. Demography) and increasing *accuracy* and *consistency* in all existing modules. In the energy module – obviously one of the most relevant sectors with regard to GHG-Emissions – two aspects are mentioned in this paper:

1. In MEDEAS only RES transformation capacities were modelled explicitly, while fossil transformation capacities provided the residual load that could not be met by RES. The implicit assumption of this approach is that there are always sufficient fossil transformation capacities available. As a consequence also investments in fossil capacities could not be covered in the financial and materials part of the model. WILIAM closes this gap by considering 53 transformation technologies, fossil and renewable, with and without carbon capture and sequestration (CCS). The energy transformation module accounts for all energy commodities along the transformation chain from final energy to primary energy and consistently accounts for losses along the way (refinery losses, transformation losses, storage- and transmission losses – see Figure 1 for a detailed view of energy commodities and transformation processes). Another improvement concerns the allocation of transformation technologies: An algorithm endogenously decides which available technologies are utilized to fulfil the required energy

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demand based on technology allocation priorities. These priorities can be a function of fuel prices, CO2 prices, policy preferences, EROI or any other variable available in the model.

2. Another shortcoming of MEDEAS was the simplified approach to consider effects of intermittent RES in form of a simple curtailment factor that depends only on the vRES share in the power system. This simplified approach tended to overestimate curtailment, leading to the build-up of unrealistically large RES overcapacities in some situations. In WILIAM a dedicated sub-module emulates the effect of different technology combinations on the annual energy balances based thousands of permutations of hourly dispatch models. It receives the required transformation output (Total demand) and the potential vRES generation (without curtailment) and returns the realizable vRES production (including curtailment), aggregated storage losses and sector coupling technology utilization (power to heat, hydrogen) based on the current energy system setup (installed capacities of vRES, flexible- and inflexible power plants, batteries, DSM technologies etc.).

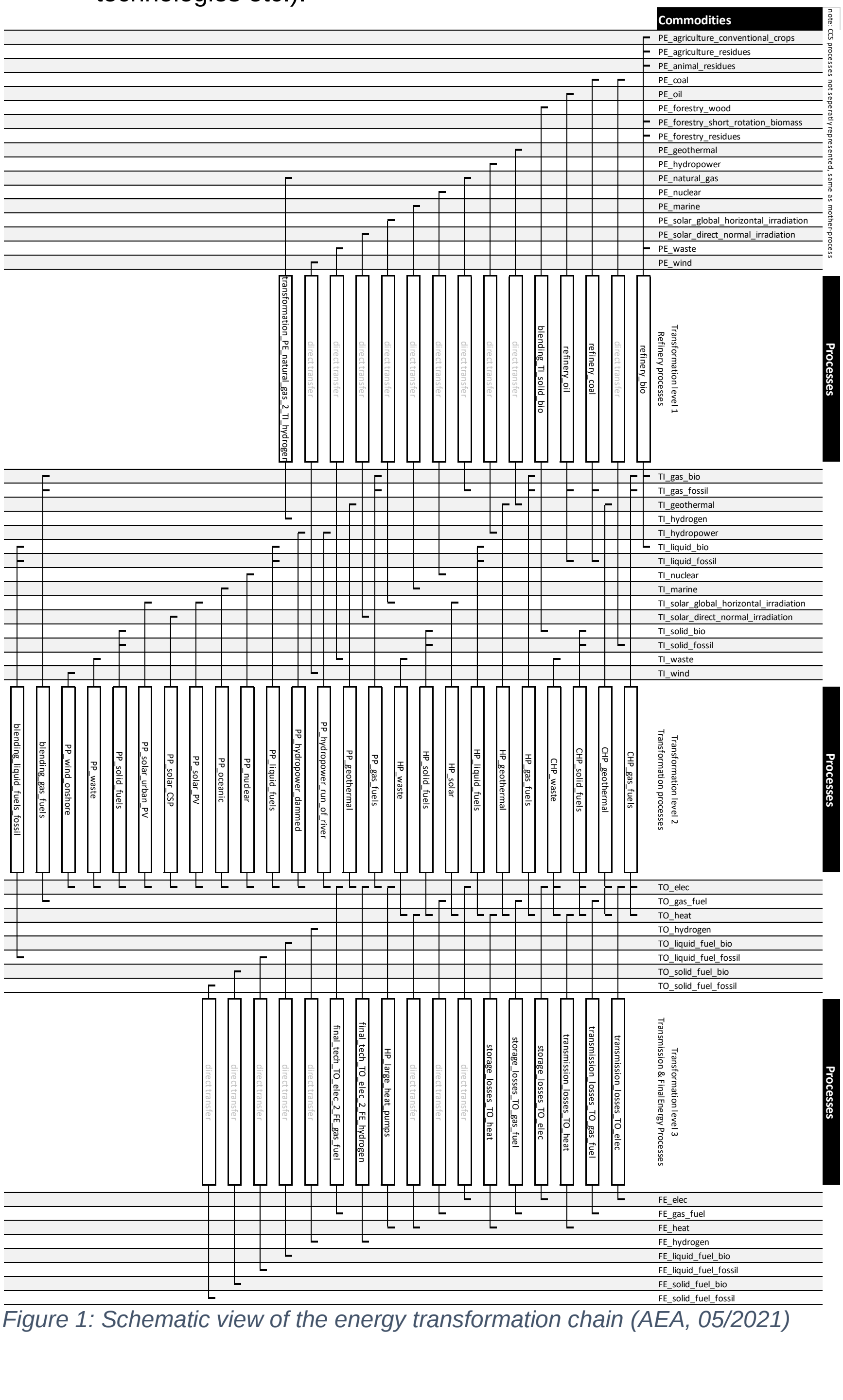

Figure 1: Schematic view of the energy transformation chain (AEA, 05/2021)

Ergebnisse und Schlussfolgerungen

The results show a significant improvement of the conceptual design of the energy module compared to the predecessor model:

- Modelling fossil *and* renewable transformation capacities allows a complete representation of the whole energy system and ensures consistent balancing of energy flows at any point of the transformation chain.
- The new allocation algorithm significantly improves the model, increasing accuracy while providing high flexibility with regard to which variables influence the technology prioritization.
- The improved representation of sub-annual intermittency effects on the annual energy balances improves the reliability of the results. It will enable high vRES integration in the energy system in case of favourable overall technology setups (DSM, Storage, sector coupling), while increasing curtailment if these these accompanying technologies are missing.

Literatur

[1] https://medeas.eu/
[2] https://www.locomotion-h2020.eu/