WP2 Task 2.3

Scenarios for feasible infrastructures in Finland

ABSTRACT

The objective of the task 2.3 was to showcase a holistic scenario building and analysis of energy systems infrastructures in Finland. The aim was to develop tools and methodologies for a universal case for optimal operation of energy systems and sector-coupling. The future energy system of Finland consisting of electricity, heat, hydrogen, and CO_2 grids and storages was modelled in Backbone modelling environment based on GAMS (General Algebraic Modelling System) modelling engine.

Scenario analyses showed how these different cases affect the national energy system structure and operation including system flexibility needs, energy balances in different regions of the country, and needs of electricity and hydrogen transmission between different regions. Analyses showed the need to strengthen the power grids, either electric or gas grids, depending on the locations of hydrogen production units compared with electricity production units. Also the vital need of flexible energy resources, i.e. flexible operation of electrolyzers to follow variable renewable electricity production, energy storages (mainly hydrogen and heat) to buffer energy for end-use, import and export electricity transmission capacity to smooth and optimize energy production and usage on Nordic and northern Europe area, renewable electricity production curtailment in extreme excess situations to optimize required transmission and storage capacities, and the integration of electrolyzer waste heat to district heating systems to enhance the overall efficiency, were shown.

MOTIVATION

The value chain of a Power to X (PtX) economy is a system of systems consisting of several links from renewable electricity production and markets to hydrogen production, various PtX synthesis units, storage and end use. This system of systems includes sectoral interconnections between different systems such as district heating, biogenic CO_2 capture, and energy transmission and storing in different forms. One key issue is how the operation of variable renewable electricity powered electricity production can be matched with hydrogen end use in different industrial processes operated typically at constant production conditions. A systemic approach is needed to analyze what kind of structures, components and properties are needed to make the whole value chain operable. Systemic analysis is based on dynamic modelling and simulation of the system at electricity market time resolution. It is used to define needed generation, transmission, demand response and storage capacities and their locations to make the whole system techno-economically feasible.

RESULTS

The first result of this task is the energy system model framework (Backbone) applied to scenario analyses. Three different scenarios for years 2035 and 2050 were modelled and analyzed, Business as Usual (BAU), Self Sufficiency (SS), and Maximal Utilization (MU). BAU scenario was based on moderate increase in investments on green energy, in SS scenario all national energy consumption was supplied by national green energy investments, and in MU scenario national renewable electricity potentials were highly utilized to produce energy also for high volume export business.

The Backbone model divides Finland in nine regions and includes a huge amount of information about the components, structures, and sectoral interconnections, how the national energy system is built up and running. The second result is the scenario analyses illustrating how much electricity and hydrogen production capacities are needed for supplying needs for BAU, SS and MU scenarios, and how these different configurations influence on the operation of the whole energy system.

Electricity and hydrogen transmission requirements depend on the location of production and use of hydrogen. The main cases are that the hydrogen production units are co-located near renewable electricity production, or the production units are located near end use and end product production areas based on hydrogen. The existing industrial sites are mainly in southern part of Finland. In the first option a large share of energy must be transmitted as hydrogen via gas grid and in the second option as electricity via electric grid. Figure 1 shows electric and hydrogen energy imbalances (annual production vs. consumption) in nine regions of energy system model. The simulated cases are BAU and SS for 2035. In both scenarios the installed wind power capacity was 35 GW located mainly in coastal areas and northern part of Finland, and solar PV capacity in BAU 8 GW and in SS 35 GW was distributed to southern part of Finland. Case SS is simulated with two different locations of electrolyzers, co-located with renewable electricity production and co-located with hydrogen end use.

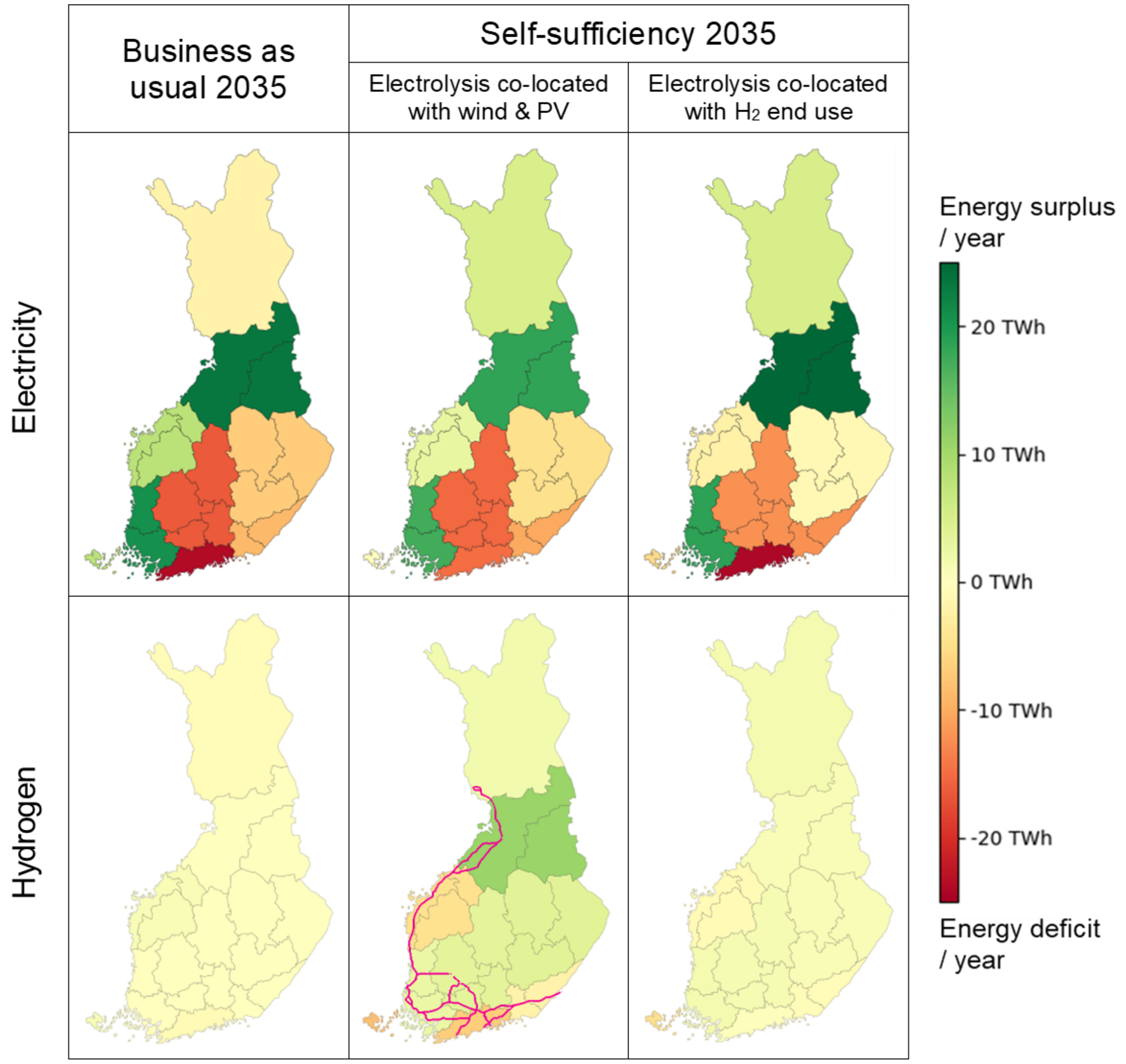

Figure 1. Electric and hydrogen energy imbalances of 2035 scenarios in Business as Usual and Self-Sufficiency cases for year 2035. Self-Sufficiency scenario is analysed with two different locations of electrolyzer plants, near electricity production and near end-use.

Energy imbalances between regions must be balanced by energy transfer between surplus and deficit areas. Figure 2 shows the duration of the curves of electric power transmission for the biggest importer and exporter regions. The peak electricity transmission capacity increases remarkably compared to the existing available capacity and varies quite a lot depending on the scenario. The existing transmission capacity is about 4000 MW between northern and southern Finland but note also that the Figure 2 is not representing the total power flow between north and south. Especially in SS scenario B, where electrolyzers are co-located with existing industrial sites increases the need for electricity transmission capacity. In SS scenario A, part of energy from excess to deficit areas is transferred in the form of hydrogen, which naturally decreases the need for electricity transmission capacity. Without energy storage and renewable electricity curtailment, the need for the peak electricity transmission capacity would be higher.

The duration curve of SS scenario B is also steeper than other two scenarios, which means that it utilizes the electricity transmission capacity less efficiently, which leads to situation where the electricity grid investments are required to payback with higher electricity transfer usage per unit cost. Therefore, the mechanisms to reduce the electricity transmission need would be very welcome to avoid investments for transmission capacity used very seldomly. Other option is to utilize the internal congestion management of Finland price area to avoid internal bottleneck, but the operation cost of redispatch or counter trading might increase to very high level. In the future, the option to divide Finland to two price areas might be necessary, if the investments for electricity transmission capacity are not progressing as fast as the investments for renewable electricity and electrolyzes. This is likely to happen, because the project timeline from the decision to build to the deployment of the investment is several years longer for electricity grid compared to renewable energy or a hydrogen production plant. Two or more price areas within Finland would remarkably impact for electricity cost of consumers in deficit areas (increasing) and producers in excess areas (decreasing), which would impact negatively for many electrification investments already made and those to come.

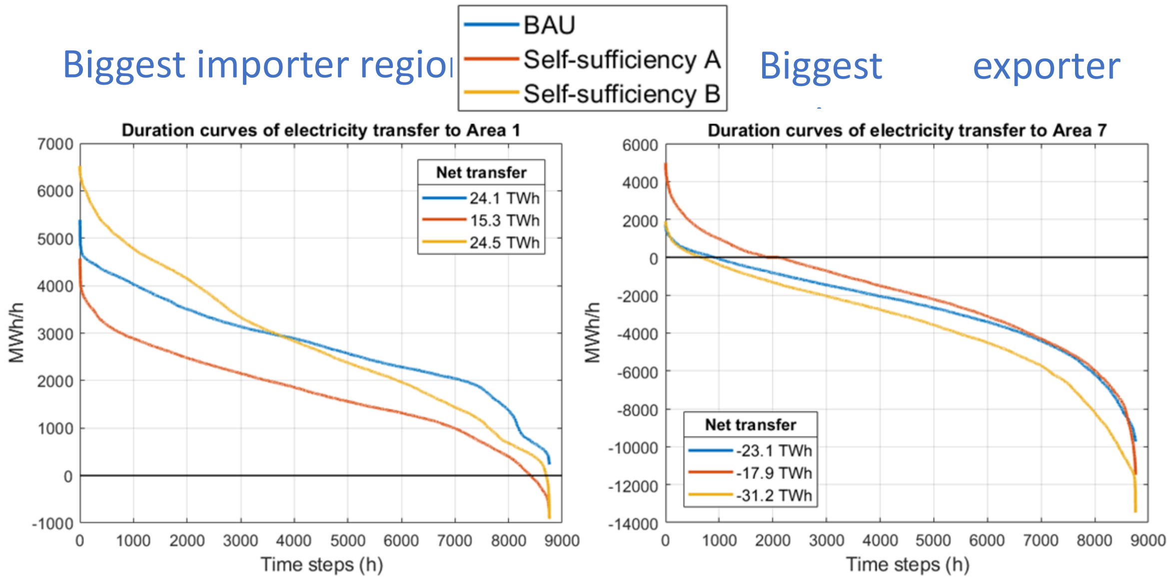

Figure 2. Simulation results showing a) the variation of the feed streams and reaction products, b) power of the compressors, c) heat duties of heat exchangers, d) compressor discharge temperatures.

The third category of results is presented in the Table 1. The electricity generation and consumption would increase from existing about 80 TWh level to remarkably higher levels and the primary energy sources in these scenarios have been wind and solar power. The balance of power system has achieved by curtailing about 2 TWh of variable renewable energy (VRE), by utilizing import and export capacities extensively (roughly 10 % of electricity is balanced in larger area than in Finland), and by utilizing electrolyzers flexible way and storing hydrogen to buffer storages. The approximation of the required hydrogen storage capacity needed to run the energy system consisting of variable hydrogen production and constant load operation of the hydrogen end use was estimated to be 2,5 TWh in BAU scenario and 8 TWh in SS scenarios. These are rough estimates but illustrate the huge need of storage capacity needed to balance the system, and the size depends on how flexible the electricity production and the demand side will be in the future.

Table 1. Characteristics values of BAU and SS scenarios.

	BAU2035	SS2035A	SS2035B
Electricity generation (TWh)	173,9	189,3	189,3
Electricity consumption (TWh)	172,2	191,2	190,9
Electricity generation, wind (TWh)	101,2	90,8	90,8
Electricity generation, PV (TWh)	7,7	33,4	33,4
Curtailed VRE generation (TWh)	1,8	2,23	2,24
Imported electricity (TWh)	16,4	19,3	19,5
Exported electricity (TWh)	15,4	14,9	14,8
Peak electricity load (GW)	29,9	36,8	36,9
Electricity to H2 production (TWh)	47,4	68,0	67,7
Maximum H2 storage capacity used (TWh)	2,5	8,1	7,9

APPLICATIONS/IMPACT

The results of the task help to evaluate the systemic requirements of the PtX economy to the whole energy system. With planned capacities of future hydrogen production and end use facilities, extensive investments are required to strengthen the existing energy transmission system. Increased amounts of energy must be transferred between distributed renewable energy production sites and end-use or final product refinery locations. Although a single hydrogen production plant can be connected to any part of the system, but the total impact of all electrification projects around Finland will create a tremendous impact for the whole energy system infrastructure and market in the long run. Therefore, the collaboration of energy producers, consumers and delivery companies are required to avoid unnecessary infrastructure costs and harmful market impacts. Sectoral interconnections between hydrogen, heat and CO_2 systems must also be considered in the design of the system structures and optimal locations. Model based systemic approach helps also in the evaluation and design of these capabilities. Also, in the early phase of the investment it is important to recognise that, since we are dealing with a system of systems, early decisions lead to a selected paths and the path dependency has to be considered in decision making.

MAIN CONTACT

Sami Repo, Tampere University, sami.repo@tuni.fi

AUTHORS

Yrjö Majanne, Venla Vilhonen, Sami Repo, Matti Vilkko