Question 3.2.1 *What are international experiences on matching between increasingly top-down energy targets and private driven generation/storage investments? And how do grid operators organise their grid planning in this increased complexity?*

Top-down energy targets and private driven generation/storage investments result in a change of the energy system. However, it is unknown how these top-down energy targets will evolve, and what the impact is of these targets on energy consumption and investment behavior of public or private actors resulting in a changing landscape of generation / storage assets.

The grid capacity in a geographic area should be planned to facilitate this evolving energy system. The long lead times of grid capacity expansion projects require grid operators to plan capacity investments on possible future transport capacity requirements in the medium-term. Furthermore, spatial and executional constraints limit the maximum rate of future long-term grid capacity expansion. Therefore, for grid planning, the potential transport capacity growth in the long run is also important to take into account.

So, grid operators need to consider the potential evolution of the energy system over a long time horizon for understanding the possible range of future transport capacity demand evolution over the planning horizon. In this long time horizon, the possible ways the energy system can evolve is huge. In other words, the future energy system evolution is deeply uncertain. This poses a challenge for grid planning. How does this deep uncertain system evolution looks like and what evolutions do we consider to be socially desirable? Which investments should be planned now in order to facilitate the wide range of socially desirable possible energy system evolution pathways while keeping the risk of stranded assets to an acceptable level? Which variables in the energy system should be monitored for a timely future adaptation of the investment plan to adequately respond to future potential growing transport capacity demand?

In the current practice of grid planning three to four scenario (cornerstone) points, describing possible future states of the energy system, are used for the representation of the uncertainty of the energy system evolution. Energy infrastructure capacity plans are created that can fulfill the transport requirements in these scenarios. This information forms the basis for capacity investment planning for an individual grid operator. In this practice, the dependency of energy system evolution by grid planning decisions of other grid operators in the same geographic region, is not always taken into account.

Shortcomings of this current practice are among others that no deep uncertainty about the energy system evolution is taken into account. The definition of scenario cornerstone points aims at the upfront prediction of the limits of the energy system evolution that lead to extremes in transport capacity demand evolution. This, however, is impossible, given the wide range of possible energy system evolution pathways and the very diverse consequences for energy transport capacity development over time. Furthermore, the current practice does not lead to an adaptive investment plan that enables timely decision-making on additional grid expansion investments in dealing with the uncertainty about the future transport capacity demand growth. Suboptimal alignment of investment plans of grid operators, that jointly enable pathways for energy system evolution, is another feature of the current practice of grid planning that risks a timely energy transition.

In order to cope with the shortcomings of the current grid planning practice a consortium has developed the Gridmaster method. Basis of this method is the stress testing of an investment path in many transient scenarios for the potential energy system evolution. This investment path considers multiple energy grids to enable coordination of investments across these grids. For stress testing, instead of three to four scenario (cornerstone) points, a scenario space is developed that comprises a huge set of transient scenarios for the potential evolution of the energy system. Via large scale simulation, the evolution of overload in different grids, e.g. the methane, hydrogen and electricity grids, across many scenarios is examined.

Analysis of this large scale simulation results, leads to insights into the possible range of overload evolution in the considered energy grids. This leads to insights into necessary no regret investments to deal with the medium-term uncertainty of transport capacity demand evolution. By planning these no regret investments, sufficient additional transport capacity is created for the facilitation of all or the majority of potential scenarios in the medium-term.

Via the application of an advanced algorithm on the simulation results, the main drivers for overload evolution of the considered energy grids in the long run are revealed. This information is used for the creation of adaptive investments. Adaptive investments are potential future investments that are only planned in case the long-term evolution of the energy system requires additional transport capacity on top of the realized transport capacity in the medium-term. By monitoring the main drivers for transport capacity growth, it can be assessed whether or not specific adaptive investments should be launched. In case the main drivers for transport capacity growth evolve in such a way that the transport capacity demand will not grow, no adaptive investments need to be planned. On the other hand, in case these drivers evolve in a way that the transport capacity demand is likely to substantially grow, these adaptive investments should be planned in order to facilitate the evolving energy system. In this way, these adaptive investments enable timely sufficient transport capacity for the facilitation of the energy transition while stranded assets in energy infrastructure are prevented as much as possible.

In summary, the increasingly top-down energy targets interact with future investment decisions in generation and storage assets by private actors in an unknown way. This leads to deep uncertainty about the transport capacity demand evolution over time, posing a challenge in grid planning. In order to deal with this deep uncertainty, the Gridmaster method has been developed. Stress testing of an investment path of integrated energy infrastructure leads to insights in no regret and adaptive investments. This leads to coordinated adaptive investment plans across different energy grids that effectively deal with this deep uncertainty: future socially desirable energy system evolution pathways can be facilitated while the risk on stranded assets is limited to an acceptable extent.