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144

Hannu Karjunen, Päivi Sikiö, Jukka Lassila, Julius Vilppo, Otto Räisänen, Eero Inkeri, Tero Tynjälä, Petteri Laaksonen

# South-East Finland Hydrogen Valley Project report

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# Abstract

### South-East Finland Hydrogen Valley – Research report

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This report describes the work carried during the spring of 2022 about the hydrogen valley study situated in eastern and south-eastern Finland. The work was carried out by LUT university on the behalf of the local municipalities (Joensuu, Kitee, Imatra, Lappeenranta, Kouvola, Kotka, Hamina) and regional development companies. The co-operation of the local actors in eastern Finland is seen as important to aid the regional vitality and renewal of the industry.

The study characterized the regional opportunities relating hydrogen economy in eastern and south-eastern Finland. The study charted the local industrial actors, current hydrogen producers and users, and most significant $CO_2$ emissions. Using this information, the power-to-X (PtX) production potential using renewable hydrogen was evaluated. The study region covers South and North Karelia, Kymenlaakso and parts of the Eastern Uusimaa (Loviisa, Porvoo). The goal of the project was to evaluate the possibilities and challenges to the development of local industry, as well as map the plausible further actions to promote hydrogen economy investments.

The project had already started prior to the war in Ukraine. Due to the Russian invasion and sanctions arising from it, the project became even more relevant, among other things, because of the restrictions in natural gas, oil and wood imports. The war also limits the transfer of goods and travelling over the eastern border, which will affect many local companies. Then again, the crisis expedited the green transition, thus opening new opportunities to increase energy self-sufficiency, speeding up the fulfillment of climate goals, and enabling the development of new export products.

The study region has significant renewable electricity production potential, and ample amounts of bio-based carbon dioxide – both of which are crucial ingredients for developing new PtX products. The radars related to border surveillance have so far limited the permitting of wind power in the region. The existing electricity transmission grid is also not sufficient to permit the full-scale utilization of the local solar and wind potential. Solving these challenges would enable investments in the scale of billions of euros, bringing new industrial activities to the area, increasing the energy self-sufficiency of Finland and improving the electricity grid balance significantly. The local actors (municipalities, companies, universities, research organizations) have organized and these challenges will be addressed in future projects.

# Tiivistelmä

## Itä- ja Kaakkois-Suomen vetylaakso – tutkimusraportti

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Tämä raportti kuvaa keväällä 2022 toteutettua Itä- ja Kaakkois-Suomen vetylaaksohanketta. Hanke toteutettiin LUT yliopiston toimesta alueen kuntien (Joensuu, Kitee, Imatra, Lappeenranta, Kouvola, Kotka, Hamina) ja alueellisten kehitysyhtiöiden toimeksiannosta. Itä- ja Kaakkois-Suomen kuntien yhteistyö nähdään erittäin tärkeänä alueen elinvoiman ja teollisuuden uudistumisen kannalta.

Hankkeessa selvitettiin Itä- ja Kaakkois-Suomen alueellisia mahdollisuuksia vetytalouteen liittyen. Selvityksessä kartoitettiin alueen teolliset toimijat, nykyiset vedyn tuottajat ja kuluttajat, sekä merkittävimmät $CO_2$ päästölähteet. Näitä tietoja hyödyntäen arvioitiin uusiutuvaan vetyyn pohjautuvien Power-to-X (PtX) tuotteiden tuotantopotentiaalia. Tarkasteltava alue kattaa Etelä- ja Pohjois-Karjalan, Kymenlaakson sekä osan itäistä Uuttamaata (Loviisa, Porvoo). Hankkeen tavoitteena oli arvioida mahdollisuuksia ja haasteita alueen teollisuuden kehitykselle, sekä kartoittaa mahdollisia jatkotoimenpiteitä vetytalousinvestointien edistämiseksi.

Hanke oli käynnistetty jo ennen Ukrainan sotaa. Venäjän hyökkäyksen ja siitä seuranneiden pakotteiden vuoksi hanke nousi entistä ajankohtaisemmaksi mm. Venäjältä tuodun maakaasun, öljyn ja puun tuontirajoitusten seurauksena. Sota rajoittaa myös ihmisten ja tavaroiden liikkumista itärajan yli, mikä tulee vaikuttamaan moniin alueen yrityksiin. Toisaalta kriisi nopeuttaa vihreää siirtymää, avaten uusia mahdollisuuksia energiaomavaraisuuden kasvattamiseen, nopeuttaen hiilineutraaliustavoitteiden saavuttamista, sekä mahdollistaen uusien vientituotteiden jalostamisen.

Tarkastelualueella on merkittävää uusiutuvan sähkön tuotantopotentiaalia, sekä runsaasti bioperäistä hiilidioksidia – joista molemmat ovat keskeisiä raaka-aineita uusien PtX-tuotteiden kehittämisessä. Rajavalvontaan liittyvät tutkat ovat rajoittaneet tuulivoiman kaavoittamista alueelle. Olemassa oleva sähkönsiirtoverkko ei mahdollista myöskään alueen aurinko- ja tuulivoimapotentiaalin täysimittaista hyödyntämistä. Näiden haasteiden ratkaisu mahdollistaisi miljardi-investoinnit, toisi uutta teollista toimintaa alueelle, sekä lisäisi Suomen energiaomavaraisuutta ja sähköverkon tasapainoa merkittävästi. Alueen toimijat (kunnat, yritykset, yliopistot/tutkimuslaitokset) ovat järjestäytyneet ja näihin haasteisiin tullaan paneutumaan tarkemmin tulevissa hankkeissa.

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# 1 Introduction

The transformation of the energy system will substantially affect future energy production and use. The current fossil-based system will essentially be replaced by renewable energy forms. The increasing share of variable renewable electricity will pose new challenges to the energy transport and storage infrastructure. Power-to-X (PtX) technologies may have an important role in the future in replacing fossil products and balancing variable energy production. A new economy, based largely on renewable hydrogen as an energy carrier, will also chance the geographical energy landscape significantly. A clear vision and a long-term investment plan are necessary for the critical energy infrastructures and industrial sites. To this end, this study focuses on the potential for industrial activities relating to hydrogen economy in Eastern and South-Eastern Finland. The study is continuation of regional studies conducted at LUT University for Carbon Negative Åland (Pyrhönen et al., 2021) and Bothninan Bay area (Karjunen et al., 2021).

In this study, the maximum wind and solar power potentials in the studied region were evaluated based on wind conditions and existing geographical limitations. Also, sources of biogenic and fossil carbon dioxide were evaluated to estimate production potential for different PtX hydrocarbon fuels and chemicals. Geographic information system (GIS) data was extracted and processed from the available open databases (e.g. Maanmittauslaitos, 2021) to perform the analyses. Additionally, the participating entities were interviewed so that the local development projects and relevant companies could be more thoroughly vetted. Based on this initial interview round, eight local companies were then interviewed in separate sessions.

Sector integration between electricity, heat, and fuels is one of the keys for increasing variable renewable electricity in the grid and possibilities for that is also briefly discussed. Based on the maximum potential, some estimates about prospective investment needs for the energy infrastructure (electricity and gas grids), and different options for energy transmission were compared. Also, an estimation about the possible investments for energy production were conducted.

The aim was to make prefeasibility study of regional potential on upper level, as well as network and organize between different actors (cities, industry, research institutes) in the area. The study does not go to details and is not meant to be exhaustive. Possible future funding opportunities are also reviewed to continue elaborating findings of this study in different following projects and strategic planning. The study involved in total six local public entities and development companies from Kotka-Hamina region, Kouvola, Lappeenranta, Imatra, Kitee and Joensuu. The responsibility areas of the listed actors also extend to the neighboring cities in most cases.

# 2 Power to X processes briefly

Power-to-X process refers to converting (renewable) electric power to different fuels materials or chemicals (X). It is key technology in green electrification, where the aim is to increase share of variable renewable electricity in energy mix significantly and use renewable and recycled resources instead of mining of limited fossil resources. Often by PtX is meant the production of different hydrocarbons from green hydrogen ($H_2$) and carbon dioxide ($CO_2$) captured from air or from sustainable (or difficult to abate fossil emissions sectors) point sources, as presented in Figure 1.

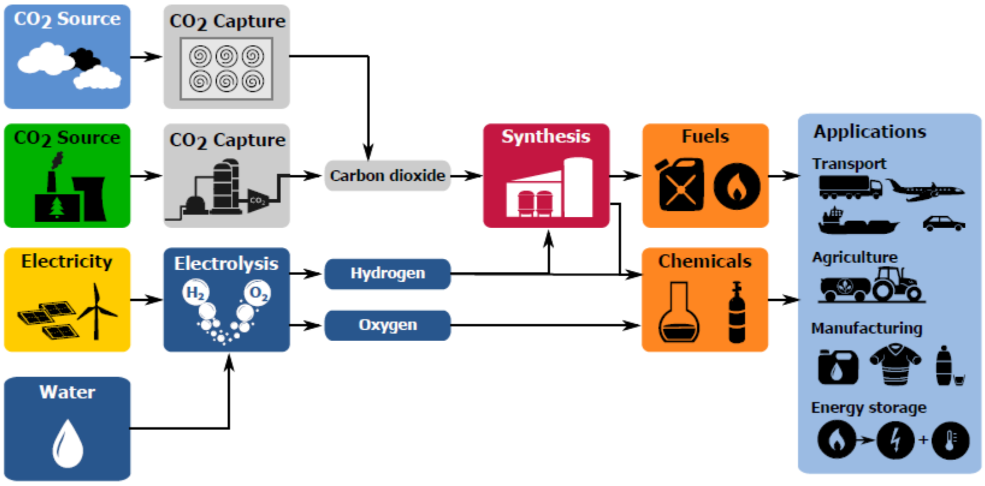

Figure 1 Principle of Power-to-X production chain

Also, other conversions besides $CO_2$ and $H_2$ can be applied such as production of ammonia ($NH_3$) from nitrogen ($N_2$) and hydrogen. In Table 1, some of the most potential PtX products are listed.

Table 1 Some of the most potential Power-to-X products.

| Product | Reaction | Use |
|---|---|---|
| Methane ($CH_4$) | $CO_2 + 4H_2 => CH_4 + 2H_2O$ | Replacement of natural gas/biogas in transport and industry |
| Methanol ($CH_3OH$) | $CO_2 + 3H_2 => CH_3OH + H_2O$ | Transport fuel, base chemical that can be further converted to DME, gasoline, plastics, etc. |
| Ammonia ($NH_{3ph}$) | $N_2 + 3H_2 => 2NH_3$ | Fertilizer, transport fuel |

## 2.1 Selection of PtX plant location

Energy conversions contain always irreversibilities. This leads to an inevitable increase in primary energy consumption when PtX processes are compared to direct utilization of fossil counterparts. In other words, the electricity consumption will increase significantly in the future, despite efficiency improvements in many sectors. To minimize the energy losses and maximize PtX plant productivity, some key aspects that should be considered in plant location are:

- Availability of cheap (emission free) electricity for hydrogen production
    - Direct connection to nearby wind park or hybrid wind/solar park
    - Strong grid connection for transmitting (certified) renewable electricity to site
- Availability of steady concentrated flow of (biogenic) $CO_2$ (not needed for ammonia)
    - Most preferred $CO_2$ from ethanol production or biogas plant (limited volumes)
    - Lime kiln or other industrial biomass boilers with high annual full load hours
    - Industrial and municipal CHP plants
    - Rail/pipeline connection to more distant large steady $CO_2$ source.
- Use for side stream electrolyser (low temperature) and synthesis (medium to high temperature) heat
    - Close to district heating network (preferably with large thermal energy storage)
    - Industrial heat consumer nearby
- Use for side stream oxygen
    - Pulp mills, wastewater treatment plants, oxygen enriched combustion
    - Production process of cathode active materials (CAM) in battery manufacturing industry
    - Hydrogen peroxide production
- Transport of PtX products to markets
    - Good logistic location (rail, road, harbors)
    - Pipeline transport option for final or intermediate products ($CH_4$, $H_2$, $CO_2$)

# 3 Study region

The study region covers the Eastern and South-Eastern part of Finland (Figure 2). Geographically, the region is dotted with numerous lakes, the largest of which is Saimaa that extends also beyond the studied region. Another notable feature of the region is the strong presence of pulp and paper industry, supported by forestry areas as well as road, rail- and waterways for logistic operations. Two nuclear reactors are also located in Loviisa with a combined capacity over 1000 MW. Numerous hydroelectric power stations are also situated in the region. The Imatra hydropower plant is the largest in Finland with a capacity of nearly 200 MW. The Porvoo refinery at the Southern edge of the study region is one of Finland's largest emitters in terms of fossil $CO_2$ emissions.

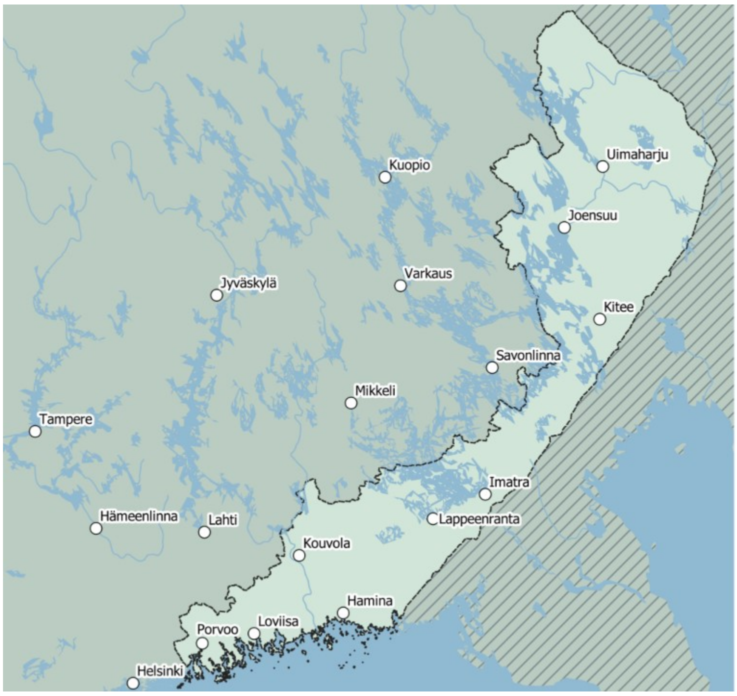

Figure 2. Study region.

## 3.1 Local infrastructure

A natural gas pipeline travels across the southern region of the study area. The distribution of biogas and synthetic methane would thus be possible using the existing pipeline. The conversion of the pipeline to hydrogen is also a possibility in the future. An LNG terminal is also scheduled to be in commercial use by autumn 2022 in Hamina. The terminal could feed 3 TWh of natural gas annually to the grid, as well as an additional 3 TWh by using road transport. There are already plans to increase the regasification capacity (Hamina LNG, 2022). The total consumption of natural gas in Finland in 2020 was 25.4 TWh based on the higher heating value (Energy Authority, 2021).

Regarding the electricity grid, there is a 400 kV main grid connection following the coastline which then routes to Northwest near Lappeenranta. A cross-border connection to Russia is also present, with a capacity of 1300 MW from the Russian side to Finland, and 320 MW the other way around (Fingrid, 2021).

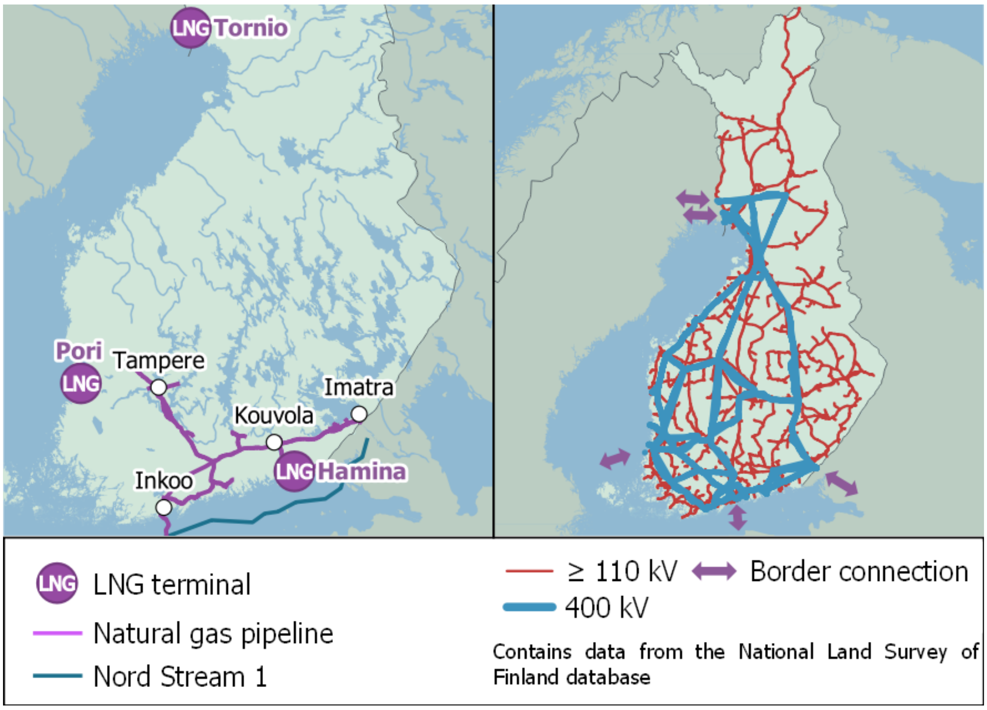

Figure 2. Overview of natural gas (left) and electricity (right) infrastructure.

The freight logistics is supported by the ports of Kotka-Hamina, Kilpilahti (Sköldvik), and Loviisa. Railway junctions at Kouvola and Joensuu are also vital for freight transport. A combined road and rail logistic terminal is being built in the Kouvola RRT project that is scheduled to be completed in 2023 (City of Kouvola, 2022).

The Saimaa Canal connects lake Saimaa to the Gulf of Finland, and the inland water connections enable shipping connections all the way to Joensuu in eastern Finland. Currently the Saimaa Canal is practically unused due to the war in Ukraine and the future of the canal is unclear. For the same reason, energy and pulp wood import from Russia has stopped, which changes the weights of transport directions and causes more load for rail and road transport to Finnish inland directions.

# 4 Hydrogen economy in South-East Finland

This section introduces the local actors in South-East Finland and presents an overview of ongoing activities and future plans relating to hydrogen production and use. Interviews and discussions with the local companies and experts were utilized extensively in the formulation of this section.

## 4.1 Current activities related to hydrogen economy

The identification of potential hydrogen users was started with a general familiarization of the different actors involved with industrial production and other energy-intensive activities. Partially, these were identified from open data sources (Section 4.2). Additional local actors were identified based on the interviews. Some of these are listed in Table 2. In addition to the listed operators, local heat generation and distribution companies, waste management services, and military garrisons were also identified for numerous regions.  As this study can still be considered as a preliminary survey, there are still numerous notable companies and industrial sites which are not included in these presented examples.

Table 2. Notable companies with local activities that were identified in the interviews.

| | | |
|---|---|---|
| Adven | Kolsin Vesivoimatuotanto | Danisko Sweeteners |
| Bakelite | Leca Finland | Solvay Chemicals Finland |
| Fazer | Metsä Board | Suomen Voima |
| Gasgrid | Metsä Group | Surfactor Finland |
| Gasum | Neles | Tetra Pak |
| Google Data Centers | Ovako | UPM Plywood |
| Helen (hydropower) | Roxia | Wienerberger |
| Kemira | Rämö | Woikoski |

Based on the interviews of the local public entities and development companies, some local actors were chosen to be interviewed in separate sessions. The purpose of these interviews was to discover their current activities, plans and thoughts related to hydrogen economy. These actors are presented in Table 3 with their current activities related to hydrogen production and usage. As seen in the table, hydrogen is currently mainly used in refining processes and chemical industry. Hydrogen is usually produced from natural gas. Hydrogen is generated for example as byproduct in the production of formaldehyde to be further used in energy production.

Table 3 Interviewed companies and their current activities related to hydrogen economy.

| | |
|---|---|
| Bakelite Oy | Hydrogen is released in the production of formaldehyde from methanol and is used in energy production. |
| Fortum Oyj | No hydrogen production jet, but hydrogen is one of the main development articles in company strategy. |
| KSS Energia OY | Participating in local pilot projects related to hydrogen. |
| Neste Oyj | Neste is the biggest hydrogen user in Finland. Hydrogen is used in the production of fuels. |
| Savon Voima Oyj | Possibilities related to hydrogen are included in current development plans. |
| Solvay Chemicals Finland Oy | Hydrogen is used to produce hydrogen peroxide. Currently hydrogen is produced from natural gas. |
| St1 | Hydrogen is used at the refinery. Currently hydrogen is produced from natural gas. |
| UPM | At UPM Lappeenranta biorefinery hydrogen is used for production of biofuels. Currently hydrogen is produced from natural gas. |

In addition to the interviewed companies, some hydrogen actors were stated in the interviews of city representatives. Danisko Sweeteners Oy uses hydrogen in the hydrogenation process of xylitol. Hydrogen is generated in Kemira Chemicals Oy facility as byproduct in the production process of natrium chlorate and used by Adven Oy in district heat production. Furthermore, Woikoski Oy is a manufacturer of green hydrogen.

## 4.2 Carbon dioxide sources and users

Based on public emission data from the year 2020 (EEA, 2021), the identified large plants (emitting over 100 kt of $CO_2$ annually) are listed in Table 4, with their corresponding locations in Figure 3. Only emissions from large point sources are readily available from the database, so a significant number of other potential $CO_2$ sources are neglected. Smaller, bio-based $CO_2$ sources could be viable in local applications and early demonstrations. Based on the EU emission trading system register, there are over 70 facilities in the study region that remain below 100 kt/a of annual fossil $CO_2$ emissions, many of which are local heat stations primarily utilizing biomass. One challenge of heat-only stations is their low annual capacity factor, which increases the $CO_2$ capture costs. Biogas plants, breweries and other high-purity sources could also be utilized.

Table 4 Facilities from the region which release over 100 kt of $CO_2$ annually. Data is for the year 2020 (EEA, 2021).

| **Facility Name** | **$CO_2$ total (Mt)** | **$CO_2$ biogenic (Mt)** | **$CO_2$ fossil (Mt)** | **Activity** | **Map ID** |
|---|---|---|---|---|---|
| Neste Oyj, Porvoon jalostamo | 2.66 | 0.00 | 2.66 | Oil and gas | 1 |
| Stora Enso Oyj, Imatran tehtaat | 2.16 | 1.98 | 0.18 | Pulp and paper | 7 |
| UPM-Kymmene Oyj, Kymi | 1.99 | 1.92 | 0.07 | Pulp and paper | 4 |
| UPM-Kymmene Oyj, Kaukaan tehtaat | 1.93 | 1.84 | 0.09 | Pulp and paper | 5 |
| Metsä Fibre Oy, Joutsenon tehdas | 1.46 | 1.43 | 0.03 | Pulp and paper | 6 |
| Stora Enso Oyj, Enocellin tehdas | 1.43 | 1.36 | 0.07 | Pulp and paper | 9 |
| Stora Enso Oyj, Sunilan tehdas | 0.64 | 0.60 | 0.04 | Pulp and paper | 2 |
| Borealis Polymers Oy, Petrokemian laitokset | 0.54 | 0.00 | 0.54 | Chemicals | 1 |
| Kaukaan Voima Oy, Energiantuotanto | 0.50 | 0.45 | 0.04 | Power and heat | 5 |
| Kotkamills Oy, Kotkan tehtaat | 0.49 | 0.25 | 0.25 | Pulp and paper | 2 |
| Kymin Voima Oy, Energiantuotanto | 0.41 | 0.36 | 0.05 | Power and heat | 4 |
| Finnsementti Oy, Lappeenrannan sementtitehdas | 0.32 | 0.00 | 0.32 | Cement | 5 |
| Savon Voima Joensuu Oy, Joensuun voimalaitos | 0.26 | 0.17 | 0.09 | Power and heat | 8 |
| Stora Enso Publication Papers Oy Ltd, Anjalankosken tehtaat | 0.22 | 0.13 | 0.08 | Pulp and paper | 3 |
| Linde Gas Oy Ab, Kilpilahden vedyntuotantolaitos | 0.19 | 0.00 | 0.19 | Chemicals | 1 |
| Porvoon Energia Oy, Tolkkisten voimalaitokset | 0.16 | 0.16 | 0.00 | Power and heat | 1 |
| Kotkan Energia Oy, Hovinsaaren voimalaitos | 0.14 | 0.09 | 0.05 | Power and heat | 2 |
| **Total** | **15.5** | **10.8** | **4.7** | | |

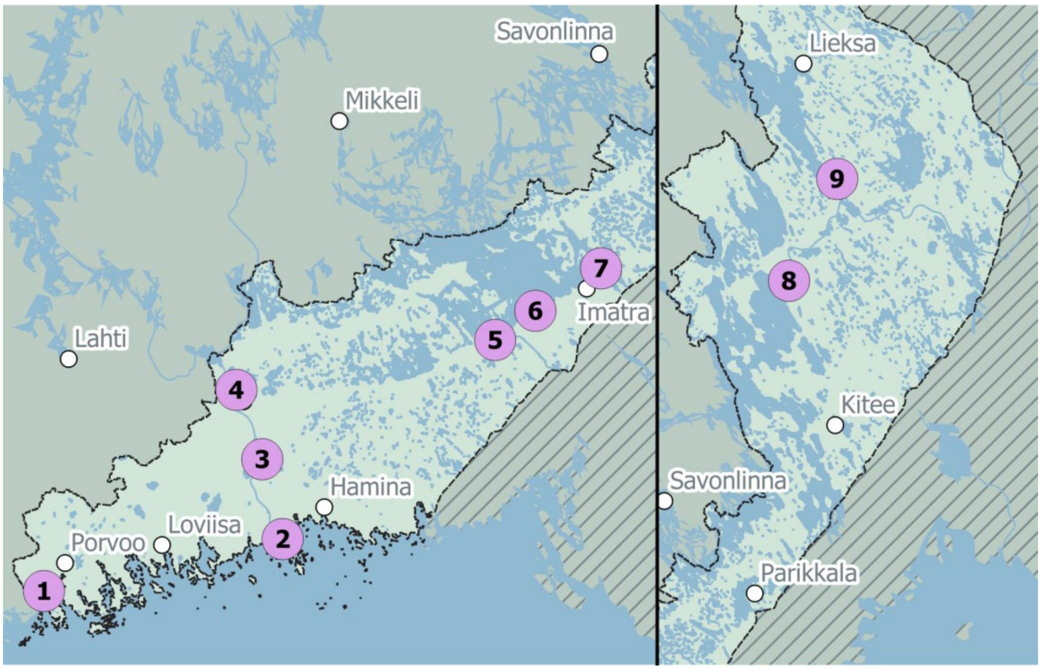

Figure 3. Location and identification number for large point sources of $CO_2$.

The interviewed companies disclosed their current activities and plans related to $CO_2$ usage, generation and Carbon capture and storage (CCS) as shown in Table 5. Possibilities are seen in the carbon capture for production of synthetic hydrocarbons, $CO_2$-based products, such as polycarbonate, as well as for permanent storage.

Table 5 Initiatives, plans and projects related to carbon dioxide in the interviewed companies.

| | |
|---|---|
| Bakelite Oy | Case Puhos: binding $CO_2$ in formaldehyde resin. |
| Fortum Oyj | Carbon capture for PtX-production is interesting, all synthetic hydrocarbons are possible. Possibilities are seen in $CO_2$ -based products, such as polycarbonate. Carbon capture and storage (CCS) is one probable operation mode. |
| KSS Energia Oy | Carbon capture from combustion processes could be possible. Individual solutions for customers, such as $CO_2$ for the food industry, could be possible. |
| Neste Oyj | The SHARC project includes carbon capture and storage (CCS) solutions. Possibilities are seen in CO2 -based products, such as fuels and chemicals. |
| Savon Voima Oyj | Possibilities are seen in utilizing $CO_2$ from combustion processes in the production of synthetic fuels. |
| St1 | $CO_2$ emissions from refinery activity, carbon capture is planned for production of synthetic renewable PtX fuels. |
| UPM | Research is underway on the carbon capture for production of synthetic hydrocarbons, $CO_2$ -based products and carbon capture and storage. |

The interviews revealed that the $CO_2$ potential in the area has been noticed widely as a possibility to utilize in PtX-technologies. Other possible users of $CO_2$ could be, for example, the food industry and greenhouses.

## 4.3 Other chemicals and materials

Water electrolysis produces significant amounts of oxygen and heat as a byproduct. Significant industrial users of oxygen include steel industry, mining and metal refining industry, pulp and paper sector, and chemical industry. The national oxygen use has been estimated to be 1.3 Mt in Finland (Hurskainen, 2017). In terms of electricity use, about 8.8 TWh would be required to replace the estimated oxygen production with electrolysers. A large portion of the current oxygen production is done on-site, which can complicate the replacement.

Table 6 shows the activities of the interviewed companies related to oxygen and other chemicals and materials. Other actors in the area are Kemira Chemicals Oy in Joutseno and Kouvola, producing chlorate and chlorine dioxide to be used in pulp bleaching, and Green Fuel

Nordic Oy Lieksa facility, which is producing advanced bio-oil from sawmill byproducts and biostem using pyrolysis technology.

Table 6 The production and use of oxygen and other chemicals and materials in the companies interviewed.

| | |
|---|---|
| Bakelite Oy | Methanol and urea are used in the production of phenol and urea formaldehyde resin. |
| Fortum Oyj | Oxygen could be used in oxygen combustion processes. |
| Neste Oyj | Oxygen is used in sulphur recovery units at the refinery. Production of renewable fuels. |
| Savon Voima Oyj | Synthetic fuels could replace oil, that is used for backup and peak production. |
| Solvay Chemicals Finland Oy | Oxygen is used in the production of hydrogen peroxide. Currently oxygen is produced from air. If the needed hydrogen was produced by electrolysis, oxygen would come as a byproduct. |
| St1 | Oil refinery. HVO (Hydrotreated Vegetable Oil, renewable diesel oil) production will begin in Göteborg in Sveden in 2023. Lignin, which is a byproduct of bioethanol production, is being studied for replacing bitumen as adhesive of asphalt. |
| UPM | Oxygen is used for bleaching pulp. Currently, oxygen is bought from an external deliverer. Biodiesel is produced for traffic use. Industrial biochemicals will be produced in biorefinery in Leuna, Germany. |

## 4.4 Current plans and projects related to hydrogen economy

The interviews gave an insight into the plans and initiatives on the field of hydrogen economy. It is apparent that there are a lot of discussions and plans underway in the area. Various operators have an interest on pure hydrogen discussions including traffic use and plans for hydrogen refueling stations in addition to industrial scale hydrogen production. Production of synthetic fuels using PtX-technologies is considered as one good option to utilize green hydrogen.

Table 7 presents some recent public studies on the subject. For example, Case Puhos is an ecosystem modelling of hydrogen-methanol economy. Hydrogen is produced by electrolysis using renewable electricity, and $CO_2$ is captured from waste incinerator. Methanol is generated from hydrogen and $CO_2$, and further used in the production of formaldehyde resin.

Table 7 LUT Studies related to hydrogen economy.

| | |
|---|---|
| Bothnian Bay Hydrogen Valley – Research report (Karjunen et al. 2021) | Hydrogen ecosystem analysis on strategic level for the Bothnian Bay. |
| Case Puhos (Mankonen et al. 2022) | LUT University research report on ecosystem modelling of hydrogen-methanol economy in Puhos, Kitee. Methanol production from hydrogen (produced by electrolysis using renewable electricity), and CO2 (from waste incinerator) and further binding CO2 in products such as formaldehyde resin. |
| Carbon Negative Åland: Strategic Roadmap (Pyrhönen et al. 2021) | Analysis of offshore wind power potential and value creation opportunities for Åland. The most feasible solutions for exporting of green electricity, feasibility of hydrogen production and transmission, alternative strategies, and steps for developing offshore wind-based business in Aland. |
| Feasibility study on synthetic fuels pilot plant in Lappeenranta (Laaksonen et al. 2021) | LUT University and a group of companies performed a feasibility study on synthetic fuels industrial scale pilot plant in Lappeenranta. In the study, the production possibilities and profitability of carbon neutral transportation fuels produced from Finnsementti cement facility CO2 emissions and excess hydrogen from Kemira Chemicals Oy production. |

Specific hydrogen related plans and initiatives of the interviewed companies can be found in Table 8. Many of the companies are exploring the possibility to produce hydrogen by water electrolysis and synthetic fuels by PtX-technologies. Furthermore, the byproduct heat from electrolysis is found interesting. Besides these plans revealed in the interviews, it is also worth mentioning that Kotkan Energia Oy and Nordic Ren-Gas Oy are planning a Power-to-Gas facility producing renewable methane and green hydrogen with electrolyser in Kotka. Moreover, Gasgrid Finland, Kemira Oyj and Ovako Imatra Oy Ab study the potential construction of pipeline infrastructure between Joutseno (Lappeenranta) and Imatra.

Table 8 Initiatives, plans, and projects related to synthetic chemicals (hydrogen, ammonia) and hydrocarbons (methane, methanol, gasoline, diesel, kerosine, urea)

| | |
|---|---|
| Bakelite Oy | Case Puhos. Methanol and urea acquisition is being re-planned due to sanctions on Russia. Methanol could be produced from green hydrogen and CO2. Ammonia would be an interesting source for urea. |
| Fortum Oyj | Large scale hydrogen production through electrolysis (30–500 MW) are considered. Involved in SSAB's fossil free steel project in Raahe to produce hydrogen by electrolysis. |
| KSS Energia Oy | Involved in local hydrogen projects and pilots. KSS Energia is interested in byproduct heat from electrolysis. |
| Neste Oyj | SHARC project (Sustainable hydrogen and recovery of carbon): Electrolysis and carbon capture and storage (CCS) solutions are planned to the refinery. Project is in the feasibility phase. |
| Savon Voima Oyj | Possibilities are seen in utilizing byproduct heat from electrolysis in district heating systems and synthetic fuels instead of oil in backup and peak production. P2X Solutions and Savon Voima study the possibility to produce green hydrogen and e-fuels in Joensuu (electrolyzer capacity 30-50 MW and byproduct heat up to 15-20 % of Joensuu’s district heating). |
| Solvay Chemicals Finland Oy | Hydrogen production by electrolysis is considered as a good option to replace hydrogen production via natural gas steam reforming. |
| St1 | Involved in the synthetic fuels pilot plant project in Lappeenranta. Target is to produce carbon neutral transportation fuels from Finnsementti cement facility CO2 emissions and green hydrogen from electrolysis. |
| UPM | UPM Lappeenranta biorefinery plans to produce the needed hydrogen by electrolysis. |

## 4.5 Current plans and projects related to renewable energy and storage

One key question to energy self-sufficiency in Finland is the utilization of renewable energy production possibilities and potential in South-East Finland. In the interviews with the local actors in the area current plans and projects related to renewable energy were mapped out. It became clear that there is substantial interest in the area in enhancing renewable energy investments. Companies and cities are waiting for the solution to the problem of wind turbine interference to military radars to enable wind power projects in the area. Meanwhile, other renewable projects, such as solar power and bioenergy are advanced. Table 9 shows the main activities related to renewable energy in the area.

Table 9. Current plans and projects related to renewable energy.

| Wind power | Solar power | Bioenergy | Other |
|---|---|---|---|
| There is significant potential in the area. | There is a lot of interest in solar power and multiple projects in progress in the area. | Combustion of wood residues in DH and CHP production is the dominating source of energy in the area. | Lappeenrannan energia oy is interested in and planning on utilizing by-product heat in district heat network. |
| The problem of wind turbine interference to military radars should be solved to enhance wind energy investments. | In Kotka-Hamina area there are several operators considering industrial scale solar power plants up to 100-500 MW. | The amount of biogenic CO2 remains high as wood is substituting use of energy peat within a few years. | KSS Energia Oy: Waste heat is interesting for example from industry and hydrogen production, even small waste heat sources are interesting. |
| Many business actors, national and foreign, are waiting for the solution to military radar problem to start investing in wind power in the area. | Former peat production areas and their immediate surroundings are considered for solar power production in the area especially in Kouvola and Kitee and by Savon Voima | Savon Voima Oyj: Peat will be replaced by biomass. Participating in Taaleri's Joensuu Biocoal Oy, which will build a bioindustry plant producing torrefied biomass in Joensuu. | Savon Voima Oyj: Interested in waste heat from electrolysis and production of bio-coal. Geothermal energy production potential is analyzed in Joensuu in co-operation with Geological Survey of Finland (GTK). |
| New wind power is seen essential for further energy intensive investments in the area. | NEOEN-project in Joensuu: 100 MW solar power plant is planned in Joensuu. | KSS energia Oy: Heat trade expanding to new areas is probably based on biomass-based production. | UPM: Interested in hydropower and nuclear power. |
| . | Forus project, 250 MW solar power plant is planned in Lappeenranta. | Bakelite Oy: Biomass gasification is one option for producing carbon dioxide. | |
| | 3Flash Solar Oy plans 40 MW solar power plant in Imatra. | UPM: Bioenergy is strongly part of the strategy. | |

Energy flexibility is one important part of a self-sufficient renewable energy system. There is a lot of interest in energy storage investments in the area. In table 10 are listed the main findings in the interviews concerning plans and projects related to energy storage.

Table 10. Current plans and projects related to energy storage.

| Electricity | Heat | Hydrogen | Other |
|---|---|---|---|
| There is a lot of interest in the electricity storage in the area to support the electricity network and optimize hydro power production. | Lappeenranta: thermal battery based on phase change technology is in test phase in Mustola. Elstor thermal battery is tested in Kaskein Marja. Rock cavern heat storage is planned. | There is cautious interest in the storage of hydrogen in the area and it is seen important to find suitable solutions for hydrogen storage. | Sector-integration is seen important to optimize the complex system, as well as demand side flexibility and reserve market. Also, water storage in electricity production is found interesting. |
| UPM Energy is investing in an ultracapacitor, which produces fast reserve power at its Ontojoki hydropower plants in Kuhmo. | There is a lot of interest in heat storage in the area. The increasing number of heat pumps increases the need for heat storage. | Short time buffer storage can be useful in hydrogen processes. Long-term storage is possible, if the market situation is beneficial. | Power-to-Liquid fuels are seen as one good option to store electricity. Water storage in electricity production is found interesting. LNG is considered a good option for storing energy. |
| | Lappeenrannan energia Oy investigates the usability of large heat storages. | | Water storage in electricity production is also found interesting. |

One question in the interviews concerned electrification, meaning the replacing of systems using fossil fuels with for example heat pumps, electric boilers, or electric vehicles. The interviews revealed interest in heat pumps in addition to electrification of public transportation and charging infrastructure investments. The table 11 shows some local thoughts in electrification of systems.

Table 11. The plans and initiatives towards electrification of processes and systems.

| **Heat pump systems and heat production** | **Traffic** | **Industrial systems** |
|---|---|---|
| Heat pumps are in an important role in utilizing the waste heat from electrolyser. | Several cities have decided or are considering electrification of public transport. | Industrial heat pumps and electric boilers are seen as one option to replace natural gas usage. |
| The number of heat pumps is seen to increase in the heating systems in the area. | Electric car charging arrangements are being planned in the area. | |
| Kitee: waste heat utilization possibilities are seen in Puhos industrial processes. | Battery cluster producing battery materials is being planned in the Kotka-Hamina region. | |
| Imatran Lämpö considers heat pumps in heat production.<br>Lappeenrannan Energia has an electric boiler project. | In addition to public transportation, in Kotka-Hamina area the harbor transport heavy-duty vehicles are planned to be electrified. | |
| In Joensuu, waste heat point sources are searched actively to be utilized by heat pumps. In apartment buildings and terraced houses heat pump solutions are becoming common and in new company buildings heat pumps are typically part of the energy system. Dispersed settlement oil solutions are being replaced by heat pumps. | | |

# 5 Case studies

This section introduces the methodology used in the case studies and investigations relating to local energy resources from the region. $CO_2$ sources, as well as renewable electricity sources (wind and solar photovoltaic (PV)) are in focus.

## 5.1 Carbon dioxide and power-to-X

$CO_2$ can be converted into various different products by combining it with hydrogen. Power-to-X can also be performed just by using hydrogen. As the market size of power-to-X products is vast, the upper limit of production is likely limited either by the amount of renewable energy, or $CO_2$. Thus, the maximum quantity of available $CO_2$ can be used as an indicator for the production cap, which in turn can be used to estimate the potential electricity demand. In practice, the production volume (and thus also electricity demand) is probably smaller.

A summary of the amount of $CO_2$ obtainable from different sources is given in Table 9. The majority of the $CO_2$ originates from pulp and paper mills, but another significant source is the oil refinery in Porvoo. As a base scenario, it was assumed that 100% of both fossil and biogenic $CO_2$ would be captured and converted into methanol, which functions as a feedstock for several different chemical products. Capturing the fossil $CO_2$ from Porvoo would make little sense in practice if it were merely used as a feedstock for Power-to-X processes, but as the $CO_2$ volumes are in this study related to electricity demand (via water electrolysis and hydrogen production), it is worthwhile to also include the fossil emissions. The estimated electricity consumption is therefore associated with the replacement of fossil hydrogen. More reliable estimations of the viability and volumes related to replacing fossil hydrogen feedstocks is left to further studies.

The portion of utilized $CO_2$ would be much lower than 100%, even for individual sites, as there could be numerous separate streams which release $CO_2$ from different process steps. Furthermore, conventional amine technologies only capture around 90% of the $CO_2$. As a final note, the remaining lifetime and overall suitability of some individual plants could exclude them as a potential capture candidate.

Electricity consumption is estimated by assuming that 0.137 kg of hydrogen is required per one kilogram of $CO_2$, and that 52.55 kWh of electricity is required to produce one kilogram of hydrogen. Additionally, 0.73 kg of methanol is assumed to be formed from one kilogram of $CO_2$.

Table 9. Available $CO_2$ volumes under different scenarios.

| **Scenario name** | **Base** | | | |
|---|---|---|---|---|
| $CO_2$ emission facility type | (All) | (All) | Pulp and paper | (All) |
| $CO_2$ type | Total | Biogenic | Biogenic | Biogenic |
| Portion of $CO_2$ utilized | 100 % | 100 % | 100 % | 20 % |
| $CO_2$ utilized (Mt) | 15.5 | 10.8 | 9.5 | 2.2 |
| Methanol production (Mt) | 11.3 | 7.8 | 6.9 | 1.6 |
| Hydrogen demand (Mt) | 2.1 | 1.5 | 1.3 | 0.3 |
| **Electrolyser electricity demand (TWh)** | **112** | **78** | **69** | **16** |

Power-to-X sites can be placed alongside $CO_2$ sources, but other strategies may also be valid. Sites with significant renewable power potential, or areas that are closer to population centers and heat demand could as well be viable. In this study, it is assumed that $CO_2$ sources would be used to determine the principal location of the power-to-X facility. In Figure 4 Distribution of $CO_2$ point sources in the studied area and share fossil vs. biogenic $CO_2$ (Mt/a).Figure 5 shows the resulting regional distribution of power-to-X electricity demand in TWh.

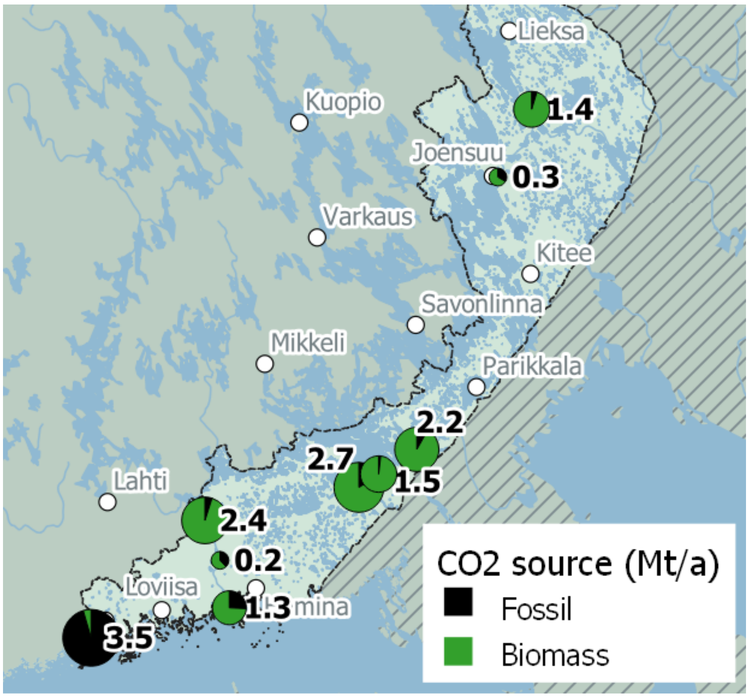

Figure 4 Distribution of $CO_2$ point sources in the studied area and share fossil vs. biogenic $CO_2$ (Mt/a).

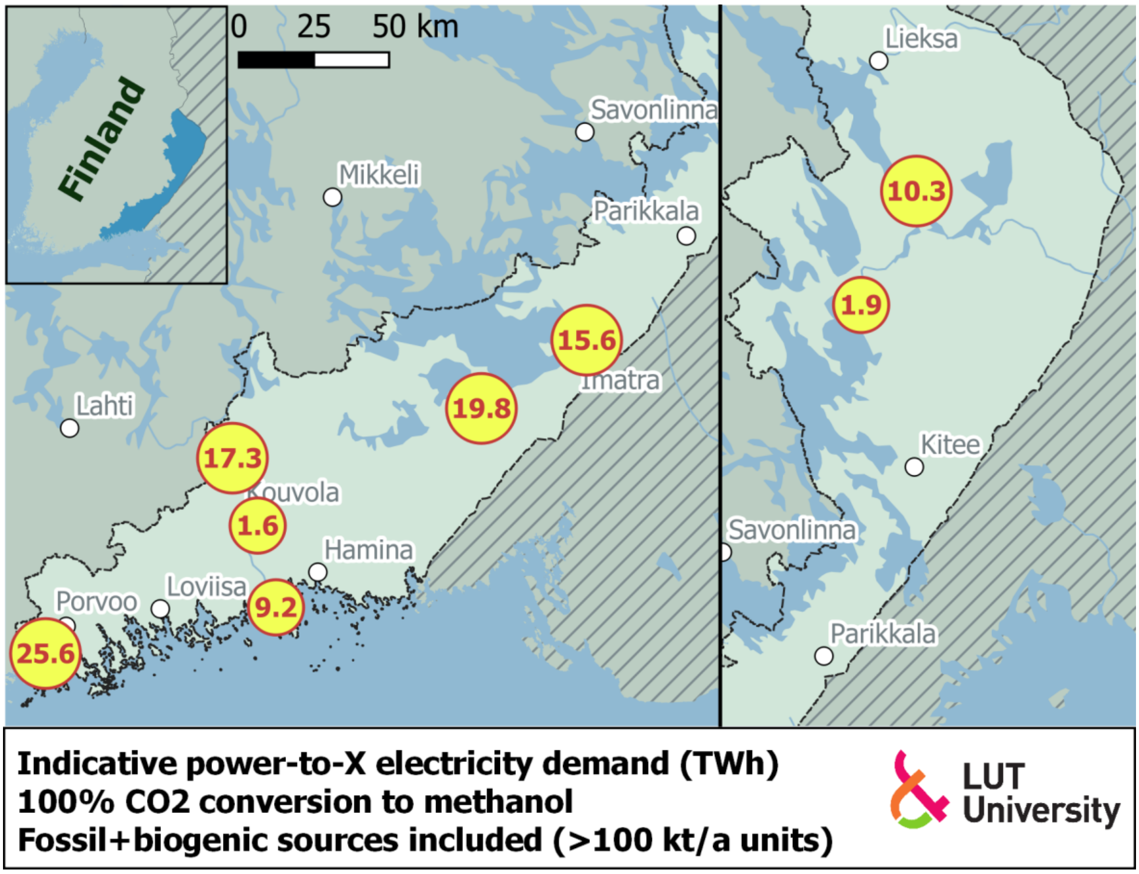

Figure 5. Power-to-X electricity demand when 100% of total $CO_2$ sources are used for methanol production.

## 5.2 Wind power

Wind power would offer a cost-effective renewable power source to the region, but the interference of wind turbines is a significant challenge to air surveillance radars. Numerous wind farm projects have been cancelled due to a statement issued by the Finnish Defense Forces, which puts the region into a disadvantageous position compared to the rest of Finland. The placement of wind farms in Eastern Finland would balance the fluctuations in electricity production as the wind turbines would be placed more evenly inside the nation’s borders. Furthermore, the property tax revenue from wind turbines would be a significant boost to local communities.

Wind conditions in southeastern part of Finland are not drastically different from the rest of Finland. Lake areas are highlighted in the wind atlas data (Figure 6), but these regions are typically used for recreational purposes and thus largely unavailable for wind power.

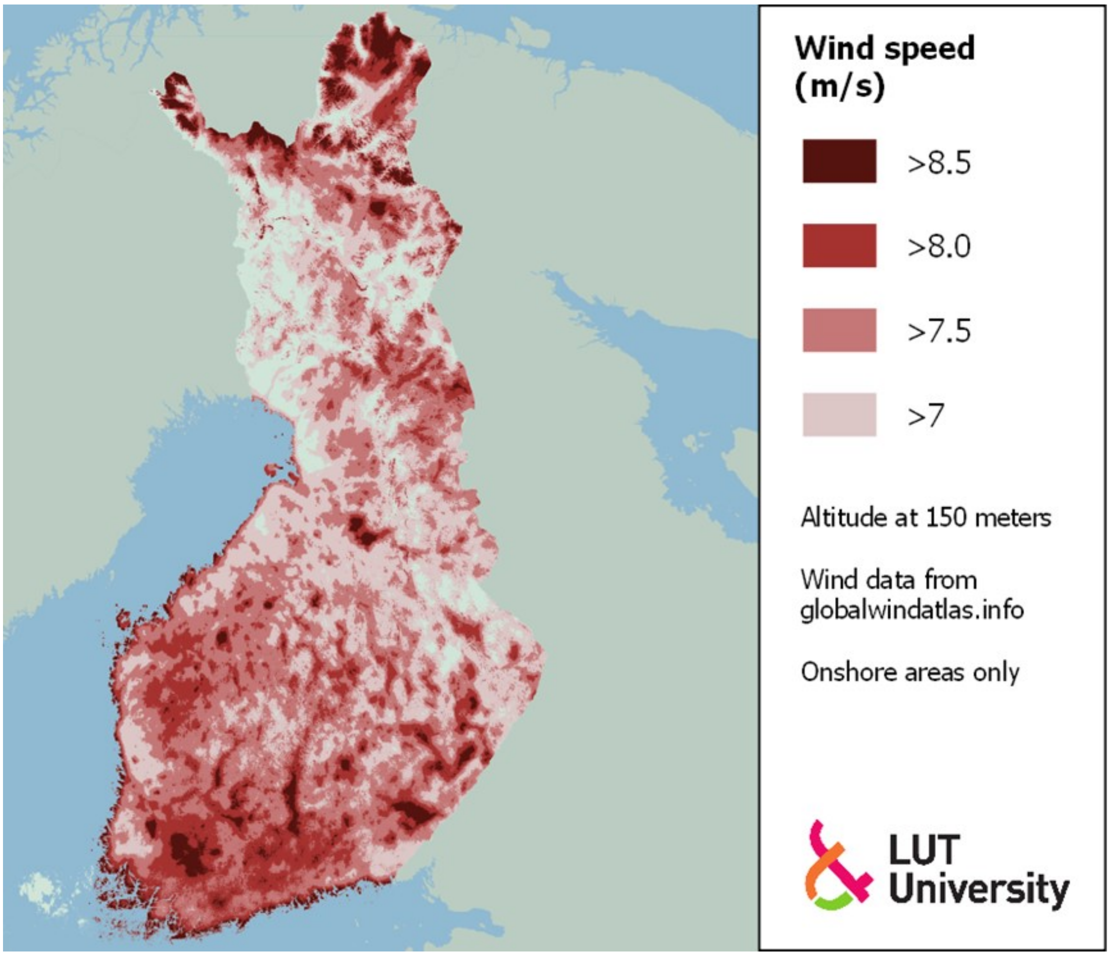

Figure 6. Wind conditions in Finland.

This study assumes that wind farms would be implemented freely without consideration to air surveillance. This approach is beneficial in assessing the economic impacts of land restrictions, which may then be compared to the cost of possible solutions in later studies.

Potential wind power production regions were identified in this study by starting with a blank canvas of the region and then excluding certain restrictive elements from the map. The elements that were considered to block potential wind site locations are listed in Table 10. The most restrictive items were households, built-up areas, and conserved forest areas, hiking areas, and other such nature-related locations. Some parameters relating to the limitations were varied in the analysis, which is why there are different version numbers associated with the items.

Table 10. Wind power location analysis parameters.

| Version | Item | Buffer zone | Description |
|---|---|---|---|
| | Lakes | 0 | Only lakes that have an area of 4 hectares or above were included in the analysis. |
| | Built-up areas | 2 km | |
| V1 | Households and free-time residences | From kernel density estimation | Density limit: 3 buildings of specified type within a 2000m radius. Built-up regions removed first. |
| V2 | Households and free-time residences | From kernel density estimation | Density limit: 1500m radius, 3 building limit |
| | Roads: main | 500 | Primary roads with national ID number 1 - 39 |
| | Roads: other | 300 | Paved roads which have a national ID number greater than 39 |
| | Border zone | 3 km | Buffer zone extending inwards from the eastern border of Finland |
| | Airport | 2km + 4 – 10 km | 2 km circular buffer + 4 – 10 km buffer zone aligned with runway orientation. Larger commercial airports have a larger buffer. |
| | Shooting ranges | 0 | |
| V1 | Nature parks, conserved forests etc. | 1 km | |
| V2 | Nature parks, conserved forests etc. | 0.5 / 1.5 km | 1.5 km with nature parks etc. that are larger than 30 hectares, 0.5 km buffer otherwise |

After the locations for potential wind turbines were identified, a fixed square grid pattern was overlaid into the area to represent wind turbine placements. An illustrative example is shown in Figure 7. Not all turbines would be built in reality, but this approach can give an early indication of possible potential. The ratio of turbines that would be implemented is taken as an additional parameter that is varied in the analysis.

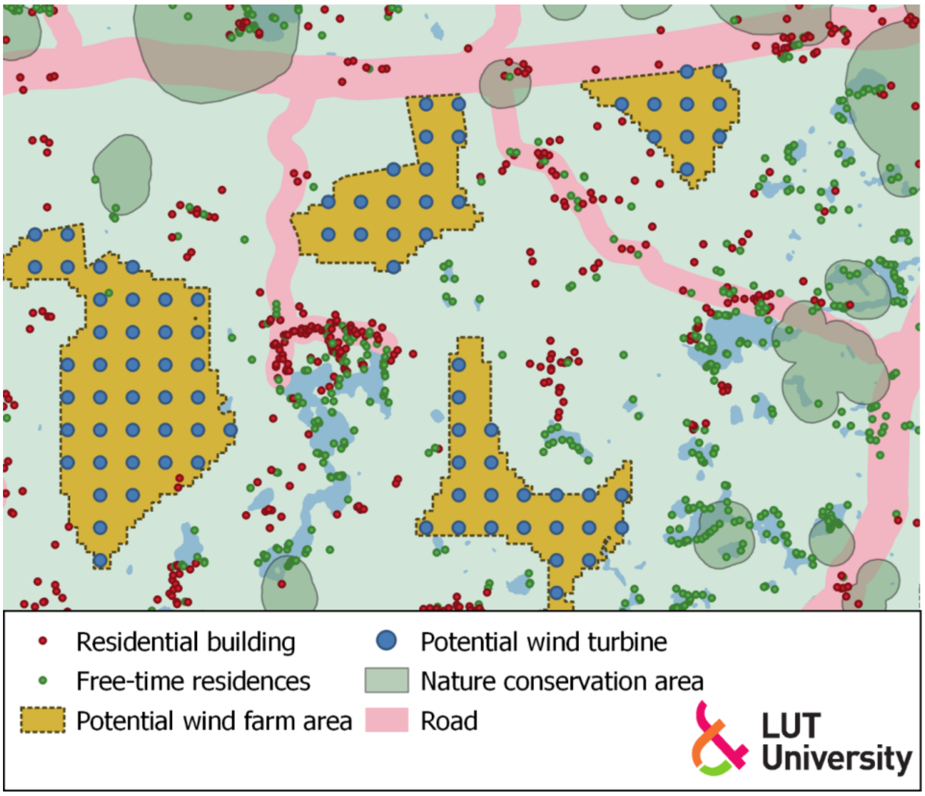

Figure 7. Demonstration of the methodology for locating suitable find farm areas.

The annual average wind speed was extracted from the global wind atlas for each turbine independently. The obtained wind speed at a height of 150 meters was then used to estimate the annual production of each turbine by using a performance curve of a wind turbine manufacturer. The wind speed data was obtained from the Global Wind Atlas (2022).

The height of the turbine has a significant effect on the wind conditions and production. As an illustrative example, the annual average wind conditions for all identified farm areas are illustrated in Figure 8 at three different height levels. The average range wind speeds increases by over 2 m/s when the height is increased from 100 to 200 meters. The energy content of the wind varies with the cube of the wind speed. For instance, a 33% increase in wind speed would result in a staggering 137% increase in the energy content. On the other hand, a higher hub height can also affect the spacing of the turbines, meaning that less turbines could be fitted to the same area.

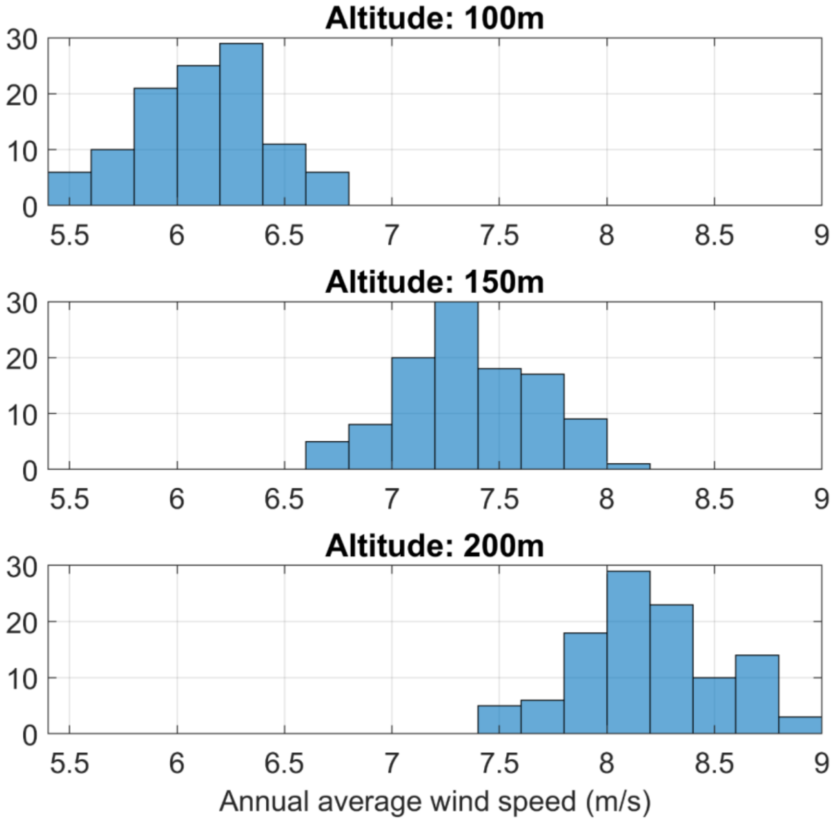

Figure 8. A histogram showing the average wind speed of identified wind farm regions for three different altitude levels.

Figure 9 shows that the best wind conditions are found from the Porvoo-Loviisa-Kotka area, as well as from some minor areas around Lappeenranta, Imatra and Kitee. In Eastern Finland, the best conditions are located beside the Russian border; far from population centers and existing electricity infrastructure. On the other hand, significantly smaller wind farms that are closer to existing infrastructure would likely be techno-economically favorable. Best wind sites were identified on the shores of lakes and beside the sea, but these were considered unavailable due to presence of recreational buildings and households. Offshore wind potential was not estimated in this work.

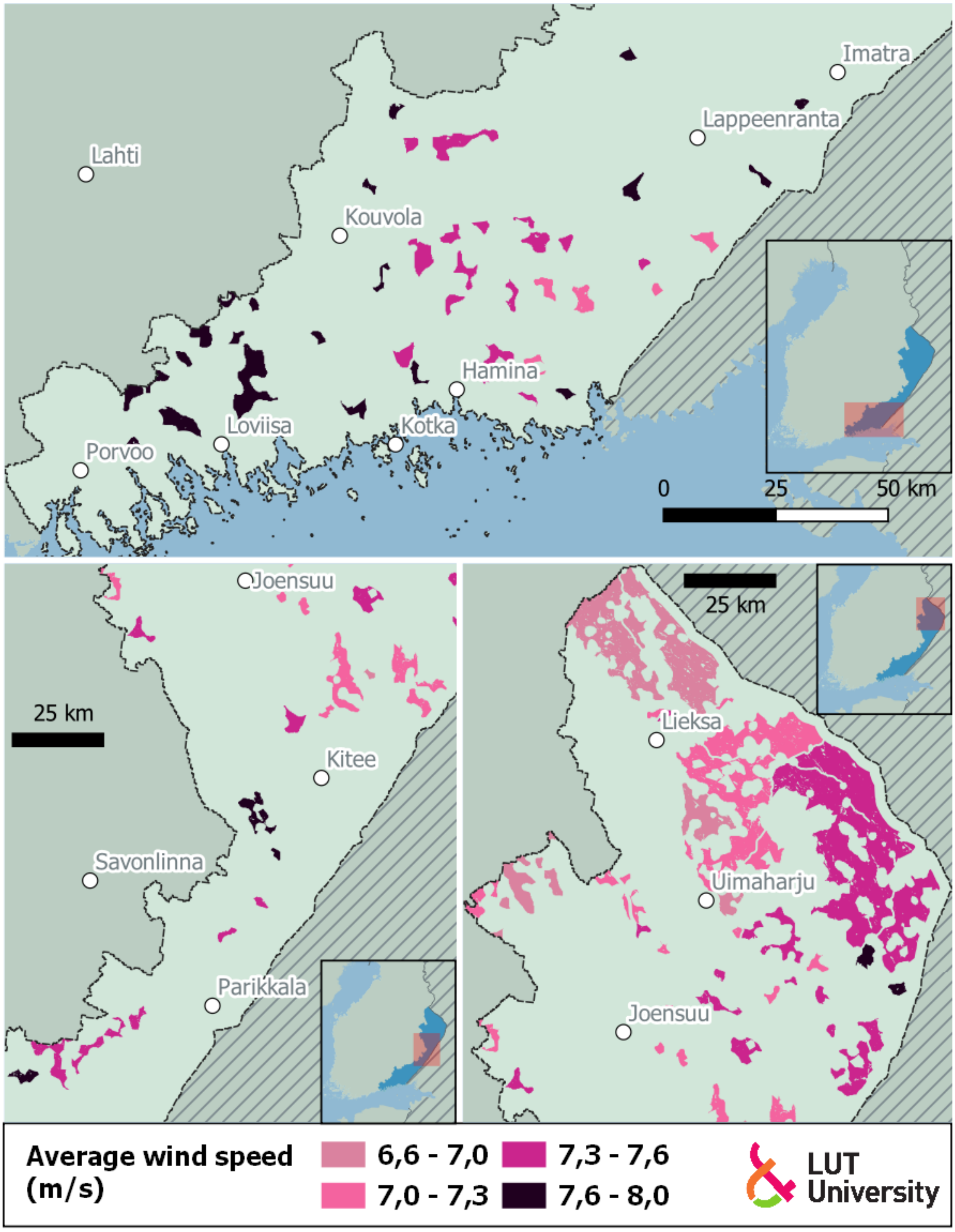

Figure 9. Annual average wind speeds for each wind farm. The assumed altitude is 150 meters.

All turbines were assumed to be of the same type: V150-6.0 MW IEC S (Vestas, 2022). More realistic estimations would need to match the local wind conditions to the optimal hub height and turbine. The obtained production numbers from individual turbines were then aggregated to individual wind parks and larger wind hub locations.

Some alternative scenarios were generated to assess the sensitivity of the results. The production potential ranged from about 25 TWh to nearly 190 TWh between the different scenarios, which stresses the importance of the input parameters and critical interpretation of the results. The varied parameters and the resulting production are illustrated in Table 11 and Figure 10. The “version” column refers to land analysis parameters described earlier in Table 10. The techno-economically feasible wind power potential can also be lower than in any of the presented scenarios. Not all identified wind sites would be realized due to possible conflicts and challenges with permits, wind conditions, grid connections and land use restrictions.

Table 11. Wind power study case parameters.

| **Case number** (-) | **Version** (-) | **Turbine grid spacing** (meters) | **Turbine implementation ratio** (%) | **Annual production** (TWh) | **Peak power** (GW) |
|---|---|---|---|---|---|
| 1 (Base) | V1 | 800 | 50 | 56 | 17.0 |
| 2 | V1 | 800 | 100 | 112 | 34.0 |
| 3 | V1 | 1200 | 50 | 25 | 7.5 |
| 4 | V1 | 1200 | 100 | 50 | 15.1 |
| 5 | V2 | 800 | 50 | 94 | 28.0 |
| 6 | V2 | 800 | 100 | 189 | 55.9 |
| 7 | V2 | 1200 | 50 | 42 | 12.4 |
| 8 | V2 | 1200 | 100 | 84 | 24.8 |

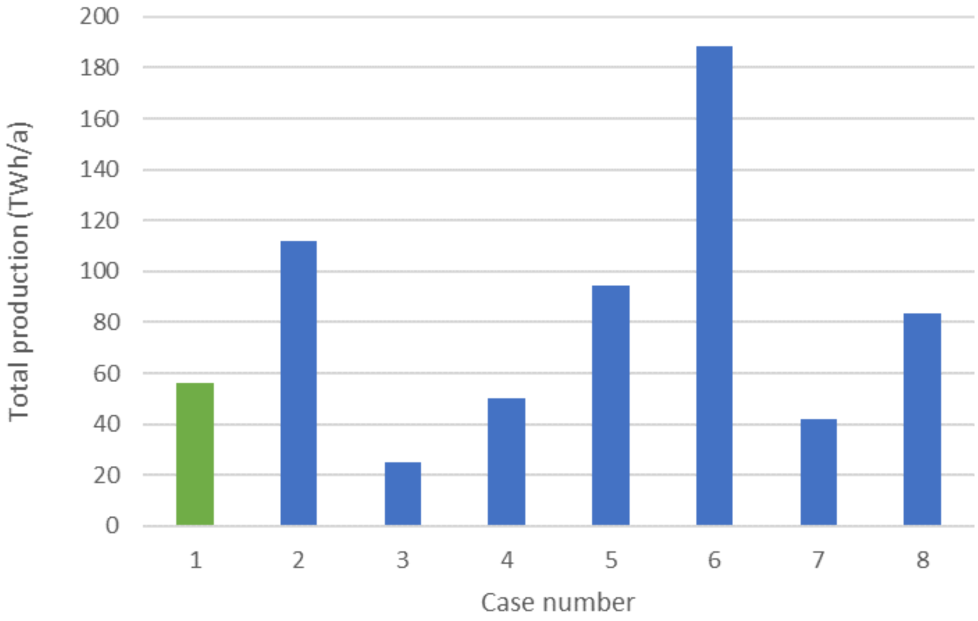

Figure 10. Annual wind electricity production of the different cases, with the base case (1) highlighted.

Detailed regional results for the base case are shown in Figure 11, The overwhelming majority of the observed wind power potential is located in the Pohjois-Karjala region (region C in Figure 11), primarily due to low population density leading to good land availability. The suitability of the soil and terrain for wind power construction work was not evaluated. Thus, especially wet and marshy terrain conditions could limit the suitable area further. As an additional challenge, the electricity infrastructure of the Pohjois-Karjala region is underdeveloped and cannot easily integrate and transfer such quantities of electricity. These challenges are discussed later in Section 6.

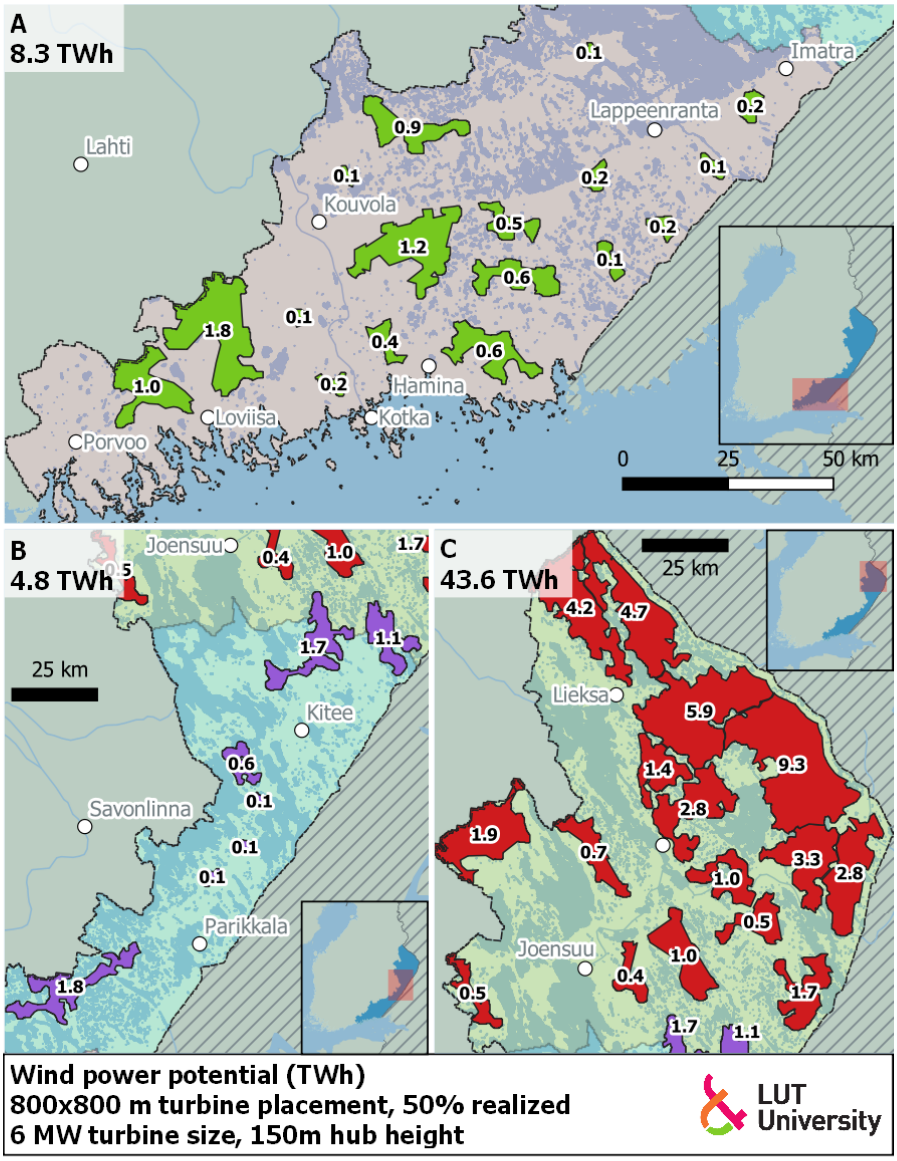

Figure 11. Wind power potential for the base scenario 1 in terms of annual energy production (TWh). See the appendix for a similar diagram using peak power as the unit.

A regional summary of the production is visible in Figure 12. The regional limits (maakuntarajat) do not exactly follow the same geographical boundaries as used in the study (see Appendix III). For instance, the former municipality of Jaala (now part of Kouvola in Kymenlaakso region) was not part of the study. The wind power capacity of Jaala was evaluated separately after the primary study, adding about 10 turbines total to the Kymenlaakso region. Furthermore, Nurmes, Juuka, Outokumpu and Heinävesi would be part of Pohjois-Karjala but were not considered in the study. Likewise, these municipalities were later evaluated to have a potential of about 2450 turbines, or about 45 TWh in terms of annual production that should be allocated to Pohjois-Karjala. From the Itä-Uusimaa region, only Loviisa, Porvoo, Askola and Lapinjärvi were included. As a final remark, the former municipality of Punkaharju was included in the analysis even though it is part of Etelä-Savo and thus not in the focus area. However, its effect was miniscule in terms of capacity addition.

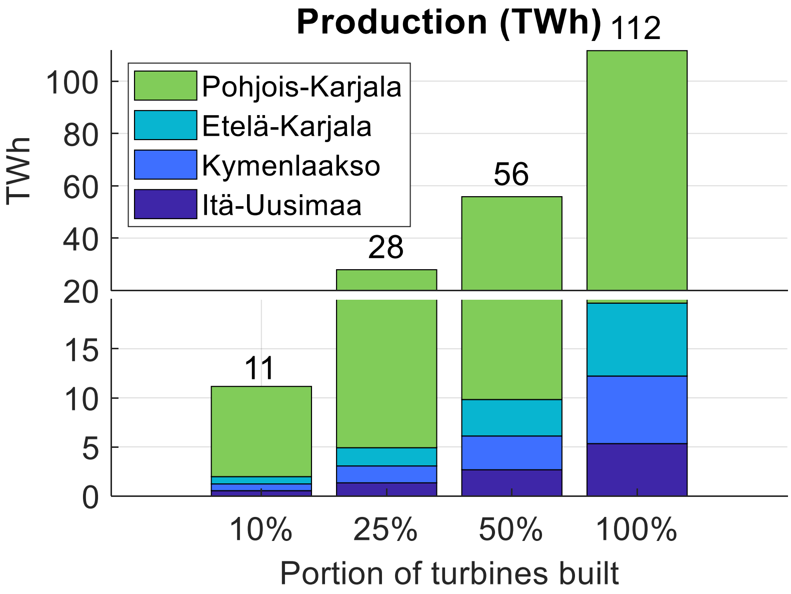

Figure 12. Approximate annual wind power regional production as a function of the percentage of turbines realized. Region limits do not fully agree with the national province boundaries (see Appendix III). The vertical axis has been split into two sections to visualize the lower energy volumes more clearly.

### 5.3 Photovoltaics

In addition to wind power, the production potential of PV installations has been studied within the case area. The studied PV potential can be divided into two categories. Firstly, larger PV farms that would utilize the surface area available in peat production areas. Secondly, building rooftop surfaces. Full load utilization time of 850 h/a is used for all PV production sites to derive the yearly energy produced. Considering the larger PV farms, electricity network interconnection costs related to them are discussed later in Section 6.2.

Power density regarding PV installations for peat production areas is assumed to be 100 MW/km$^2$. Active peat production areas in municipalities within the case area and their production potentials are listed in Table 12. In addition to active peat production areas, there exists some old peat production areas in Finland. However, information about these sites is not directly available from the data provided by the national land survey of Finland.

Table 12. Active peat production areas and their PV production potential

| **Municipality** | **Site area** km$^2$ | **Capacity** MW | **Production** TWh/a |
|---|---|---|---|
| Kouvola | 17.6 | 1 757 | 1.5 |
| Joensuu | 11.7 | 1 168 | 1.0 |
| Tohmajärvi | 9.5 | 955 | 0.8 |
| Kitee | 8.3 | 834 | 0.7 |
| Lappeenranta | 7.8 | 781 | 0.7 |
| Luumäki | 6.2 | 619 | 0.5 |
| Ilomantsi | 6.1 | 611 | 0.5 |
| Taipalsaari | 4.9 | 490 | 0.4 |
| Kontiolahti | 3.5 | 353 | 0.3 |
| Ruokolahti | 2.9 | 286 | 0.2 |
| Loviisa | 2.8 | 285 | 0.2 |
| Rääkkylä | 1.7 | 174 | 0.1 |
| Rautjärvi | 1.0 | 101 | 0.1 |
| Savitaipale | 0.8 | 79 | 0.1 |
| Pyhtää | 0.7 | 75 | 0.1 |
| Polvijärvi | 0.7 | 71 | 0.1 |
| Hamina | 0.6 | 59 | 0.1 |
| Kotka | 0.5 | 51 | 0.04 |
| **Total** | **87.5** | **8 747** | **7.4** |

The sizes of individual peat production sites in terms of potential installed PV power range from hundreds of kW's up to 358 MW. The distribution of site sizes is presented in Figure 13. The regions are visualized on a map in Figure 14.

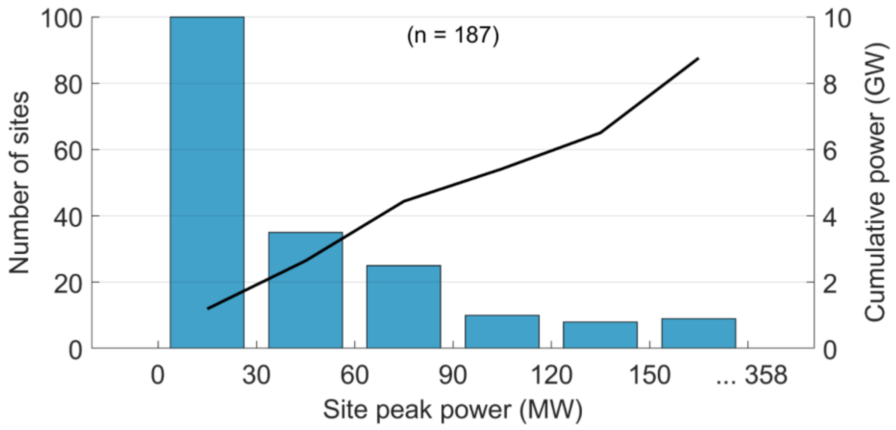

Figure 13. Amounts and sizes of PV production sites in peat production areas. Bars indicate the number of sites (left axis), whereas the line shows the cumulative peak power (right axis).

Rooftop PV potential has been determined based on the sum of available rooftop surface areas. It is assumed that roofs of buildings are pitched roof type. With this assumption half of the rooftop area is projected to the east-south-west direction. Different obstacles and restrictions on the roof such as chimneys, ventilation pipes and ladders etc. are taken into account so that PV panels utilize only a certain amount of the roof half area. (Lassila 2016)

For the purposes of this study, it is assumed that 50 % of the roof half area can be utilized for PV panels, with a power density of 5 $m^2$/kWp. As a result, the rooftop potentials for solar PV are determined and are presented in Table 13

Table 13. Rooftop PV potential in the case area.

| **Building type** | **Number** | **Rooftop surface** (km² ) | **Avg, size** ($m^2$/roof) | **Rooftop potential,** (MVA) | **Avg, size** (kVA/roof) | **Annual energy** (TWh/a) |
|---|---|---|---|---|---|---|
| Residental | 160 232 | 27 | 171 | 1 350 | 8.6 | 1.1 |
| Public | 10 600 | 7 | 669 | 350 | 33.5 | 0.3 |
| Leisure | 58 810 | 4 | 70 | 200 | 3.5 | 0.2 |
| Industry | 4 917 | 6 | 1159 | 300 | 58.0 | 0.3 |
| Other | 401 006 | 33 | 83 | 1 650 | 4.2 | 1.4 |
| **Total** | **635 565** | **78** | **122** | **3 850** | **6.1** | **3.3** |

Most of the rooftop PV potential in the case area comes from residential buildings and other buildings (such as warehouses, garages, and barns as well as unclassified buildings).

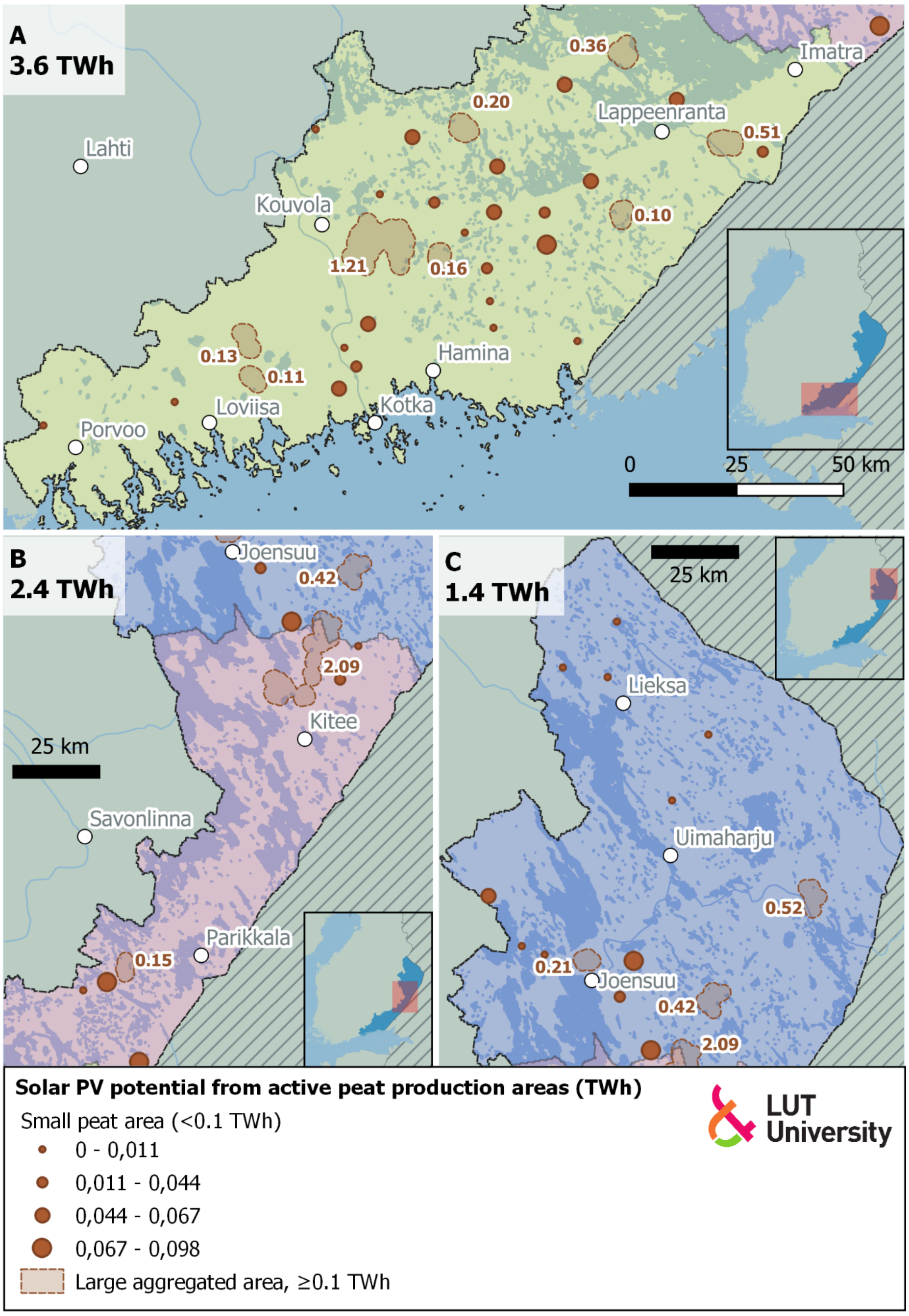

Figure 14. Active peat production areas visualized on map with PV potential. Individual small peat production sites are indicated with dots whereas large, aggregated areas are indicated with larger transparent shapes. See the appendix for a similar image using peak power as the unit.

# 6 Energy transmission

This section deals with the challenges related to the transmission of energy from its generation site to a demand location. More specifically, power-to-X sites are considered to be likely demand sites. As was noted in the previous section, the potential renewable power production volumes are vast. Thus, the current transmission network is not adequate in all locations.

Where the existing power system offers a strong grid connection point, generation is connected to it (400 kV and 110 kV substations). However, due to high portion of wind generation in the case area, new transmission capacity has to be increased significantly. The energy transmission challenges discussed in this work relate to the connecting of the new renewable power capacity to the existing grid network and linking of that capacity with the potential demand at power-to-X sites.

As a starting point for all the transmission studies, the results from the previously introduced base scenario are assumed (Figure 15). The scenario can be considered optimistic both in terms of power production and electricity demand for power-to-X.

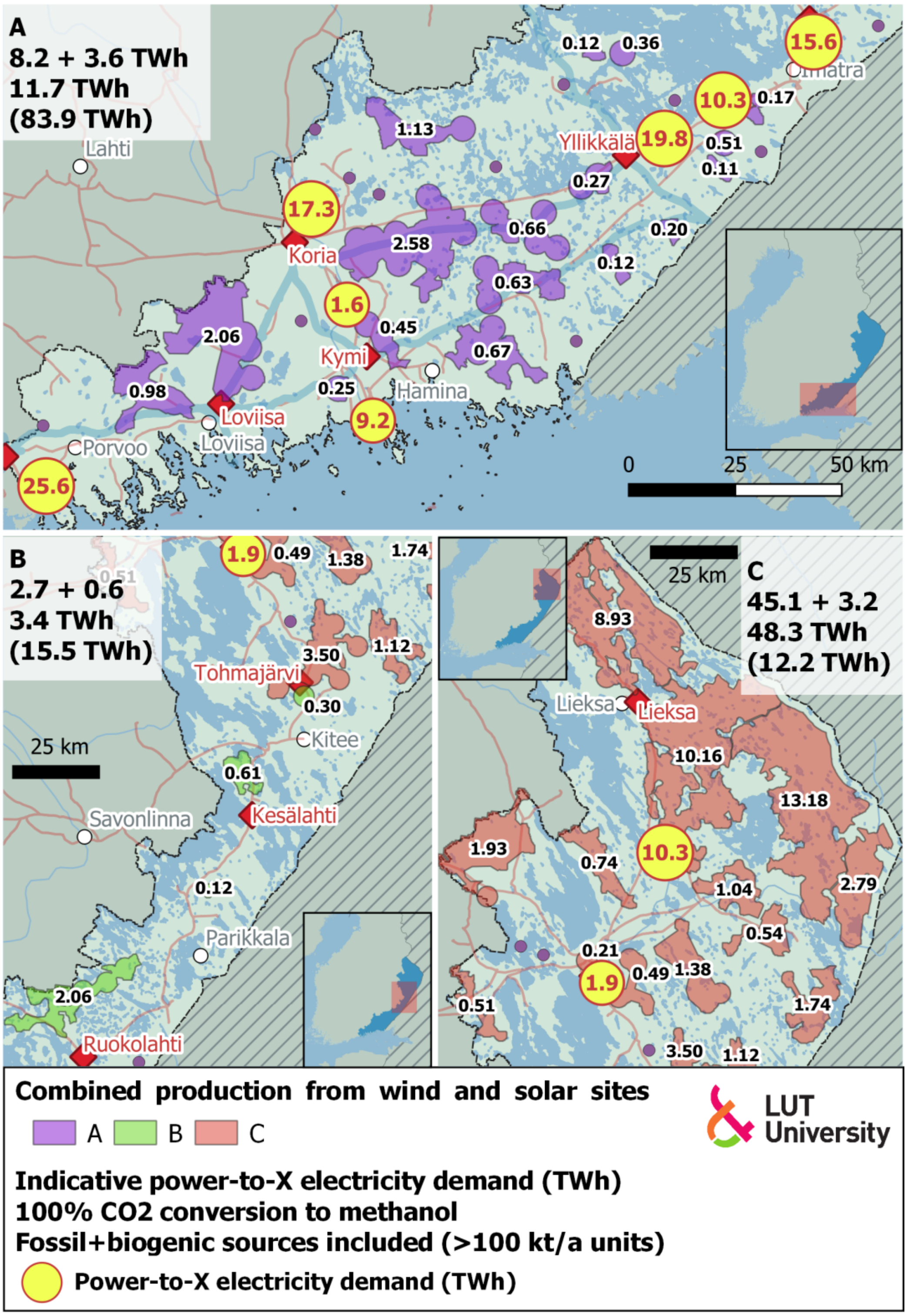

Figure 15. Combined illustration of wind power potential, solar PV potential, and power-to-X electricity demand (as defined in the base scenario). The numbers on the white box refer to wind + PV, total, and PtX demand (in brackets).

## 6.1 Electricity transmission

Due to large case area and generation capacity, study has not been done in detailed level, which means that the information of individual wind farms is not analyzed, but rather the focus is in larger ensemble. Results indicate that the location and size of wind farms have a significant effect on the cost of energy transmission. The study takes advantage of several references which focus on onshore wind network connection.

Due to nature of the study, analyses are done in strategic level. Connection and network solutions of individual turbines and photovoltaic plants and substations are not planned in detail, nor is route planning performed. In the study, several assumptions take place in the analyses. The most relevant are listed next.

1. Generation units and wind and solar conditions
    - Area -specific wind and solar conditions have been taken into account regarding full load hours
    - PV farms are connected to the same collecting wind hub substations as wind farms wherever it is economically feasible
2. Network and components
    - Capacity of the network is dimensioned based on maximum nominal power of wind and PV farms
    - High voltage alternating current (HVAC) is used as interconnection technology due to relative low distances
3. Power system
    - Assumption is that all wind and PV farms (power capacity) can be connected to power system
    - Interconnection costs defined in the study do not include possible system level costs in power system. The required length of the high voltage line between the generation site and the transmission system connection point is determined by the shortest direct distance. However, distance route factor is taken into account (direct distance between two points vs. line route with curves) to indicate realistic line lengths. The direct distance is measured using the centroid of the power generation area, which might not be the most practical solution in reality.
4. Analyses in overall
    - Reliability (and outage costs) of turbines and electricity network has not been taken into account from the perspective of electricity not delivered due to interruption
    - Study does not include traditional power flow analyses but prefer understanding, in which scale transmission and substation capacities should be added to be able to connect all the generation to the grid

The existing electricity grid and transformer stations are shown in Figure 16. Transmission capacity in existing infrastructure is relatively low when considering the scale of wind and PV farms in the case areas. From Lappeenranta to north-east only 110 kV transmission (and sub-transmission) is available. However, this study assumes that existing substations serve as a connection link for the additional electricity production. These generation collecting points are reinforced with required capacities.

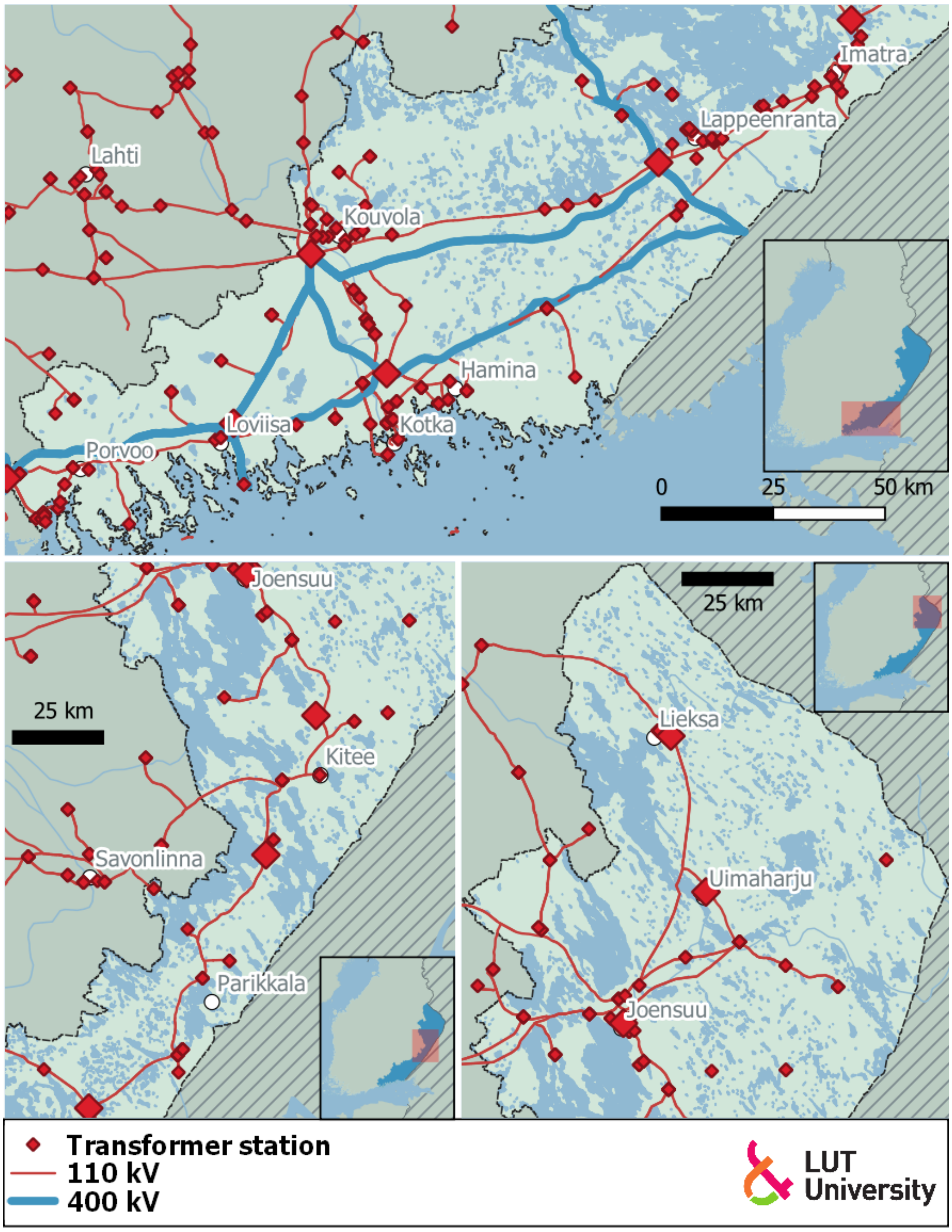

Figure 16. Existing electricity transmission grid and substations.

The interconnection of grid connection points to power system is shown in Figure 17. For the purposes of this study, in addition to the shown transmission line length, an additional distance of 145 km in the northern part of the study region from Lieksa to Siilinjärvi is added to reach the nearest 400 kV connection point in the existing power system. Due to transmitted power capacities, further system-level development and costs would be needed beyond the power system connection in this study.

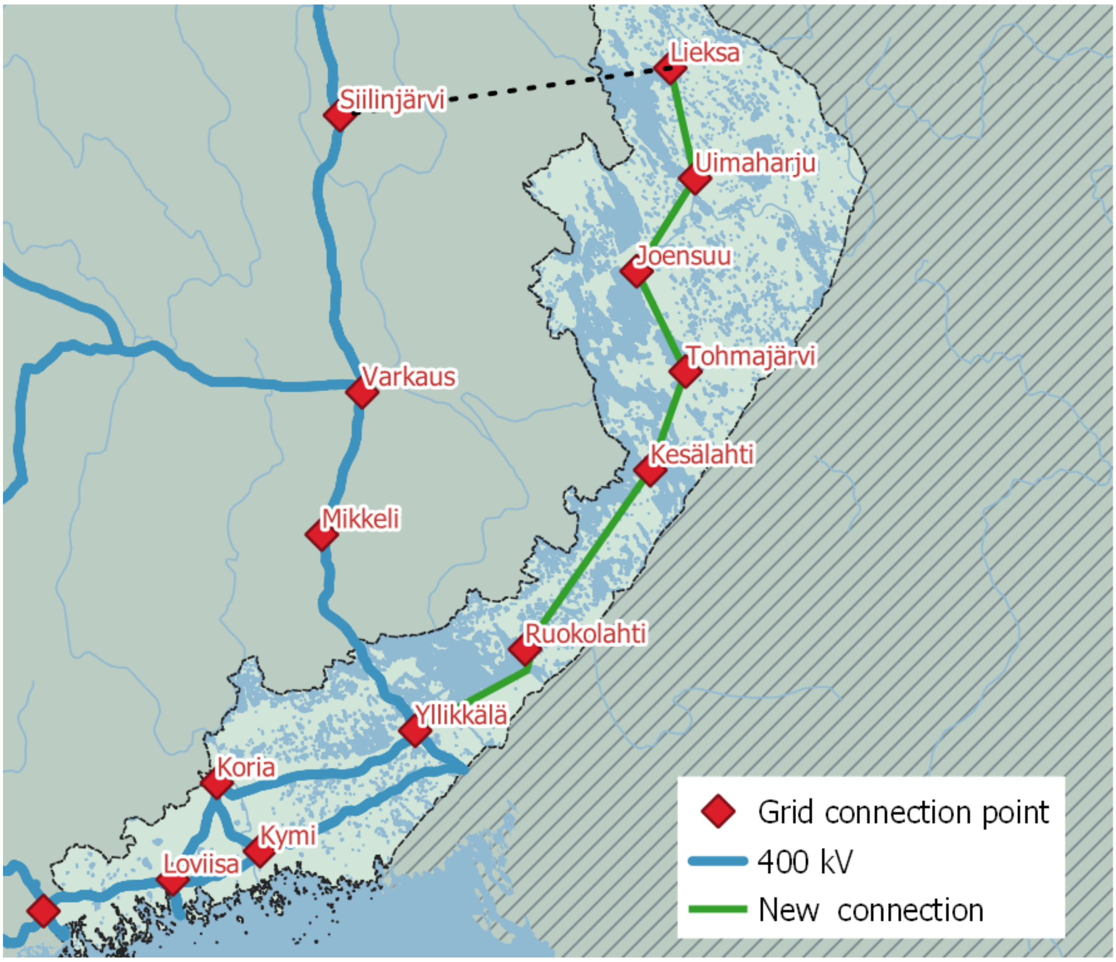

Figure 17. Major grid connection points (400 kV) and new line route in the case area.

Wind hub areas and their connections to the defined grid connection points are presented in Figure 18 along with area-specific background data in Table 14. The greyed-out rows in Table 14 indicate that the wind hub area had too low power-to-distance ratio and is not realized. Out of possible 40 wind hub areas, 31 are realized.

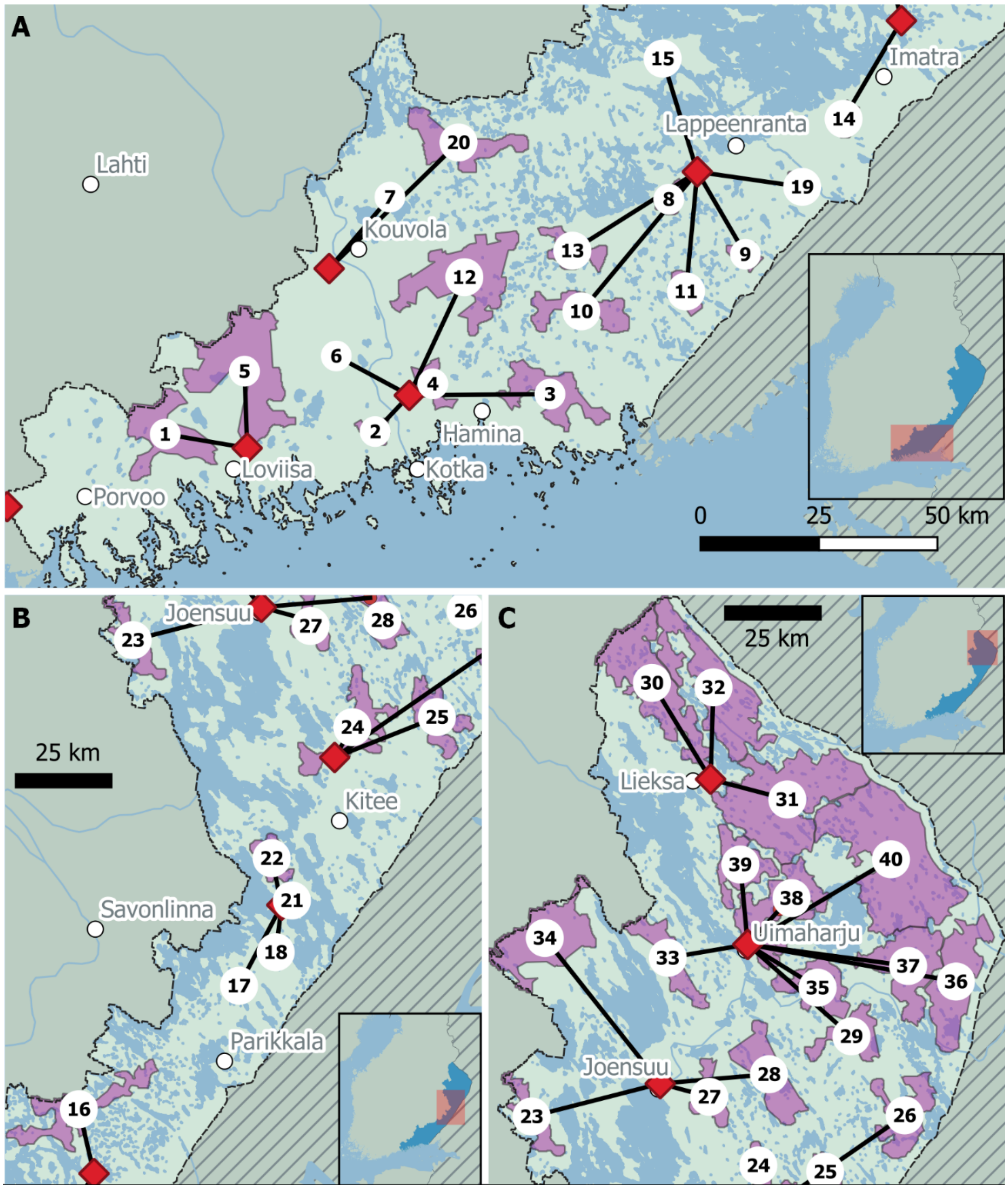

Figure 18. Wind hub collection points and grid connection points

Table 14. Wind hub area -specific background data. The smallest and the furthest wind farms have been neglected in the table (grey text).

| Grid connection point | Wind hub collection point ID | Power (MW) | Direct distance to grid connection point (km) | Full load utilization time (h/a) | Yearly produced energy (TWh/a) |
|---|---|---|---|---|---|
| Joensuu | 34 | 561 | 49 | 3004 | 1,7 |
| Joensuu | 28 | 258 | 29 | 3352 | 0,9 |
| Joensuu | 23 | 150 | 35 | 3369 | 0,5 |
| Joensuu | 27 | 111 | 13 | 3232 | 0,4 |
| Kesälahti | 22 | 168 | 13 | 3647 | 0,6 |
| Kesälahti | 21 | 24 | 3 | 3536 | 0,1 |
| *Kesälahti* | *17* | - | *24* | - | - |
| *Kesälahti* | *18* | - | *12* | - | - |
| Koria | 20 | 246 | 38 | 3479 | 0,9 |
| *Koria* | *7* | - | *20* | - | - |
| Kymi | 12 | 318 | 28 | 3457 | 1,1 |
| Kymi | 3 | 189 | 30 | 3415 | 0,6 |
| Kymi | 4 | 111 | 6 | 3520 | 0,4 |
| Kymi | 2 | 51 | 11 | 3590 | 0,2 |
| *Kymi* | *6* | - | *18* | - | - |
| Lieksa | 31 | 1854 | 21 | 3204 | 5,9 |
| Lieksa | 32 | 1515 | 24 | 3077 | 4,7 |
| Lieksa | 30 | 1293 | 30 | 3078 | 4,0 |
| Loviisa | 5 | 480 | 16 | 3618 | 1,7 |
| Loviisa | 1 | 270 | 18 | 3615 | 1,0 |
| Ruokolahti | 16 | 528 | 17 | 3435 | 1,8 |
| *Ruokolahti* | *14* | - | *24* | - | - |
| Tohmajärvi | 26 | 507 | 54 | 3437 | 1,7 |
| Tohmajärvi | 24 | 489 | 9 | 3320 | 1,6 |
| Tohmajärvi | 25 | 348 | 29 | 3219 | 1,1 |
| Uimaharju | 40 | 2832 | 44 | 3300 | 9,3 |
| Uimaharju | 37 | 954 | 42 | 3471 | 3,3 |
| Uimaharju | 38 | 873 | 12 | 3193 | 2,8 |
| Uimaharju | 36 | 807 | 55 | 3456 | 2,8 |
| Uimaharju | 39 | 459 | 21 | 3122 | 1,4 |
| Uimaharju | 35 | 279 | 21 | 3420 | 1,0 |
| Uimaharju | 33 | 204 | 21 | 3259 | 0,7 |
| Uimaharju | 29 | 162 | 36 | 3340 | 0,5 |
| Yllikkälä | 10 | 183 | 38 | 3270 | 0,6 |
| Yllikkälä | 13 | 135 | 31 | 3410 | 0,5 |
| Yllikkälä | 8 | 57 | 8 | 3544 | 0,2 |
| *Yllikkälä* | *9* | - | *20* | - | - |
| *Yllikkälä* | *11* | - | *25* | - | - |
| *Yllikkälä* | *15* | - | *25* | - | - |
| *Yllikkälä* | *19* | - | *22* | - | - |
|  |  | **16416** |  |  | **54,0** |

Wind hubs are assumed to be connected to a few manually selected grid connection points, which already have significant electricity infrastructure in place and would be better suited to handle the required electricity volumes (Figure 19). The wind hubs themselves would function as an aggregate point for several individual wind farms (Figure 20). The scope of this study does not include the optimization of internal connections within individual wind farms.

Distances between different connection points are taken directly without considering the topology or any special features, such as lakes and residential areas. Actual connections would need to bypass such obstacles, causing additional costs. For the purposes of this study, it was assumed that a distance route factor between 1.3 to 1.5 would provide an adequate distance for cost estimations.

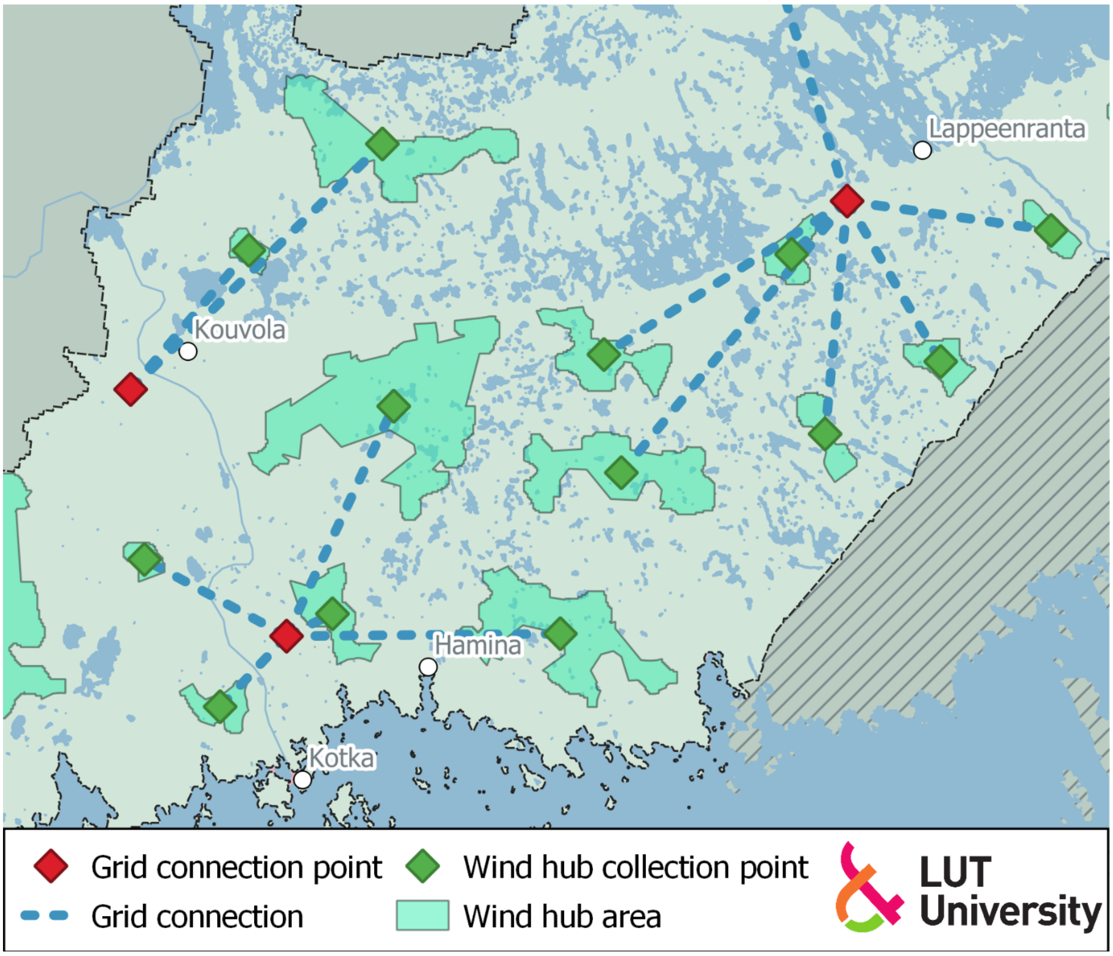

Figure 19. Regional scale of wind hub connections

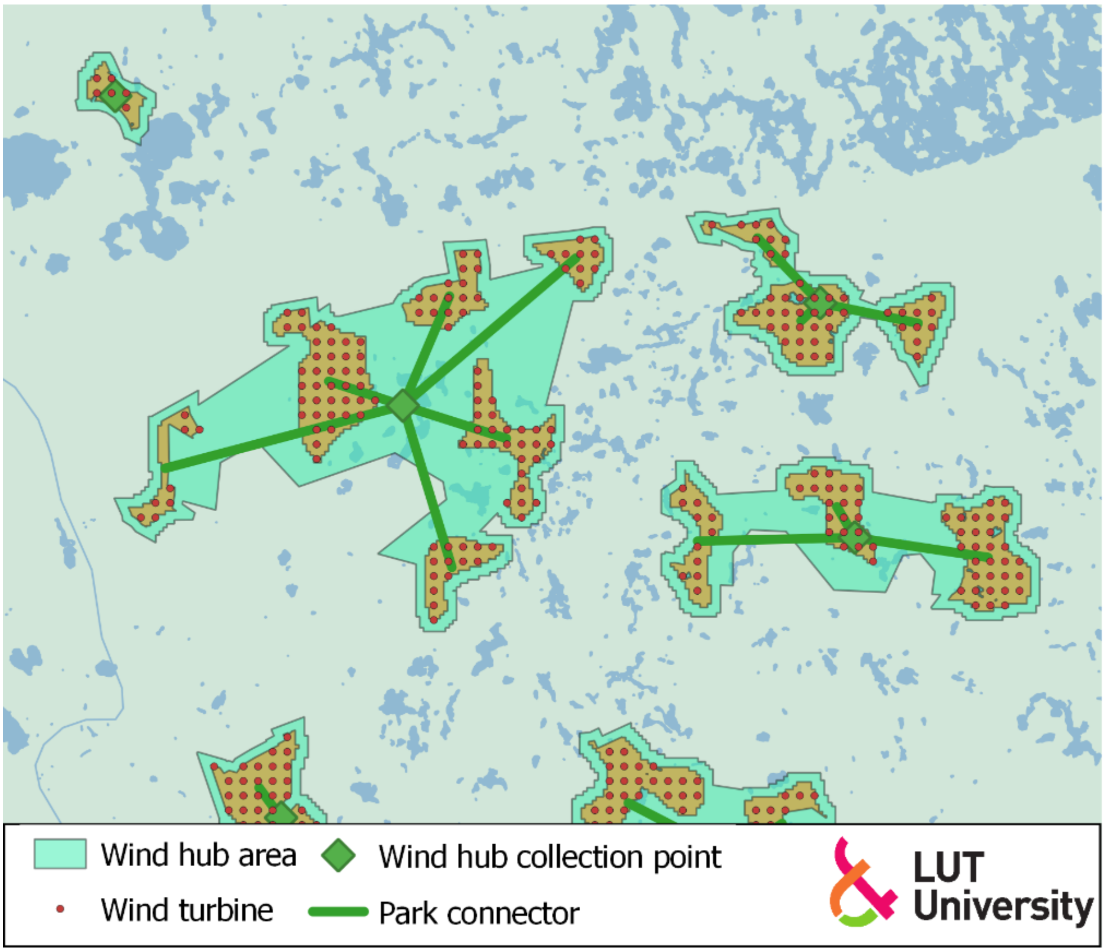

Figure 20. Internal connections of the hub collection point.

As a basis for defining costs for interconnection of wind power, structures of Figure 21 are applied in the case areas.

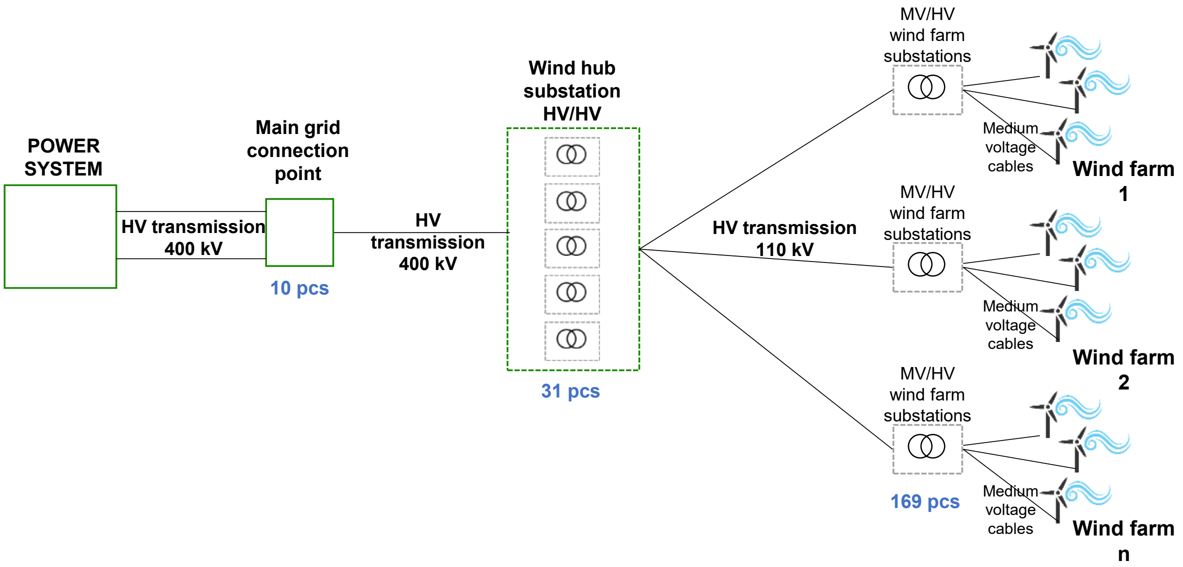

Figure 21. Principles of interconnection of wind farms. Case related numbers of main grid connection points and substations presented under each element.

The basic case presented in Figure 21 is applied to the studied areas with relevant assumptions regarding the principles of interconnection costs listed next.

1. For wind farm medium voltage cabling it is assumed that 2 or 3 turbines can be connected via single feeder cable.
2. Amount of needed wind farm substations and their sizes are defined based on the number of turbines, with either 10 or 20 turbines able to be connected to one substation.
3. Each high voltage transmission connection from wind farm substation to wind hub collection point considers the number of parallel circuits needed for the transmitted power to derive the total kilometers of transmission line needed.
4. Transmission lines between grid connection points and power system dimensioned based on the highest (nominal) power across the entire transmission network due to the meshed network nature of the power system. For this reason, same transmission capacity is applied from southern most part to northern most part.

The life-time costs of interconnection have been defined for this basic case, and it is scaled up depending on the size of the actual wind hub areas. Interconnection costs (€/MWh) depends strongly on distance, power (reserved transmission capacity), and wind conditions (full load utilization time) of the wind hub area. A summary of the costs for the studied areas are presented in Table 15.

Table 15. Summary of electricity network interconnection costs. Annuity includes a fixed OPEX at 1 % of CAPEX in addition to CAPEX annuity.

| | | CAPEX | | CAPEX + OPEX* | Total costs |
|---|---|---|---|---|---|
| Wind power interconnection in case area | | [M€] | [M€/MW] | Annuity [M€/a] | [€/MWh] |
| Medium voltage cables | 5500 - 6800 km | 330 - 680 | 0.020 - 0.041 | 23 - 46 | 0.4 - 0.9 |
| MV/HV wind farm substations | 169 pcs | 770 - 878 | 0.047 - 0.053 | 53 - 60 | 1.0 - 1.1 |
| HV transmission lines from wind farm to hub subs. | 1090 km | 254 | 0,015 | 17 | 0,3 |
| Wind hub collection point substation HV/HV | 31 pcs | 492 | 0,030 | 34 | 0,6 |
| HV transmission lines from wind hub to grid connection | 1445 km | 549 | 0,033 | 37 | 0,7 |
| **Total** | | **2.4 - 2.9 B€** | **0.15 - 0.17** | **164 - 195** | **3.0 - 3.6** |
| | | | | | |
| Power system investments in case area | | | | | |
| Grid connection stations | 10 pcs | 328 | 0,020 | 22 | 0,4 |
| Grid HV transmission lines | 5000 - 7800 km | 2504 - 3896 | 0.174 - 0.271 | 171 - 266 | 3.6 - 5.6 |
| **Total** | | **2.8 - 4.2 B€** | **0.17 - 0.26** | **193 - 288** | **4.0 - 6.0** |

The annuity given in Table 15 includes a fixed OPEX cost that is assumed to be 1 % of CAPEX across all network components. A majority share of the total costs comes from grid transmission due to the high number of required parallel transmission lines to cover the needed transmission capacity.

## 6.2 Wind and PV hybrid

There is possibility to decrease connection costs (€/MWh) by connecting PV farms to the same connection infrastructure as wind farms. The idea is presented in Fig. 15. PV farms are connected in hybrid alternative there, where it is the most economical in sense of distance and required capacity (connection costs).

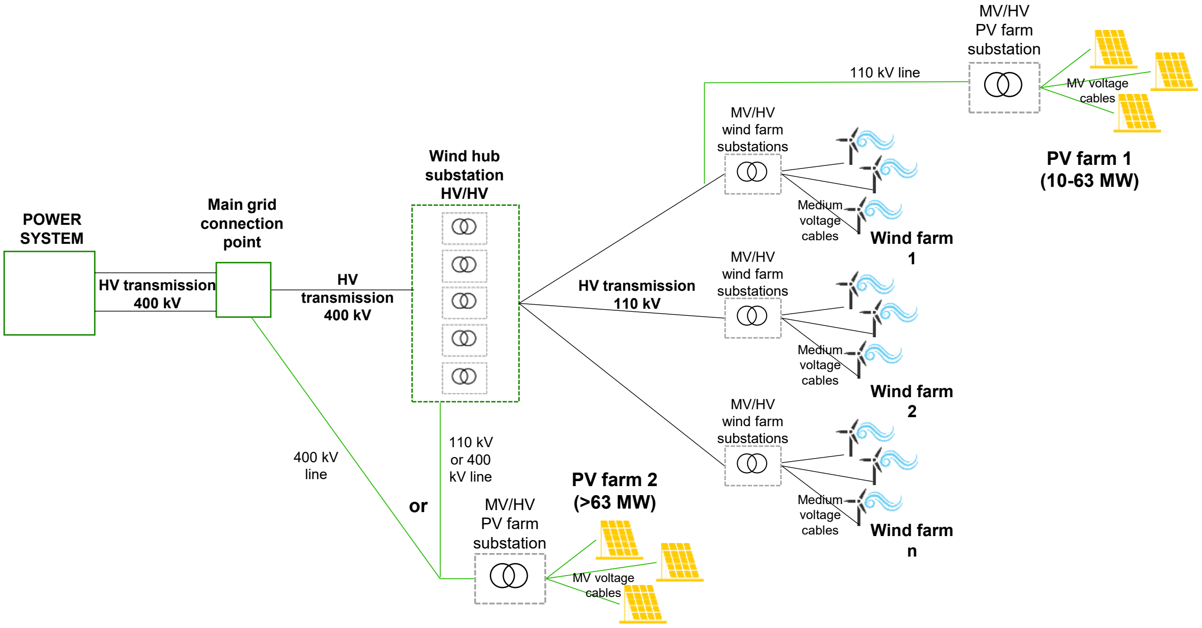

Figure 22. North-to-South transmission network.

In the case regions, about 47% of the peat land area is overlapping with identified wind farms. Figure 23 presents the locations and combined annual generation of PV and wind farms in the case area.

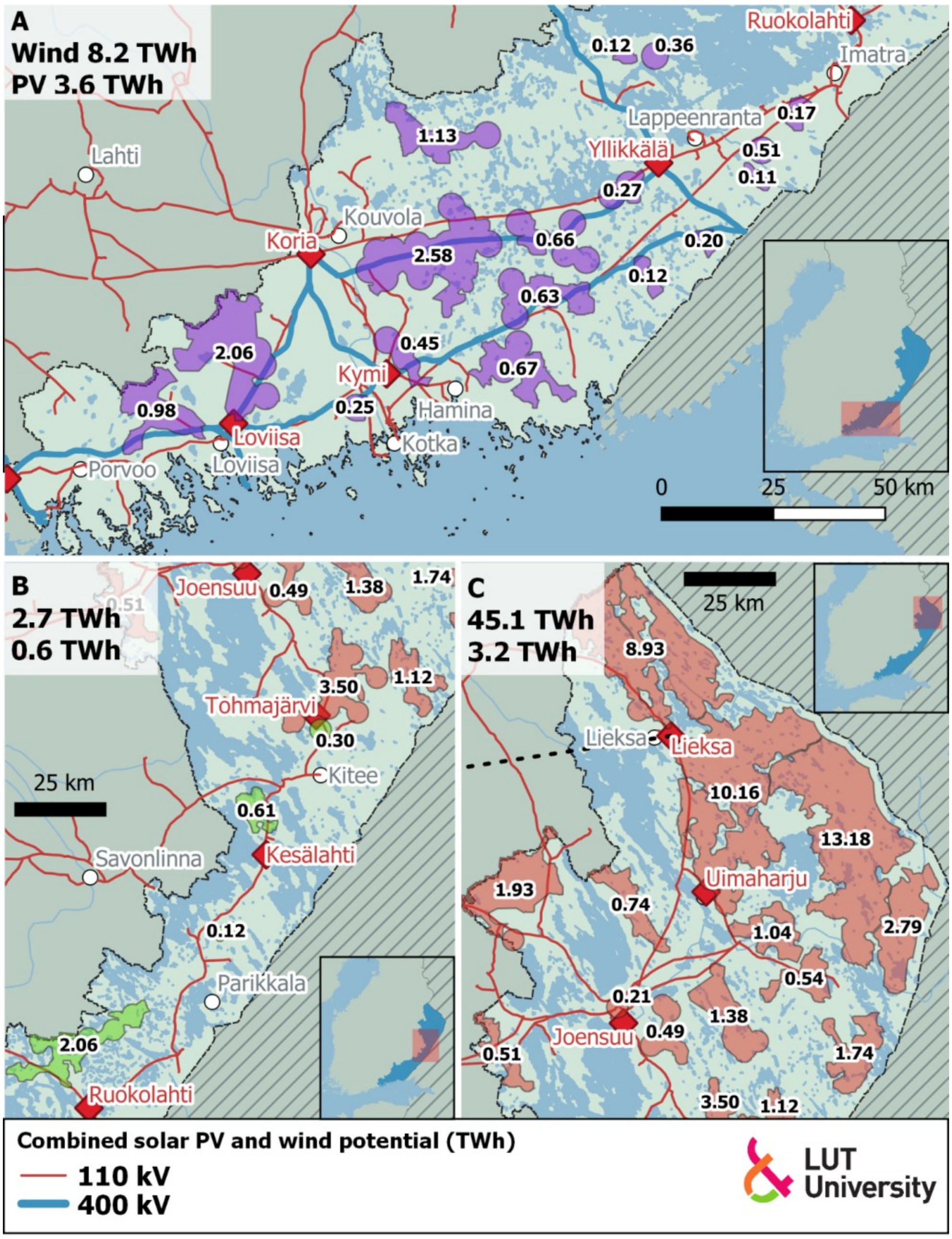

Figure 23. Combined illustration of wind and solar power potential and power-to-X electricity demand.

In Table 16, the interconnection costs of peat area PV farms are presented. PV farms smaller than 10 MW are neglected from this study because of scale and nature of the study. Interconnection costs include costs of PV farm interconnection to previously defined wind hubs and reinforcing the infrastructure shared with wind power interconnection from the wind hubs onwards, based on the additional power capacity required to be able to transmit the sum power of both wind farm and PV farm capacity. The dimensioning is based on the sum of the peak powers of both PV farms and wind farms due to the possibility of the peak powers overlapping, requiring the transmission capacity to be able to transmit their sum.

Table 16. Additional interconnection costs for connecting solar farms in hybrid solution to previously defined wind hubs. Structures that are also used for wind power interconnection are reinforced to take into account the added power capacity of PV farms. Full load utilization time for all PV farms 850 h/a. Annuity includes a fixed OPEX of 1 % of CAPEX across all network components.

| | | CAPEX | | CAPEX + OPEX* | Total costs |
|---|---|---|---|---|---|
| Solar farm interconnection in case area | | [M€] | [M€/MW] | Annuity [M€/a] | [€/MWh] |
| Medium voltage cables | 1300 km | 79 - 131 | 0.009 - 0.015 | 5 - 9 | 0.7 - 1.2 |
| MV/HV solar farm substations | 96 pcs | 432 - 464 | 0.049 - 0.053 | 30 - 32 | 4.0 - 4.3 |
| HV transmission lines from solar farm to wind hub | 1200 km | 286 | 0.033 | 20 | 2.6 |
| Wind hub collection point substations reinforcement | - | 262 | 0.030 | 18 | 2.4 |
| HV transmission lines from wind hub to grid connection reinforcement | - | 288 | 0.033 | 20 | 2.7 |
| **Total** | | **1.3 - 1.4 B€** | **0.15 - 0.16** | **92 - 98** | **12.4 - 13.2** |
| | | | | | |
| Power system investments in case area | | | | | |
| Grid connection stations reinforcement | - | 175 | 0.020 | 12 | 1.6 |
| Grid HV transmission lines reinforcement | - | 1520 - 2367 | 0.174 - 0.271 | 104 - 162 | 14.0 - 21.8 |
| **Total** | | **1.7 - 2.5 B€** | **0.19 - 0.29** | **116 - 174** | **15.6 - 23.4** |

It can be seen in Table 16 that the total costs (€/MWh) are relatively high in comparison to wind farm interconnection costs. This is due to relatively high added power capacity but low added yearly produced energy. Full load utilization time of PV farms is approximately 25 % of that of wind farms.

It might be possible to connect single PV farm sites to nearby infrastructure used for wind farm interconnections without reinforcing the shared infrastructure, if said infrastructure had just enough capacity for small additional production to be added. However, single PV farm sites would again have relatively low added energy production capabilities due to the low full load utilization times, thus not making much difference in the larger scale.

## 6.3 Gas Transmission

There are several viable strategies which could be applied for hydrogen pipelines in the region. Short, local hydrogen transmission could be used between individual sites, such as the recently announced venture which aims to connect the Kemira plant at Joutseno and Ovako at Imatra. Longer trunk connection lines could be viable to enable hydrogen transfer in the North-South-direction, but also in the East-West direction like the current natural gas network. The retrofitting or other possible benefits of the existing natural gas network is not studied in this work. Instead, this study explores the possibility of building a completely new major trunk line transporting energy along the eastern border from the north to south. Potentially, the network could continue westward mirroring the current natural gas pipeline route. A sketch of the transmission network is shown in Figure 24.

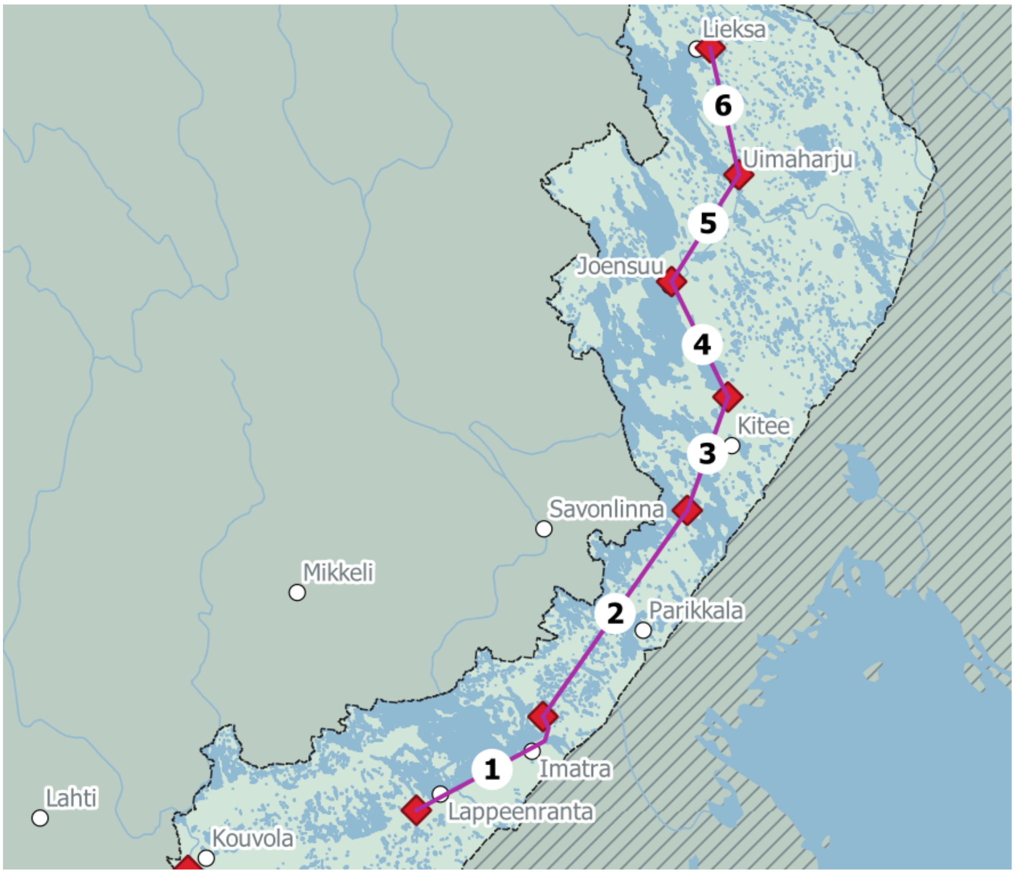

Figure 24. A visualization of the potential north-south energy transmission line.

Hydrogen gas transmission network and its costs are modelled by using the approach described by McCoy and Rubin (2008). The method relies on simplified modelling of the flow to determine the required pipeline diameter for a given throughput of material. As the original regression cost model is from realized costs of natural gas pipelines, cost escalation terms of 60%, 50%, and 25% have been assumed for material, labour, and miscellaneous project costs, respectively. The hydrogen compressor costs (3.4 M€/MW) are obtained from the 'European

Hydrogen Backbone' report (Wang, 2020). The conversion efficiency of electricity to hydrogen is assumed to be 65% (from electricity to lower heating value of hydrogen).

The pipeline is dimensioned to transport nearly 2.5 Mt of hydrogen (82 TWh) per year. The capacity of the pipeline is matched with the peak production of wind power from the region (about 14 GW of electricity). Thus, the capacity factor of the pipeline is only about 37%. The investment cost of hydrogen pipeline is estimated to be 1 – 1.3 billion euros. Compressor costs are estimated to be about 1.3 billion euros, although up to 2 billion euros could be possible especially with higher pressure levels. These presented numbers could be interpreted as a first (and very rough) estimate, rather than as polished results from a detailed engineering study. Aspects such as pipeline pressure level and material selection are not considered. Especially the hydrogen compression costs are associated with a high degree of uncertainty. A more detailed route plan would also be necessary to estimate the costs more reliably.

The estimated pipeline costs are competitive with electricity transmission, especially when the necessary upgrades in existing electricity transmission system are acknowledged. A single pipeline would have sufficient capacity to transport the considered energy quantities. The pipeline could also function as a storage with a technical capacity of around 25 – 40 GWh (assuming operation pressure range of 40 – 70 bars).

# 7 System integration

Various processes related to hydrogen require cooling, which produces waste heat. Even if only hydrogen is considered, water electrolysis and compression of hydrogen (transport, storage) are large heat sources. Furthermore, different synthesis utilizing hydrogen and $CO_2$ produce excess heat. If the produced heat could be utilized as a valuable product, the profitability of hydrogen production is increased. In this study, usage of waste heat from electrolysis for district heating and $CO_2$ capture is considered.

Main challenges of heat utilization are the rather low temperature level and intermittency of the heat production. Waste heat temperature the electrolysis is about 70ºC. Wind and solar are considered as the main electricity sources for electrolysis, thus the production of heat will vary throughout the day and year. To utilize most of the heat, thermal energy storage might be required. In addition, the temperature level of the waste heat is not sufficient as district heat for the whole year. Therefore, additional heat source as boiler or CHP plant is required. A heat pump could also be used to reach the required temperature. High coefficient of performance (COP) can be expected, as the temperature of the heat source (waste heat) is high.

In order to illustrate the potential benefits of waste heat utilization, case studies are simulated for Kotka, Lappeenranta and Joensuu. For simplicity, only the heat from electrolysis is considered, and solar power is not used.

- Cases RE10 - RE100: Convert 10%, 20% or 100% of wind power to hydrogen
- Case $CO_2$: Constant hydrogen production to match available CO2 for PtX (with generic grid electricity)

In first two first cases the production of hydrogen varies according to wind power, while in the latter case the hydrogen production is assumed constant throughout the year. Therefore, different requirements for thermal energy storage may arise. The results of the simulation are the potential of annual heat production and required capacity for thermal energy storage.

## 7.1 District heat

The district heat demand, in terms of energy and temperature, is modelled as a function of ambient temperature and full load hours, according to curves presented in Figure 25. The maximum heat demand $q_{max}$ is iterated such that the annual heat demand equals real district heat demand of the city. Measured ambient temperatures for 2016-2020 (Ilmatieteen laitos, 2022) are used in the simulation.

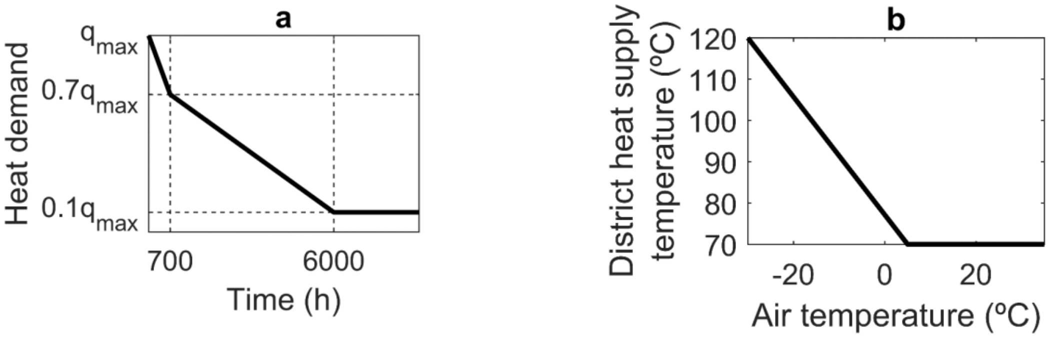

Figure 25 Modelled district heat demand (a) and temperature level (b). The maximum heat demand $q_{max}$ is iterated such that the annual heat demand equals real district heat demand.

The maximum and total heat demands are presented in Table 17. together with the total waste heat production, if all wind power would be used by electrolysis. The district heat demand of the city is estimated from statistics (Energiateollisuus ry, 2020). It is assumed that electrolyser efficiency is 65% and all the losses are obtained as waste heat at temperature of 70ºC (Sakas, 2022). The wind power potentials from Figure 11 are allocated for each city as shown in table Table 17.

Table 17. Heat-related indicators

| | **Joensuu** | **Lappeenranta** | **Kotka** |
|---|---|---|---|
| Peak heat demand $q_{max}$ (MW) | 207 | 184 | 132 |
| District heat demand (TWh) | 0.62 | 0.55 | 0.39 |
| Wind potential (TWh) | 43.6 | 4.2 | 4.1 |
| Waste heat production (TWh) | 16.57 | 1.60 | 1.56 |

Below ambient temperature of -5ºC, waste heat is not sufficient alone, but some additional high-temperature heat is required. It is however assumed that the waste heat can be used to preheat the return district heat water up to 70ºC. The return temperature of the district heat water is assumed 50ºC (Gadd and Werner, 2014). Therefore, at least part of the heat demand can be covered with waste heat also during cold weather.

The calculated potential of the waste heat for district heating is presented in Figure 26. The overall potential for district heating is illustrated as the share of district heat produced by electrolyser. Because Joensuu region has very high wind potential compared to district heat demand, electrolyser waste heat can produce 69% of the heat demand in every case. As the available wind power and waste heat decrease in cases RE20 and RE10, a higher share of waste heat is provided through storage, up to 4.8%. Similarly, the share of utilized waste heat increases from 2.8% to 26%.

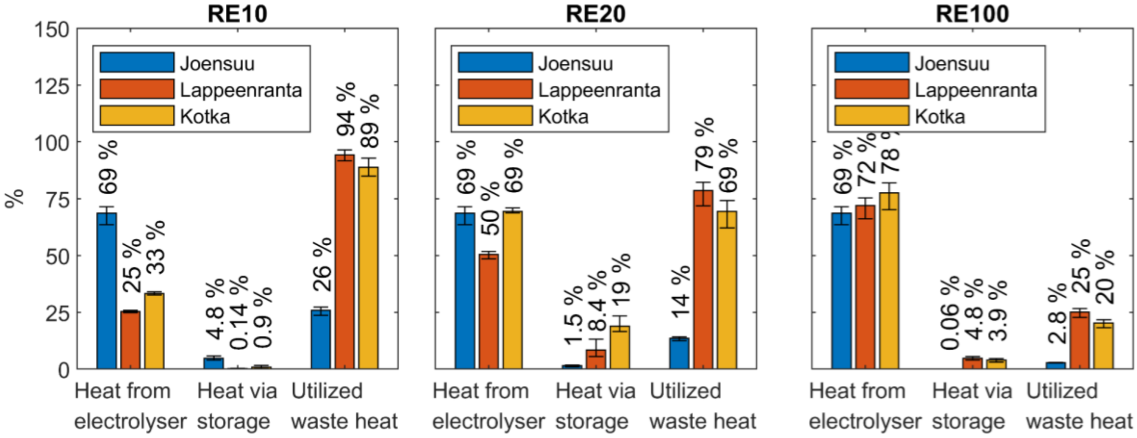

Figure 26. Average electrolyser waste heat potential for district heating. Error bars represent the variation for different years 2016-2020.

In Lappeenranta and Kotka regions the wind potential and corresponding waste heat from electrolysis are smaller compared to Joensuu. Therefore, 25-72% and 33-78% of the district heat could be produced by waste heat, respectively. The highest values, 72% and 78%, are higher than for Joensuu, because the weather is warmer and low-temperature heat can contribute more. In the case RE10, nearly all the available waste heat was utilized: 94% and 89%. In contrast, in the case RE100 over 75% of the waste heat was not used. The usage of storage peaked in case RE20, in which 8.4% of district heat in Lappeenranta and 19% of in Kotka were provided via storage.

The capacities of heat storage are presented in Figure 27. In cases RE10 and RE100, only rather small heat storages are needed: 0.22 - 3.8 GWh. In case RE20, storages up to 40.6 GWh are needed (in Kotka). As a reference, a heat storage with the world's largest capacity of 90 GWh is planned to be built in Vantaa. The variation in storage size between different years is also rather high, as observed in the case RE20 for Lappeenranta and Kotka. Generally, very little and very high amount of waste heat production led to small storage demand. For a small amount of waste heat, there is not much excess heat to be stored. In contrast, with a high amount of waste heat there is no need to store heat, as it is often available already at the right moment.

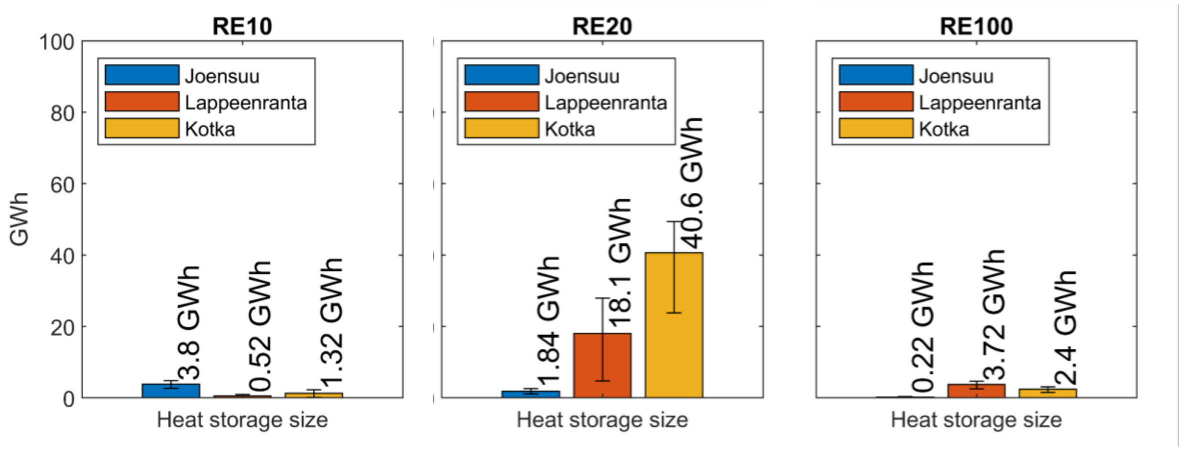

Figure 27. The average required heat storage capacity. Error bars represent the variation for different years 2016-2020.

## 7.2 $CO_2$ capture

As the PtX electricity demand (for electrolyser) of the regions (Figure 15) is a function of available $CO_2$, the waste heat potential is also already defined. Therefore, there are no differences between regions in terms of fraction of $CO_2$ heat demand that can be covered by electrolysis waste heat.

The heat demand of $CO_2$ capture is assumed to be 3.0 MJ/kg$CO_2$. As with district heat, the temperature level is not sufficient, thus some additional high-temperature heat source is required. In conventional amine process, the $CO_2$-rich solvent must be heated approximately from 45ºC up to 120ºC (Jung et al., 2013). Thus, the 70ºC waste heat from the electrolyser could provide one third of the required temperature increase, from 45ºC to 70ºC.

As an example, in Lappeenranta region electrolysers have electricity demand of 45.7 TWh (Figure 15), while the $CO_2$ production is 5.55 kt (Table 4). Total waste heat production is 16.0 TWh, and the heat demand of the $CO_2$ capture is 4.6 TWh. Thus, there is great excess heat in terms of energy. However, as the temperature level of the waste heat is too low, only third of the heat demand can be covered: 1.5 TWh. In general, only 9 % of the waste heat can be utilized in $CO_2$ capture. The same value applies to every region.

# 8 Challenges

Energy transition and rapidly deploying new technologies, amongst them hydrogen generation systems, bring along many challenges. The developing field creates demands on legal, economic and transmission infrastructure. Table 18 points out the main concerns of the interviewed local actors.

The lack of legislation and policy framework creates uncertainty and holds up the generation of hydrogen market entity covering production, transportation, storing and distribution as well as refinement to synthetic fuels. Furthermore, the long permitting processes including environmental impact assessment (EIA) can restrain various renewable energy related projects.

National security stood out in the interviews to be considered in energy policy. The need for renewable electricity grows fast and wind energy investments are needed in South-East Finland to enhance green chemical industry and other energy intensive industry. Thus, the problem of wind turbine interference to military radars needs to be solved. National security includes energy security of supply, and diverse energy production systems are needed to meet the energy consumption demand.

One risk to hydrogen investments is the availability of technology. There can be challenges in the availability of raw materials and components and the delivery times of electrolyser can be long. As for the economic challenges, the financial profitability of new investments is not easy to estimate in a changing environment. Also, green hydrogen will come to replace existing fuels and the pricing will affect the acceptance in the market. Availability of cheap renewable energy is essential for the profitability of green hydrogen. Support funding mechanisms are important for testing and commissioning new technology.

Table 18 The main challenge addressed by the local actors.

| **Legislation** | **National security** | **Local resistence** | **Technology** | **Financial profitability** | **Personnel** | **Funding** |
|---|---|---|---|---|---|---|
| The Renewable Energy Directive 2018/2001/EU (RED II) and delegated regulations. | The problem of wind turbine interference to military radars should be solved to enhance wind energy investments in South-East Finland. | Attitudes towards renewable energy projects have change more positive and the direct resistance is reduced in past years. | The uncertainty of new technology creates challenges. | Financial profitability of new technology investments is not easy to estimate beforehand. | The need for capable personnel increases rapidly, as the new technology increases. | Applying process for funding can be slow. |
| Property tax on solar power plants and its reduction or change (self-determination of municipalities). | The problems and lack of renewable electricity production in area complicate and block investments on green chemical industry and other energy intensive industry. | Local resistance may occur towards wind energy projects, but property tax income to municipalities may reduce municipal tax rate and change attitudes. | Challenges in availability of raw materials and components, e.g., in battery material industry. | Cheap renewable energy can have positive effect on the profitability of electrolysis. Availability of renewable energy should be advanced. | Installation labor is needed for building new energy facility. | Support mechanisms are important for testing and commissioning new technology. |
| Lack of regulation regarding synthetic fuels and changes in requirements of end products. | Diverse energy production technology is needed for security of supply - diversification and self-sufficiency are an essential part of National security. | Normal city planning resistance, but only single negative cases. | The delivery times of electrolyzers are long and get longer as number of projects increases. | The rise in product price due to green status is not necessarily enough to make the investment profitable. | Regional challenges in getting capable personnel. | Peaceful and stable funding environment attracts foreign funding. |
| Incomplete and rapidly changing legislation causes contingency. | Cybersecurity should be considered. |  | Availability of water could be an issue. | Uncertainty of legislation makes the profitability evaluation of projects challenging. |  | It is important to get foreign funding to Finland. |
| Permitting processes should be faster and of more specified form. |  |  |  | Profitability of investment project is difficult to evaluate in changing operational environment |  |  |
| Acknowledgment and status of bioethanol. |  |  |  | Crises in Europe affect the prices of raw materials and fuels. |  |  |
| Uncertainties in the regulation of green hydrogen. |  |  |  | . |  |  |

# 9 Future development

The role of new renewable energy sources and energy self-sufficiency has been emphasized recently. The hydrogen sector is developing fast on the demand of market. Interviews of city representatives and companies revealed the need for research and development in the field. There is also a need for training of new specialists in the area.

Infrastructure and legislation are essential to consider in South-East Finland to raise the self-sufficiency level and national security as well as create new business activity in Finland. In the interviews, it was emphasized, that solving the problem of wind turbine interference to military radars in South-East Finland is essential to enhance wind energy investments and other energy intensive investments in the area. Furthermore, electricity transmission system is seen to need strengthening in East Finland.

The next stage is to recognize the potential objectives and actors and start concrete investment projects. Feasibility studies and project planning are important in the project development stage. Also, experienced expert support can be beneficial in the processes of applying for funding to get ideas of companies refined to concrete investment projects. Concrete actions are needed especially in the following areas:

- Solving the problem of wind turbine interference to military radars
- Electricity transmission system is seen to need strengthening
- Identification of research and development needs in the field
- Recognize the potential objectives and actors and start concrete investment projects
- Training of new specialists
- Experienced expert support can be beneficial in the processes of applying for funding to get ideas of companies refined to concrete investment projects
- Great care should be taken to guarantee energy infrastructure development
- Fluent permission procedures for new power and industrial plants
- Even regional distribution of energy production and consumption

Furthermore, the actors in the area find the co-operation important in the following areas:

- Joint research, development and innovation (RDI) projects
- Co-operational education projects

- Collective trusteeship to enhance the transmission line and gas infrastructure investments
- Continuation of joint acquisition in specialist services
- Joint zoning for renewable energy in municipalities, joint acquisition for documents needed

## 9.1 Potential impact on regional and national economy and security

Investments in renewable energy has huge impact on regional economy. Availability of affordable renewable electricity is first requirement for the development of hydrogen economy and related industry. Therefore, a great care should be taken to guarantee energy infrastructure development to correspond future needs, fluent permission procedures for new power and industrial plants, and equal opportunities for different regions to benefit their natural renewable resources for sustaining local economies. Solutions for addressing national security issues should be solved in cooperation between different actors to find best solution in terms of national security, energy security and environmental impacts as well as impact to national economy.

As presented in this study, the opportunities as well as requirements for energy infrastructure are huge. More even regional distribution of energy production and consumption is balancing factor that reduces the need for energy storages and curtailment of wind power production due to insufficient energy transmission infrastructure or balancing power capacity.

Table 19 presents an estimate of the property tax, land lease income and person-workyears if a significant portion of the wind power potential would be built. The regions A, B, and C in Table 19 refer to the areas illustrated in Figure 28. The economic impacts and employment opportunities of wind power for municipal regions have been assessed by cross-referencing them against the values reported in an earlier report for South Karelia (FCG, 2021).

Table 19. Local economic and employment effects from wind power.

| **When 100% of turbines are realized** | | | | | Regional benefits | | |
|---|---|---|---|---|---|---|---|
| Region | Annual production (TWh) | Peak power (MW) | Number of turbines | Turbine investments (M€) | Property tax income (M€/a) | Land lease income (M€/a) | Person-workyears (over 30 years) |
| A | 16.6 | 4600 | 767 | 5 520 | 11 | 11 | 58 321 |
| B | 9.6 | 2800 | 467 | 3 360 | 7 | 7 | 35 500 |
| C | 87.2 | 26600 | 4433 | 31 920 | 62 | 62 | 337 250 |
| Total | 113 | 34000 | 5667 | 40 800 | 79 | 79 | 431 071 |

| **When 50% of turbines are realized** | | | | | Regional benefits | | |
|---|---|---|---|---|---|---|---|
| Region | Annual production (TWh) | Peak power (MW) | Number of turbines | Turbine investments (M€) | Property tax income (M€/a) | Land lease income (M€/a) | Person-workyears (over 30 years) |
| A | 8.3 | 2300 | 383 | 2 760 | 5 | 5 | 29 161 |
| B | 4.8 | 1400 | 233 | 1 680 | 3 | 3 | 17 750 |
| C | 43.6 | 13300 | 2217 | 15 960 | 31 | 31 | 168 625 |
| Total | 57 | 17000 | 2833 | 20 400 | 40 | 40 | 215 536 |

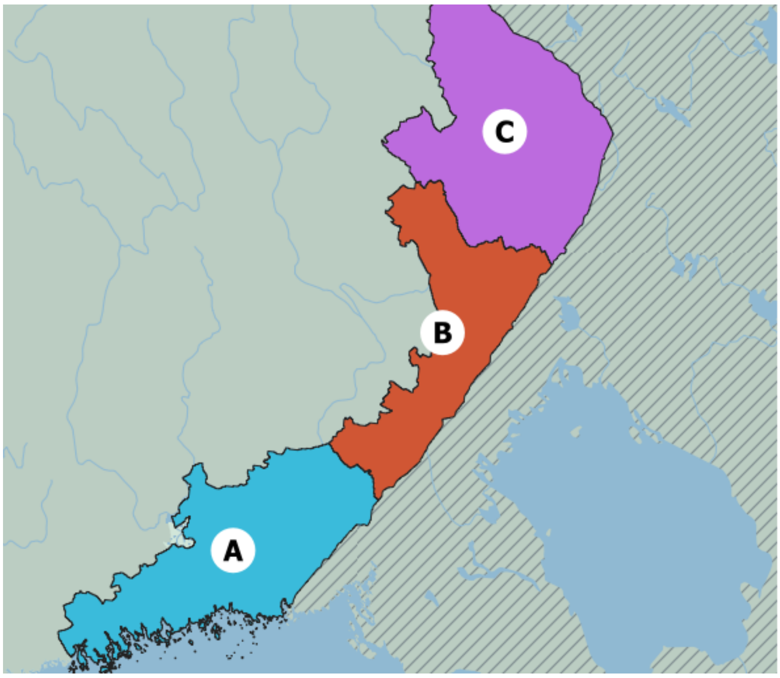

Figure 28. Study area divided into three sub-regions.

# 10 Conclusions

There are a lot of existing industrial activities in the area, which would provide good opportunities to new industrial PtX production. A distinctive feature of the area is the large amount of biological $CO_2$. Pulp and paper industry is experiencing a transition from traditional paper and cardboard production to more diversified products, including biofuels, chemicals, textiles and materials replacing plastics. Utilization of $CO_2$ in PtX processes would increase the carbon efficiency of biomass, enabling opportunities to increase the production volumes and the value of products without increasing biomass harvesting rates. Existing plant sites are often also well located and have good logistic connections and connections to electricity, heat and wastewater, which makes them good candidates also for PtX production.

Wind power potential in the area is significant. The wind conditions are on the same level as other best onshore locations in Finland, but due to lower population density, the realistic installation capacity would exceed the real onshore potential in south and south-west Finland. Solar PV potential could also balance the annual variable renewable electricity production, and peatlands are one potential location for new large scale solar power plants. Key issues hindering the realization of regional potential is radar problems limiting the wind power installations and insufficient high voltage electricity transmission lines in the north-south axis.

The southern part of the studied region has the highest demand for electricity that would be used in PtX processes. It would then be necessary to either import electricity or export $CO_2$ if the production volumes reach significant levels. The electricity grid would need extensive upgrades also beyond the target area to enable safe and reliable power transmission. Another challenge is the scale of power transmission, which reflects to the land use requirement for the power lines. Thus, a hydrogen pipeline could be a techno-economically viable alternative for transporting energy in bulk from the eastern part of Finland to the southern region. The energy resources in eastern Finland would greatly benefit the Finnish society by reducing the correlation between established wind resources, while also providing significant employment opportunities.

Biogenic-$CO_2$ available in the area is roughly 10 Mt/a, which accounts for roughly half of Finnish $CO_2$ emissions. By converting this to green methanol could lead to annual production of almost 8 Mt and turnover 5 – 8 billion € (green methanol price 600 – 1000 €/t). This accounts as energy value 156 000 TJ or 43 TWh, which is roughly the same as annual energy consumption of Finnish road traffic. Utilization of these valuable resources is essential for both national decarbonization targets, regional investments and economy.

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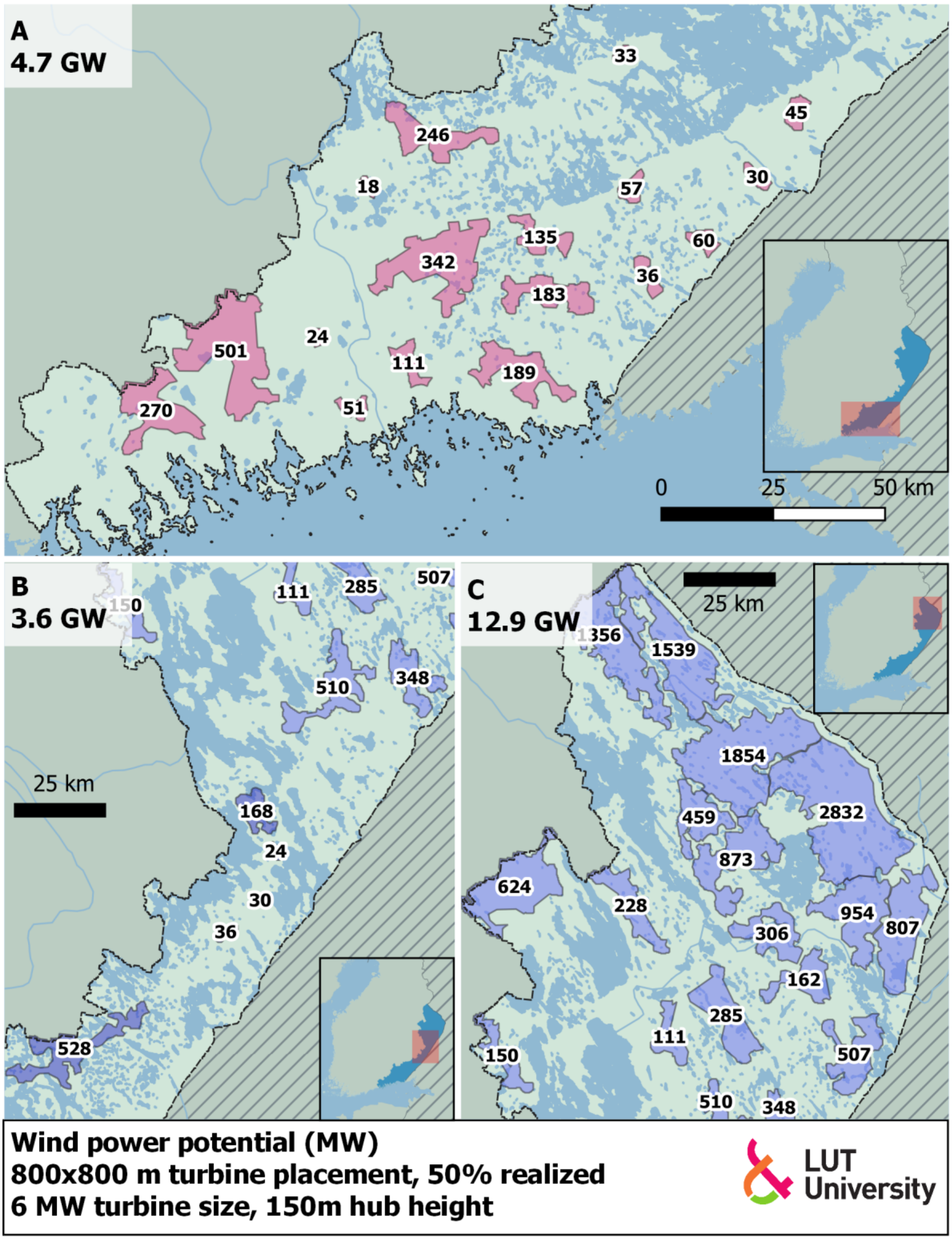
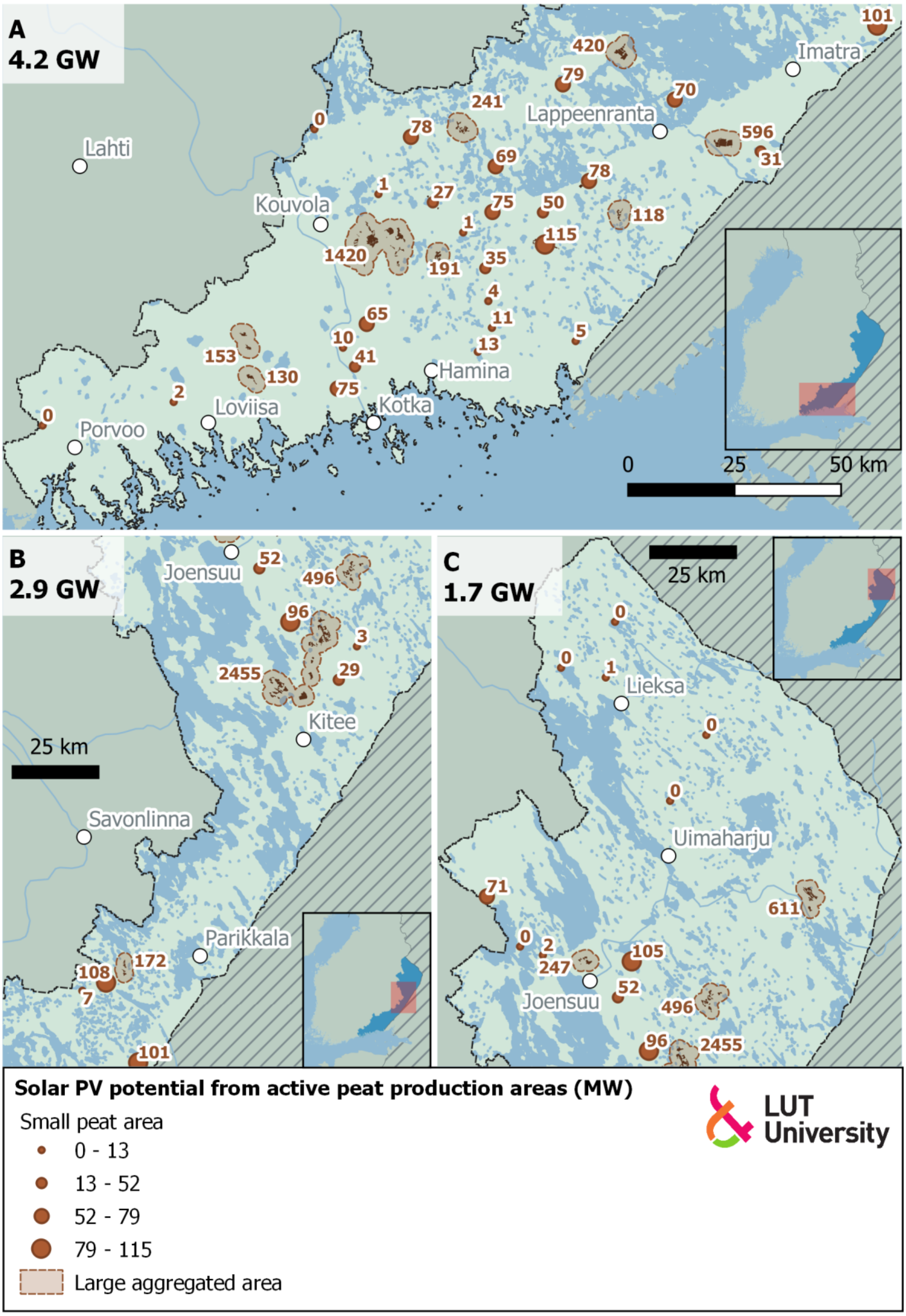
# Appendix

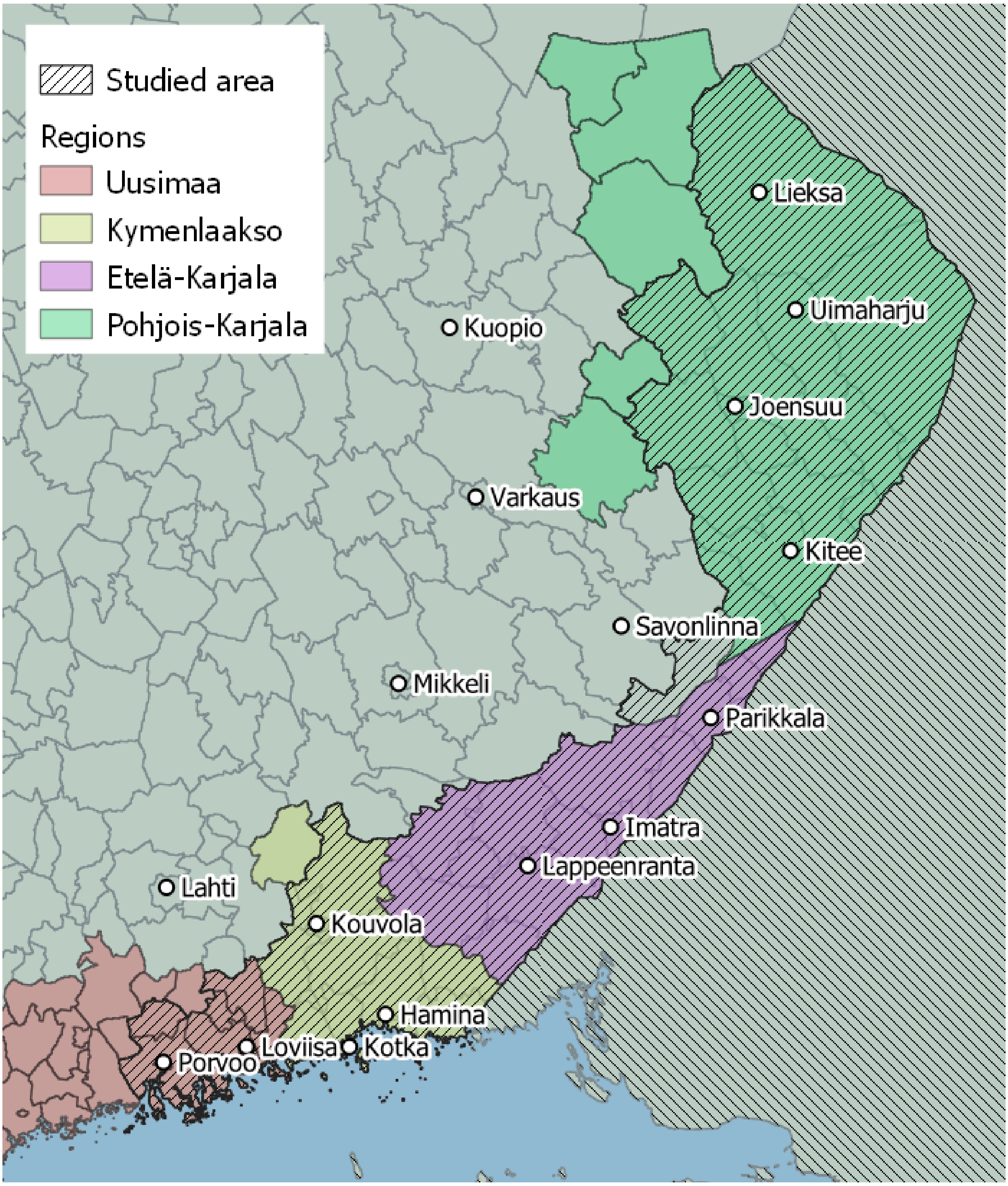
**I**: Wind power potential for the study area in terms of peak capacity.



**II** Solar PV potential (active peat production land) for the study area in terms of peak capacity



**III**: Studied area and regional (maakunta) boundaries



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