Sector coupling and system integration – key elements of the next phase of the energy system transformation

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Climate targets (e.g. following the Paris agreement of 2015) are the main drivers for transformation of our energy systems worldwide. However, recently prices for electricity generation from renewable energy sources such as solar PV and wind have become so low, that installing these systems has become economically viable even without incentives such as feed-in-tariffs. Latest electricity prices for photovoltaic in PPA's (power purchase agreements) were below 4 €-Cent per kWh even under Germany's climatic conditions. A high penetration rate of volatile renewable energy sources, however, causes major challenges on the overall energy system in terms of stability, security of supply and system control and management and thus adds to the total costs. Holistic modelling and optimization of pathways of energy system transformation can help to determine which technologies are needed at what time in order follow target trajectories for reducing greenhouse gas emissions of the energy sector at minimized overall cost. In our contribution we desribe results of different scenarios based on different boundary conditions for the transformation of Germany's energy system including all energy sources and all end-use sectors. Some robust findings which come out as result of this analysis are:

- PV and wind are becoming the dominating electricity sources.
- An increasing electricity demand will occur. Reason is that decarbonization of sectors such as heat and mobility, which today are dominated by the use of fossil energy sources, can only be realized by using higher shares of electricity („sector coupling") in these sectors. For Germany this may lead to an increase of net electricity use from about 500 TWh today to 750 – 1000 TWh in 2050, depending on the particuar boundary conditions.
- We observe a shift from a system in which generation follows demand to a system where at least partly demand follows generation. A more complex system will result in which a continous management and optimization has to be organized in order to balance demand and generation. Both, flexible residual power generation and flexible energy use will be increasingly needed. Intelligent communication and data processing technologies will be necessary in order to enable the management oft he complex system.
- A significant backup power has to be installed in order to bridge long phases with little renewable energy availability.

Beside robust findings there are also areas where different options and thus degrees of freedom in system development exist. For instance, climate targets may be achieved with different compositions of techologies in the mobility sector for road traffic (e.g. electric engines with batteries, hydrogen, synthetic fuels produed with renewable electricity, various hybrid concepts).

Optimized pathways for energy system transformation indicate that the development over the next decades should follow some major structural phases. From these phases, that will be described in more detail in our contribution, major needs for technology development and implementation can be deduced as well as some key policy instruments and market framework requirements which support a cost optimized transformation.