Energy system flexibility for renewable energy variability in IAMs

LOCOMOTION
Low-carbon society:
an enhanced modelling tool for the transition to sustainability

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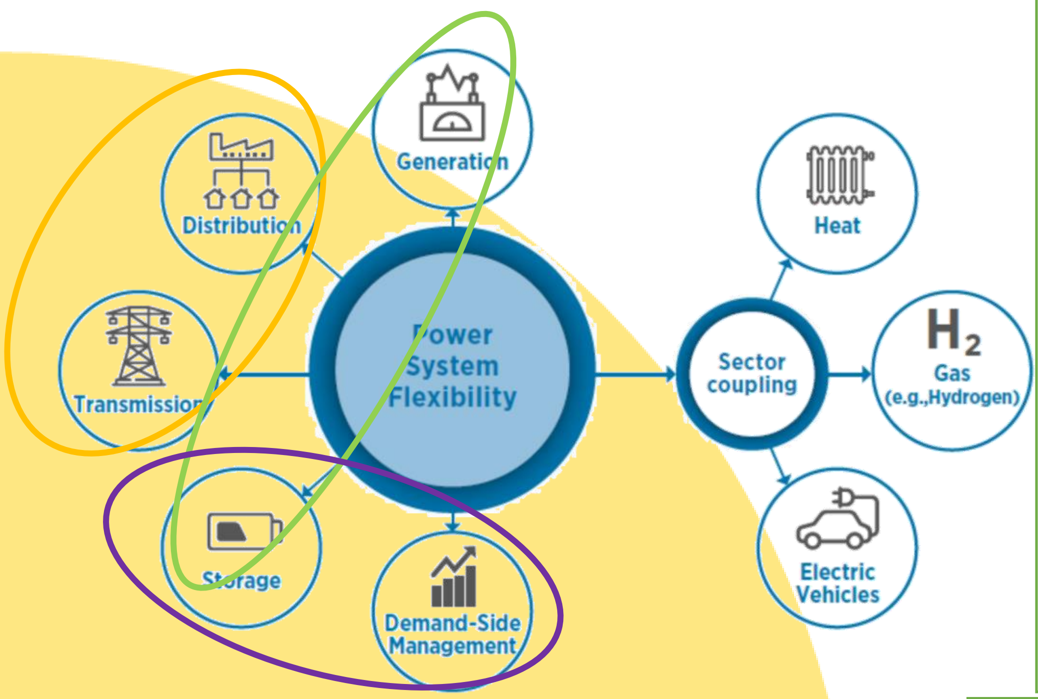
Representation the variable renewable energy supply (VRES) in the integrated assessment models (IAMs), includes the hourly variability of renewable energy modeled in EnergyPLAN software. Hourly effects of the integration have been accessed. Finally, flexibility options are recommended to accommodate this variability within existing energy system based on flexibility tecnology options and sectors coupling.

Technology options of power system flexibility extended with sector coupling (IRENA 2018b). Subchapter 1.1: green **– supply level,** yellow **– network level,** purple **– demand level**



Motivation for research

Integration of world-wide available solar and wind energy technologies into the energy systems at high share depends on its flexibility to respond to variability within **time scale of minutes and hours.** This problem has been tackled in a few studies[123] so far, but none modeled 100% renewable energy system[4] which is an almost perfect decarbonization option.

What? Representing variability of renewable sources in IAMs

1. The significance of flexibility and sector coupling **options**
2. Table represents the current use and potential significance of flexibility technologies
3. Importance of modeling flexibility technologies at hourly level in IAMs

How? Using hourly simulations (EnergyPLAN):

1. Simulation of energy generation technologies and consumption (balanced hourly)
2. Calculation: Critical Excess Electricity Production (CEEP) which must be exported (hourly, yearly)
3. Simulation of flexibility options to reduce CEEP

Example ? Bulgaria 100% renewable national energy system scenario

Why? CEEP for any scenario of renewable energy + flexibility technologies

- Capacity factors (CF) for generation technologies in energy system by simple relationships: **Energy=f(Capacity)**

Future? Possible generalization of equations to be used in WILLIAM

EnergyPLAN (https://www.energyplan.eu/about/) used for modeling energy system flexibility gap at hourly level on **supply**, **network** and **demand** levels.

Flexibility technologies **(Table on the right)** at demand (**D**), network (**N**) and supply (**S**) side of energy system currently available commercially (**Com**), or at demonstration stage (**Demo**), or even at feasibility stage (**Feas**), *currently* ***modelled*** in IAMs or ***relevant*** *for the modelling* in IAMs in future. This way:

- Existing modeling framework may be extened with **realistic CF** for the generation and storage tecnologies and **realistic flexibility gap** (CEEP), based on the hourly simulation, instead of exogenous assumptions.
- The sumulations might be perfomed for various ***climate and resource availablity*** scenarios.
- The relevant flexibility options could be modeled with a range of VRES capacities and options 0-100% keeping the CEEP acceptably low, with different ***flexibility strategies***.
- The different ***criteria*** might be imposed to these strategies to find optimal one to be suggested to decision makers (e.g. minimal monetary costs, CEEP...)
- Different ***constraints*** might be imposed to these critieria funcitons (e.g. at least share of renewable energy sources).

Technology	Level	Phase	Modelled in IAMS	Relevance
Pumped hydro storage	S	Com, 1900's	Yes	***
Compressed air energy storage	S	Com, 1970s	Yes	*
Utility scale batteries	S	Com, 2000s	Yes	***
Power to x (power to hydrogen)	S	Com, 2010s	Yes	**
Interconnector enhancements	N	Com, 1900s	No	***
Dynamic line rating	N	Demo, 2000s	No	*
Direct load control	D	Com, 1980s	No	*
Demand response – consumers active	D	Demo, 2010s	No	***
Household batteries	D	Com, 2020s	No	**
Electric vehicles	D	Com, 2015s	Yes	***
Heat storage	S	Feas, 1980s	No	**
Seawater pumped storage	S	Com, 1990s	No	*
Underground reservoir pumped storage	S	Feas, 2020s	No	*
Gravity Energy Storage	S	Demo, 2010s	No	**
Liquified Air Energy Storage	S	Demo, 2020s	No	**
Thermal Energy Storage	D	Feas, 2020s	No	*
Desalinization, smart-pumping etc	P	Demo, 2000s	Yes	**
Super capacitors	S	Com, 2000s	No	*
Super conducting magnetic energy storage	S	Com, 2000s	No	*
Flywheels	S	Com, 2000s	No	**
Compressed Carbon Energy Storage	S	Demo, 2020s	No	*

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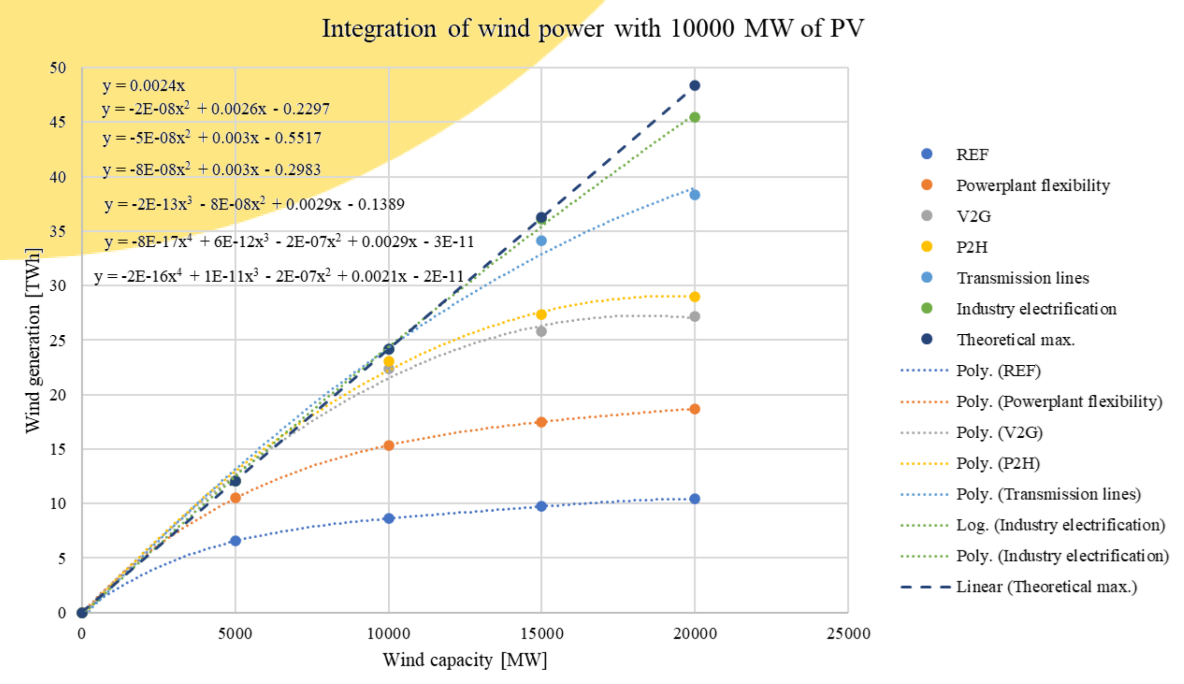

Given energy system with increased wind capacity, (**Figure on the left**) should be considered as general one, dependent on location and type of variable energy sources. However, families of figures from other energy systems exist due to differences in the conditions where they are involved (climate, policy, technology, etc.). Ideally, a VRES such as wind should be utilized at the maximum capacity as long as possible (max CF –theoretical max expressed as **black doted line**). Sector coupling of electricity sector is useful with: district heating (“**P2H**” – yellow line) and smart electrified transport (“**V2G**” - gray line). Other relevant flexibility options are: flexible power plants, the industry electrification, and additional transmission lines for increasing the interconnection’s capacity. Without sector coupling, reference energy system (REF) can integrate a limited amount of energy generated, leaving a large CEEP and a low CF for wind. In presence of sector coupling and other technologies to alleviate the flexibility gap, the utilization of the variable renewable energy converges to its theoretical maximum, even for higher wind power capacities. This is an advantage, comparing with existing assumption regarding CF for different tecnologies in IAMs. Further work, is dealing with issue of reaching the exact level (*constraint*) of renewable energy in final energy consumption (up to 100%) by applying *flexibility options*, under defined *optimality criteria* to find *optimal flexibility strategy*.

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