FACULTY OF TECHNOLOGY

LAND-USE VS. OUTPUT OF ENERGY TECHNOLOGIES IN FINLAND

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Tiivistelmä

Energiantuotannon maankäytön vaikutukset vaihtelevat energialähteittäin. Energiasektori on siirtymässä keskitetystä tuotannosta kohti hajautettua tuotantoa, ja uusiutuvan energian määrä on lisääntynyt. Tämä asettaa erilaisia vaatimuksia maankäytön suhteen energiantuotannossa sekä siirtämisessä.

Tämän kandidaatintyön tarkoitus on tarjota yleiskatsaus Suomen nykyiseen maankäytön tilanteeseen sähkön ja lämmön tuotannossa sekä verrata sitä sähkön ja lämmön tuotantomääriin. Työssä käsitellään yhdeksää erilaista tuotantomenetelmää. Pinta-ala mitataan neliökilometreinä, ja lopputulos ilmoitetaan yksikössä km^2/TJ. Esimerkkivoimalaitosten tonttien kokoja on arvioitu Maanmittauslaitoksen Karttapaikka-sovellusta apuna käyttäen. Tuontisähkön maankäytön suuruus on tässä työssä oletettu nollaksi.

Laskennan mukaan pienimmän maa-alueen tuotettua terajoulea kohti vaativat ydinvoima, kivihiili ja maakaasu. Turpeella ja vesivoimalla on suurin pinta-alavaatimus. Tässä kandidaatintyössä ei otettu huomioon tarkasteltujen energianlähteiden koko tuotannon, polttoainekierron ja jakeluketjun maankäytön tarpeita, ja tarkastelu rajoitettiin pelkästään Suomen rajojen sisällä tapahtuvaan maankäyttöön. Tuloksista on kuitenkin havaittavissa, että yleisesti ottaen uusiutuvat energialähteet vaativat suuremman maapinta-alan verrattuna uusiutumattomiin lähteisiin, mikä on sopusoinnussa muiden vastaavien tutkimustulosten kanssa.

Muita tietoja

ABSTRACT FOR THESIS

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Abstract

Energy leaves its footprint on land, and the consequences differ in sources. The energy sector is experiencing a transition towards more distributed energy production with larger share of renewable energy sources. This imposes different requirements for energy production and transmission in comparison with centralized production.

This thesis aims to provide an overview of Finland's current situation regarding energy technologies and their land-use in heat and electricity production. Nine different energy production methods are introduced in this thesis. The land is measured in square kilometers and the results are presented in km^2/TJ. The land areas of power plant properties were estimated using Karttapaikka service provided by National Land Survey of Finland. Import is considered to have no land-use in Finland.

The results indicate that nuclear power, coal and natural gas require the smallest land area per produced TJ. The poorest land-to-energy ratio belongs to peat and hydropower. However, the complete assessment of land requirements throughout the resource production and distribution chain is beyond the scope of this thesis. The nature of this thesis is rather to provide a directional overview of different energy production methods.

The full fuel cycles were not covered in this thesis. In addition, the land-use effects outside the borders of Finland were not assessed. However, the results indicate that in general, renewable energy sources tend to require more land area in comparison with non-renewable sources, which is compatible with other studies about the subject.

Additional Information

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LIST OF ABBREVIATIONS

CHP	combined heat and power
GW	gigawatt
GWh	gigawatt hour
Ha	hectare
Km^2/TJ	kilometers per terajoule
MW	megawatt
PV	photovoltaic
RES	renewable energy source
TJ	terajoule
TW	terawatt
TWh	terawatt hours
TVO	Teollisuuden Voima Oyj

1 INTRODUCTION

Energy and land use have a strong connection with each other. In order to produce and use energy, land is needed, and on the other hand, the use of land requires energy (Walker, 1995). The energy supply profile is changing, mainly driven by the pressure to mitigate climate change. The electricity generation has traditionally been based on large, centralized power plants (Cheng & Hammond, 2017). However, energy production is decentralizing and diversifying as new technologies are introduced. Finland has pledged carbon neutrality by 2035 (Finnish Government, 2019), and to reach that target, crafting appropriate energy policy is substantial. As the energy system is decentralizing and the distances between energy supply and demand are likely to get longer, the land use requirements for energy production are changing as well. When energy was produced conventionally in large power plants, the land area used for production was rather united (Cheng & Hammond, 2017). The present trend for energy production is conducting to more scattered use of land, which constitutes different basis for land-use assessment. The assessment of energy land-use requirements and constraints is essential, because it creates conditions to define theoretical capacities of energy production resources (Walker, 1995).

The share of renewable energy in electricity generating has increased throughout the years and the share of renewable energy sources (RES) is expected to have significant scale-up (IRENA, 2017). Renewable sources are often criticized for their low energy density compared with fossil fuels (Cheng & Hammond, 2017). Thus, the land-take for renewable energy technologies, such as solar photovoltaic (PV) and wind turbines, tends to be significantly larger than of conventional sources. (Cheng & Hammond, 2017) However, the exclusivity of land-use varies between different energy production technologies. For example, the upstream area of a hydropower plant is available for leisure activities such as fishing and swimming. Some areas inflict some limitations of use but are not necessarily exclusively used for energy production. Wind park area, for example, is suitable for farming and grazing in many cases. More conventional energy production facilities, such as thermal power plants, are surrounded with fences for safety reasons, making the area restricted to the public.

This thesis aims to examine, how much land different energy sources require to produce heat and electricity in Finland. The land-use of resource production, power plant, transmission and storage of waste generated are included. Firstly, the total production of each energy source is examined and secondly, the overall land-use is estimated by examination of reference power plants' production and land-use. Land is measured in square kilometers, and the assessment is presented in square kilometers over terajoule (km^2/TJ). The land areas of power plant properties were estimated using Karttapaikka service provided by National Land Survey of Finland. Since this thesis focuses on the land-use of different technologies in Finland, import is considered to have zero land-use. While the complete assessment of land requirements throughout the resource production and distribution chain is beyond the scope of this thesis, major factors inside the borders of Finland are covered.

2 ENERGY CONSUMPTION IN FINLAND

Energy consumption per capita in Finland is the highest in the EU. This originates from cold climate, energy-intensive industry and high living standards. Finland is also sparsely populated outside the metropolitan area, making the distances long. (VTT, 2003) Finland's energy consumption has five-folded from the 1950s, and started to stabilize in the 2000s which can be observed from the Figure 1 below. The halting of increasing energy consumption is mainly due to improved energy efficiency and the growth of service industry, which partially replaced heavy industry. In 2018, the total energy consumption in Finland was 1 380 000 TJ. (Official Statistics of Finland, 2019)

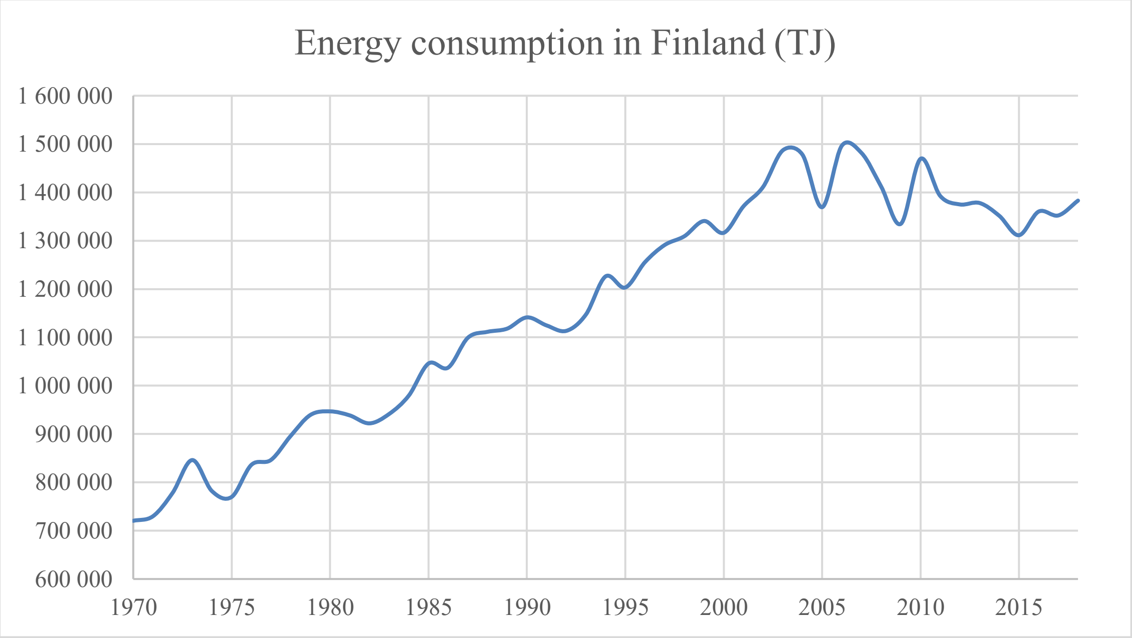

Figure 1. Energy consumption in Finland has steadily increased from 1970. The increase of energy consumption halted at the turn of the millennium and has stayed below 1,4 million terajoules in recent years (Official Statistics of Finland, 2019).

The energy mix of the most significant sources are presented in Figure 2. The Figure shows that oil has been the most used energy source in Finland, covering over 60 % of total energy consumption at best. The trend has been decreasing, however, and today oil covers nearly one fourth. Abundant forest resources have contributed to generous use of wood fuels, and after 2011, wood fuels have been the largest energy source, overtaking oil. Nuclear power was introduced in 1977, and it has accounted for nearly one fifth of the total consumption in recent years. The share of nuclear power will increase in the near future as a new power plant, Olkiluoto 3 in Eurajoki, owned by Teollisuuden Voima Oy, commences commercial operations. Hydro and wind power together have maintained a stable share of approximately 3,5 % since the 1990s. However, a slight increase can be observed after year 2014. This increase is likely due to various wind farm projects in the 2010s (Suomen Tuulivoimayhdistys ry, 2019). Regardless of halting energy consumption, Finland still relies more and more on electricity imports. Energy consumption has reached its historical maximum in 2006 and slightly decreased, but electricity consumption has not followed the ascending trend of energy consumption equally. For example, total energy consumption rates in 2001 ($1,37\times10^6$ TJ) and 2017 ($1,352\times10^6$ TJ), were close to each other. However, total electricity consumption in 2001 was 81197 gigawatt hours (GWh), whereas in 2017 total consumption was 85467 GWh.

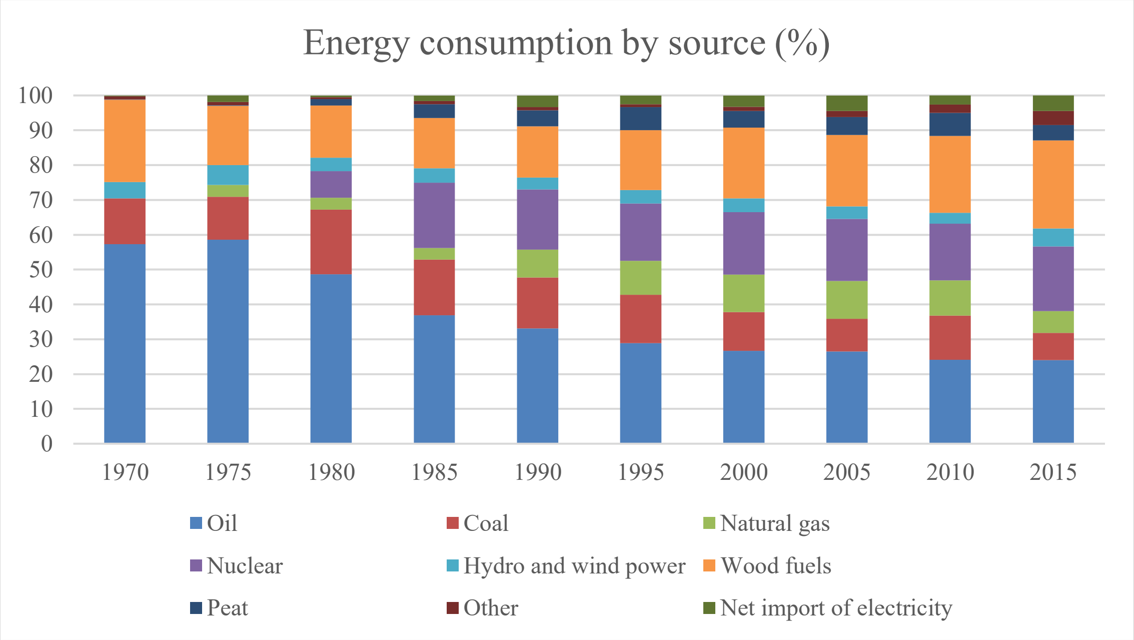

Figure 2. Energy mix has shifted towards low-carbon technologies (Official Statistics of Finland, 2019).

3 ENERGY TECHNOLOGIES IN FINLAND

The characteristic features for Finland are abundant peat and forest resources: Almost one-third of the peatlands (Montanarella et al, 2006) and 11 % of the forest area (Natural Resources Institute Finland, 2012) in Europe are in Finland. These resources are widely utilized, covering roughly half of Finland's domestic production (Official Statistics of Finland, 2017). Among wood and peat, domestic energy is produced mainly by nuclear power, hydro power and wind power. The majority of municipal waste is also recovered as energy (Official Statistics of Finland, 2019). Finland has a long tradition of combined heat and power (CHP) technology (VTT, 2003). Finland's share of CHP in electricity production is 35 %, which is the second highest in the EU (The European Environment Agency, 2012).

The majority of Finland's primary energy is imported. The most significant primary fuel resources imported are, in ascending order, crude oil and NGL, petroleum products, coal, natural gas and electricity. Traces of wood and peat are also imported. (Statistics Finland, 2017, Energy balance sheet 2017) Although nuclear power is considered as domestic production, the nuclear fuel is not of domestic origin. The largest uranium mines are located in Australia, Kazakhstan and Canada. Finland does not produce nuclear fuel. (Fennovoima, 2019)

All energy sources cannot be utilized at any given time. Fuels and energy sources can be divided into dispatchable and non-dispatchable sources. A dispatchable source of energy is a resource that can be utilized for energy generation immediately when the need arises. In other words, a dispatchable power plant can be turned on and off depending on the energy demand. (Donev et al., 2015) Dispatchable sources of energy featured in this thesis are wood fuels, oil, hydropower, natural gas and peat. However, nuclear power can be arguably categorized as dispatchable energy source as well, if the time frame is long enough. In general, nuclear power serves as a baseload power source as the startup or change of output may take many hours. For this reason, it is most economical and technically simple to run a nuclear power plant continuously and limit shutdowns. (Nuclear Power for Everybody, 2020) A non-dispatchable source of energy in turn is not continuously available for energy generation due to uncontrollable factors, e.g., the weather (Donev et al., 2018). Nuclear power, wind power and solar power are addressed as non-dispatchable energy sources in this thesis.

3.1 Wood fuels

Finland is proportionally the most forested land in the EU. More than 70 % of Finland's surface is covered with forest. Thus, wood-based fuels are the most significant source of renewable energy in Finland. The area suitable for wood production is 2×10^5 km^2. (Ministry of Agriculture and Forestry of Finland, 2019) In 2018, 78×10^6 m^3 of trees were cut, from which 11 % was directed to fuelwood, including forest chips to heat- and power plants and firewood to residential houses. Thus, the volume of trees directed to fuelwood is approximately $8{,}6\times10^6$ m^3. It should be noted, however, that energy industry uses mainly by-products and wood residues from forestry industry (Ministry of Agriculture and Forestry of Finland, 2019). Altogether $20{,}1\times10^6$ m^3 of wood fuels were used for energy generating in 2018 in power plants. When the small-scale use of wood used for heating in residential houses, farms and summer cottages is included, the total annual use of wood fuels is approximately 27×10^6 m^3. The fuel types and their quantities are presented in Figure 3 below.

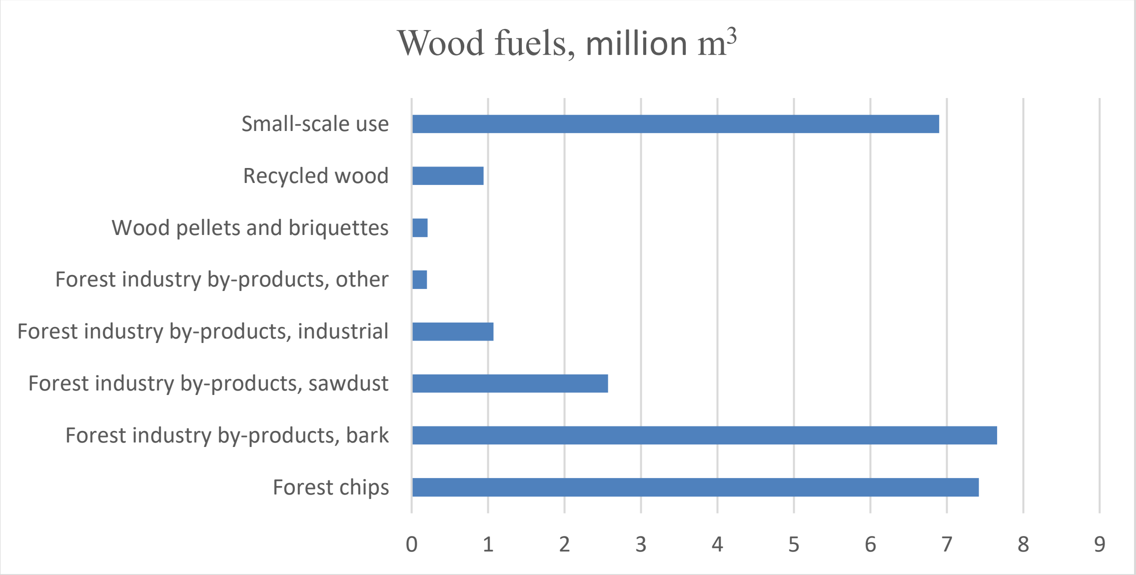

Figure 3. Solid wood fuels and their quantities used in energy production in 2018. Small-scale use represents the logs and wood chips used in residential houses, farms and summer

cottages. The remaining categories represent the wood that is used in power plants for heat and electricity production. (Ministry of Agriculture and Forestry of Finland, 2019)

Solid wood fuels produced 54 TWh in year 2018. This corresponds 194 400 TJ. As only solid wood fuels are considered, black liquor and other residual liquors derived from the forestry industry are not included in this number. Despite black liquor and other liquors constitute a significant source of wood-based fuels, approximately 45 %, the assessment of their land-use is beyond the scope of this thesis.

There are 67 power plants in total that use solid wood fuels, 32 of which use wood as a primary fuel (The Energy Authority, 2019). This thesis acknowledges only the power plants that use the examined fuel as primary fuel. The total land-use of these power plants were calculated by examining the property areas and power outputs of Oulun Energia Oy's power plants Toppila 1 and 2. After that, the area–output ratio was calculated. The result is presented in km^2/TJ. To estimate the entire land-use for wood-fueled power plants in Finland, this number was multiplied by the total amount that solid wood fuel produced in terajoules. The property area estimations were extracted from Karttapaikka by National Land Survey of Finland. An example of such estimation is presented in Figure 4.

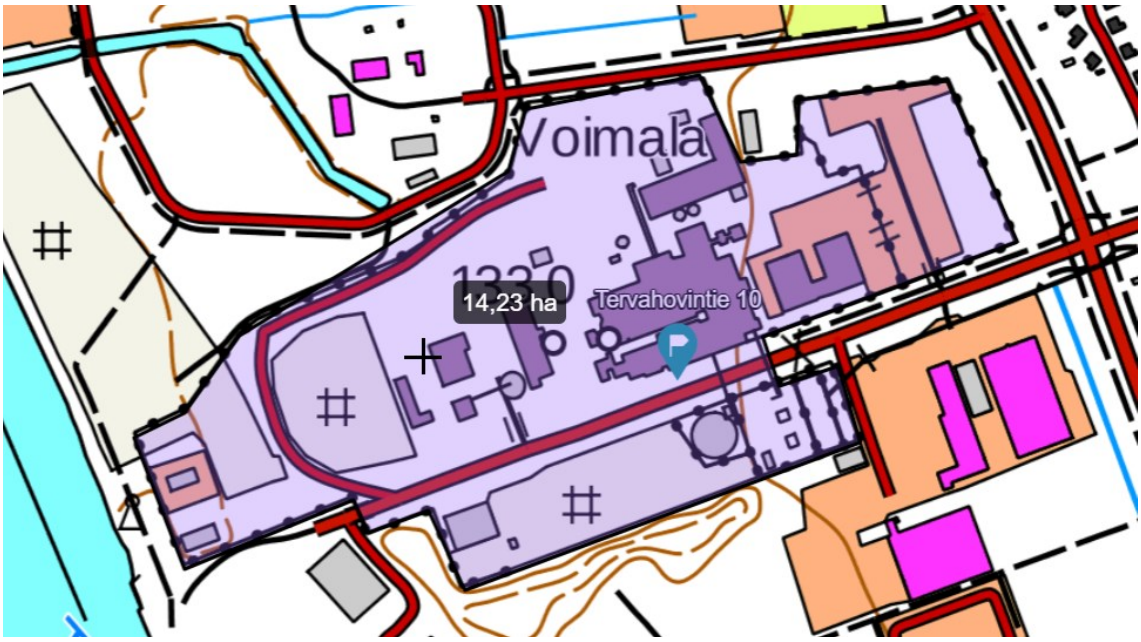

Figure 4. The area of Toppila CHP plant is estimated using Karttapaikka application by National Land Survey of Finland.

Oulun Energia Oy owns two CHP plants in Toppila, Oulu. These plants lie on the same property. Both CHP plants burn peat as primary fuel and industrial wood residue as secondary fuel. Despite the main fuel being peat, it is justified to use these power plants in calculating land-use for solid wood fuels as the plants constantly use significant amount of wood in their energy production. This principle will be used subsequently on this thesis as well. Toppila power plant's property area is 0,14 km^2. In 2018, Toppila power plants produced 1929 GWh (Oulun Energia Oy, 2020), which corresponds 6940 TJ. Hence, the land-use of this plant is $2,0\times10^{-5}$ km^2/TJ.

Precise information regarding solid wood fuel production, i.e., cutting down trees, was not available. The estimations about accumulation of fuelwood varied between 30 m^3 / hectare (ha) (Latvaenergia, 2020) and 80 m^3 / ha (Lindblad, 2013). In this thesis, the accumulation is estimated to be approximately 55 m^3 / ha as an average of the minimum and the maximum values found. Using the volume of $8,6\times10^6$ m^3 mentioned earlier, the total land-use of fuelwood cut yearly is approximately $1,6\times10^3$ km^2. When the total energy production of solid wood fuels is 194 400 TJ, the production occupies approximately 8×10^{-3} km^2/TJ. As can be observed, production constitutes the largest share of land-use for fuelwood and the land effect of energy production, in comparison with fuel production, is minor.

3.2 Oil

Oil accounts for one-fourth of Finland's energy consumption (Official Statistics of Finland 2019). No oil resources have been found in Finland (Geological Survey of Finland, 2019). Thus, crude oil is imported, and the majority is refined to diesel and gasoline (Energiamaailma 2019). Approximately one-third is utilized for heating. Power plants burn light and heavy fuel oil (Geological Survey of Finland, 2019) as reserve fuel in energy production (Energiateollisuus, 2018).

In total, approximately 9000 TJ of heat and electricity was produced using petroleum products in 2017 (Official Statistics of Finland, 2017). As oil is a minor fuel used for heat and electricity production and it is generally used in reserve power plants that operate infrequently, the land-use assessment for oil will not be performed in this thesis. However, oil-fired power plants constitute an important factor to ensure reliable energy supply at times when frequently used power plants cannot cover the demand.

The record year for oil consumption in Finland was 1973. During this time, oil became more important topic for politics due to volatile state of the Middle East. This in part contributed to accelerating development of alternative energy sources alongside fossil fuels. However, as long as vehicles run on oil-based fuels, it is not likely that the use of oil will completely end in the near future. (Official Statistics of Finland, 2007)

3.3 Nuclear power

Nuclear power is the third largest energy source in Finland with a share of 17 % of total consumption in 2018. This share corresponds to 238 700 TJ. (Official Statistics of Finland, 2019) In Finland, four nuclear reactors are currently in use. Two of them, Olkiluoto 1 and 2, are located in Eurajoki, and other two are located in Loviisa. In addition, Teollisuuden Voima Oyj (TVO) has a third nuclear reactor under construction in Olkiluoto, which is scheduled to begin electricity production in March 2021 (TVO, 2019). Furthermore, Fennovoima is waiting to acquire construction permit in 2021 for a nuclear power plant in Pyhäjoki (Fennovoima, 2019). The land-use of the latter is not discussed in this thesis. Despite the unfinished construction work of Olkiluoto 3 during the time this thesis is being written, its land-use will be included as the reactor lies within the same area with Olkiluoto 1 and 2.

Olkiluoto 1 and 2 both have gross electrical power of 920 MW. Fortum's nuclear reactors, Loviisa 1 and Loviisa 2, have gross electrical power of 531 MW each. (STUK, 2019) The power plant in Loviisa is located in Hästholmen, where Fortum owns approximately 4 km^2 of land (Fortum, 1999). TVO has approximately 2,3 km^2 of land in Olkiluoto (Kukkola, 2020). These areas contain, besides the plant units, office buildings, parking areas, maintenance buildings, etc. Both Fortum and TVO have repository for low- and medium-level waste in their properties as well as intermediate storage for spent fuel, which is high-level radioactive waste. Repository for spent fuel lies in Olkiluoto. (Kukkola, 2020)

This thesis uses the total area of these properties and ignores the classification of different units within. However, for perspective purposes, Olkiluoto 1 and 2 both have floor area of $2{,}2\times10^{-2}$ km^2 (Kukkola, 2020). Hence, in truth, the buildings where nuclear reactors lie compose a rather small share of the total area allocated for company activity. When combining both Hästholmen and Olkiluoto areas, the total area is approximately 6,3 km^2. With the production of 238 700 TJ and the land area of 6,3 km^2, the estimated land-use for nuclear power is 26×10^{-6} km^2/TJ.

3.4 Hydropower

Hydropower has traditionally had a significant role in Finland's electricity production, covering up to 90 % of electricity production in the 1950s and 1960s. Today the share of hydropower is 10-20 % of the electricity production, depending on the annual water resources (Energiateollisuus, 2019). Finland has 220 hydropower plants and approximately 3190 MW of installed capacity (EKOenergy, Motiva, 2019). In 2018, altogether 47 000 TJ of energy was produced by hydropower (Official Statistics of Finland, 2019). Only six rivers cover approximately 95 % of Finland's total hydropower production (Sipola, 2020). These rivers are Kemijoki, Vuoksi, Oulujoki, Kokemäenjoki, Kymijoki and Iijoki. The largest hydropower plant in Finland, which is located in Imatra, has maximum rated output of 192 MW. Hydropower is commonly used in electricity balancing as the water reservoirs in the adjacency of hydropower plants function as storages. Furthermore, hydropower can be regulated quickly; reserves can be dispatched within minutes if needed. (Fingrid, 2018) Due to its excellent regulation properties, hydropower constitutes an entity which enables the increasing share of other renewable technologies such as wind power. Moreover, hydropower serves locally as flood control, particularly in spring when snow is melting. (ÅF-Consult, 2019)

The greatest impact on land is created by regulation of the flow rate. The size of the reservoir created can vary greatly depending on the topography. Constructing hydroelectric power plant on a flat area tends to drown more land in comparison with an area with large differences in altitude. The topography of Finland is relatively flat, and thus, the height differences in rivers are small. It should be noted, however, that all hydropower plants do not have the authorization to participate in regulation or lack the technology needed. In such cases, the head of water and flow rates correspond to natural state. (ÅF-consult 2019)

As stated earlier, water levels are being regulated not only for energy generation but also for flood control. Hence, it is difficult to assess the land-use effects for hydropower water level regulation as the reasons for regulation are typically both energy generation and flood control. The area that is being drowned for constructing hydropower is generally wetland, or the soil is unsuitable for construction due to flood risk. (Sipola, 2020)

The extent of the upstream area change varies greatly depending on the topography (Sipola, 2020). Thus, the nationwide hydropower land-use will not be discussed in this thesis. However, two case examples are presented: Kelukoski and Matarakoski hydropower plants in Sodankylä. Kelukoski is one of the newest hydropower plants constructed in Finland, and accurate data of the topography is available of the upstream area. The areas were calculated based on available free satellite images from Google Earth Engine. Prior construction, the upstream area of Kelukoski was approximately 0,4 km^2, and after constructing the dam, the area increased to 1,1 km^2. Kelukoski hydropower plant produces on 39 GWh of electricity on average (Kemijoki Oy, 2020), which corresponds to 140 TJ. The upstream area of Matarakoski was 0,3 km^2 before and 0,7 km^2 after the dam, and the power plant has annual production of approximately 31 GWh (Kemijoki Oy, 2020), or 110 TJ. Thus, after calculating the difference in the upstream areas of these two power plants, the land-use—output ratio of these power plants are approximately 8×10^{-3} km^2/TJ and 6×10^{-3} km^2/TJ, and the average is then 7×10^{-3} km^2/TJ.

3.5 Coal

Coal is used to produce heat, electricity and process steam. The share of coal in Finland's total energy consumption is approximately 10 %. The use of coal typically varies strongly, possibly due to seasonally altering demand of heat and electricity.

There are 8 power plants that use coal as primary fuel and one power plant that is using coal as secondary fuel (The Energy Authority, 2019). The largest is Meri-Pori power plant in Tahkoluoto, Pori, which operates partly as a power reserve. Reserves are, according to

(Fingrid, 2019), “power plants and consumption resources which either increase or decrease their electric power according to the need of the power system.” It has an electrical power of 565 MW, and it was operating 3000 hours in 2018 (Hammarberg, 2019). This corresponds 1 695 GWh and 6102 TJ. The area of the plant, including coal storage field, covers approximately 1 km^2. Thus, the estimated land-use of this power plant is $0{,}16\times10^{-3}$ km^2/TJ.
Coal produced 33 200 TJ of heat and 23 200 TJ of electricity in 2017, which is, in total, 56 400 TJ (Official Statistics of Finland, 2017). Using the land-use and output ratio of Meri-Pori, and the total energy production in Finland, a rough estimation of land-use of coal in Finland would be 9×10^3 km^2.
Coal as a fuel will be prohibited in Finland starting from the 1st of May, 2029 as a part of Finland’s energy policy strategy. However, the law does not apply to reserve power plants (416/2019). Hence, the energy use of coal is not likely to completely seize in Finland.

3.6 Wind power

Finland’s wind power capacity at the end of year 2018 was 2041 MW. With that capacity, the wind turbines were able to produce 5,8 TWh, which covered approximately 6,7 % of Finland’s electricity consumption that year. (Suomen Tuulivoimayhdistys, 2019) The majority of wind power, 42 %, is installed in Northern Ostrobothnia. This thesis concentrates on onshore wind.

To avoid interference, wind turbines require correspondingly large area clear of trees and other turbines. A heuristic rule for placing two windmills is, that the distance between must be at least five times the rotor diameter. Large wind parks require typically even more space. (Suomen Tuulivoimayhdistys ry, 2019) Average capacity of a windmill in Finland is 3,3 MW (Suomen Tuulivoimayhdistys ry, 2019). This thesis uses Tohkoja wind park as an example to calculate an estimation of total land-use of wind power in Finland.

Tohkoja wind park area in Kalajoki is approximately 11 km^2, and its 22 windmills have capacity of 3,3 MW. Thus, the total power of the wind park is 73 MW. The distance between the windmills varies from 400 meters to 600 meters. (wdp Finland Oy, 2019)

Therefore, Tohkoja wind park requires 0,15 km^2/MW. As stated before, Finland produced 5,8 TWh in 2018, which corresponds 20 900 TJ. When the capacity, 2041 MW is multiplied by 0,15 km^2/MW, the total land-use of wind power in Finland would then be approximately 306 km^2. When the total land-use is divided by the total production of 20 900 TJ, the land-use—output ratio of wind power is approximately 15×10^{-3} km^2/TJ.

3.7 Natural gas

Finland does not possess natural gas reserves, hence there is no natural gas production either. The majority of natural gas is transferred to Finland from Russia via natural gas network. Liquefied natural gas is imported by marine transport. (The Energy Authority, 2019) Since the quantity of biogas produced in Finland and fed to natural gas network is relatively small, 100 GWh in 2017, the land-use of domestic biogas production will not be discussed in this thesis.

In total, 9300 GWh of heat and electricity was produced by natural gas in 2018 (Suomen Kaasuyhdistys, 2019). This corresponds 33 500 TJ. According to (The Energy Authority, 2019), there are currently 23 power plants that use natural gas as primary fuel. All of them are not constantly in operation. Natural gas power plants may be on standby and be dispatched as peaker plants, or mothballed (Lindfors, 2020). All 23 plants are included in the calculation in this thesis, despite the current status of the plants.

Power plant that will be used as an example in this thesis is Vuosaari B, which lies in Helsinki. In 2017, Vuosaari B produced 1536 GWh of electricity and 1497 GWh of district heat (Huovilainen, 2018) which translates to 10 900 TJ. Power plant area is approximately 0,11 km^2, hence the land-use of Vuosaari B using these values is $9,8\times10^{-6}$ km^2/TJ. With the assumption that all 23 power plants would require 0,11 km^2, the total land-use would be 2,5 km^2 at the most.

Assessing the land-use of natural gas network, two types of gas pipelines are considered in this thesis: transmission pipeline and distribution pipeline. Transmission pipeline consists of underground steel pipe with a diameter of 600-800 mm (DN > 500). There is totally 1196 km of transmission pipeline in Finland. Distribution pipeline has smaller diameter (DN ≤ 200) and is 2011 km long in total. (Lindfors, 2020) Safety distances of these pipelines are defined in (551/2009). The pipe diameter for DN > 500 is 10-20 m and for DN ≤ 200 the distance is 5-10 m. Safety distance depends on the type of building. In this thesis, the safety distance used is an average: 15 m for DN > 500 and 7,5 m for DN ≤ 200. Thus, transmission pipeline and distribution pipeline require approximately 33 km^2 of land in total.

Transmission pipe network contains valve stations every 8-32 km (Lindfors, 2020). This thesis assumes that there is a valve station every 20 km in the transmission pipe system. Thus, when the length of transmission pipe network is 1196 km, the quantity of these stations is approximately 60. Safety distances for these stations are, likewise, defined in (551/2009). This thesis uses 50 m safety distance. Hence, 60 stations would require approximately an area of $60 \times 50 \text{ m} \times 50 \text{ m} = 0{,}15 \text{ km}^2$

When the land-use of power plants, pipelines and valve stations are summed, the land-use of natural gas is, in total, 36 km^2. When the total production of natural gas is 33 500 TJ, the land-use per energy produced is 1×10^{-3} km^2/TJ.

3.8 Peat

Peatlands comprise an area of $9{,}2\times10^4$ km^2 in Finland, which is almost one third of the total area of Finland. Approximately 600 km^2 is currently being used for peat production, of which 90 % is produced for energy industry. Thus, 540 km^2 of peatland is used for energy generation purposes. Peat covers approximately 7 % of Finland's energy supply, and in district heat production, the share of peat is approximately 20 %. (Geological Survey of Finland, 2019)

Peat as a fuel produced approximately 36 000 TJ of heat and electricity in 2017 (Official Statistics of Finland, 2019).

In Finland, there are 26 power plants that are using peat as their primary fuel. (The Energy Authority, 2019). Estimating land-use of peat, this thesis uses two power plants as reference: Seinäjoen Voima Oy's power plant in Seinäjoki and Oulun Energia Oy's two power plants in Oulu. Seinäjoen Voima Oy's power plant produced 1050 GWh in 2018, which corresponds 3780 TJ (Seinäjoen Voima Oy, 2020). The power plant area is approximately 0,13 km^2. Thus, the power plant requires $3{,}4\times10^{-5}$ km^2/TJ. Oulun Energia's power plant land-use, 0,14 km^2 and $2{,}1\times10^{-5}$ km^2/TJ, was calculated earlier in the wood fuels section. Assuming that an average power plant size of a CHP plant burning peat is approximately 0,14 km^2, then 26 power plants would require 3,6 km^2. When the total area of peatland used for energy generation purposes is 540 km^2, and peat produced 36 000 TJ in year 2018, the land-use for peat as an energy source would then obtain 15×10^{-3} km^2/TJ. In conclusion, production constitutes the largest portion of the land-use of peat in Finland, and energy production itself represents only a minuscule share in the total land-use.

Peat is often burned with wood fuels as peat prevents the corrosive effects of chlorine originating from wood and energy crops. Wood fuels, on the other hand, bind the sulphur that peat contains. Using peat with wood fuels also reduces malfunctions caused by ash and bed material sticking together as well as reduces the need for sweeping the boiler. (Bioenergia ry, 2019)

3.9 Solar power

The share of solar power in Finland's energy production is less than a percent for the time being. In 2018, the generation of solar energy was 162 GWh, which was 0,2 % of total consumption (Official Statistics of Finland, 2019) Finland's climate is well suitable for photovoltaic energy production (LUT University, 2019). Yearly in-plane solar irradiation on an optimally installed solar panel is approximately 1500 kWh/m^2, whereas in Germany, the same number is approximately 1700 kWh/m^2 (European Commission, 2019). There are approximately 15 000 PV systems in operation in Finland (Ahola, 2018). Power plant registry of Finland only has one PV system listed (Energiateollisuus, 2019).

Solar panels have the best efficiency in cold temperatures. Facade installations perform well in the Nordic countries too, since the Sun is shining low during winter and there is no snow accumulation on vertical panels (LUT University, 2019). However, this thesis concentrates on land occupation and consequently, due to the rareness of ground installations in Finland, the land-use of solar power will not be assessed. Nevertheless, PV systems are rapidly gaining popularity among companies and private persons due to quickly decreased price of solar panels (Austin, 2019). Hence, the effects of solar power in perspective of land-use are likely to increase in the future.

4 DISCUSSION AND CONCLUSIONS

The results indicate that fossil fuels possess smaller land-to-energy ratio in comparison with renewable fuels, with the exception of peat. Nuclear power has the smallest land-use requirement among the technologies examined, followed by coal and natural gas. The poorest land-to-energy ratio belong to peat and wind power. Calculating the land-use of natural gas, the transmission was also included, which increased the number. With regard to wood fuels and peat, the land-use of production was included in the calculations. The result for hydropower was acquired by calculating the upstream effect of two hydropower plants located in Northern Finland. Thus, the results are not fully compatible as the assessment itself is incomplete. The results are collected in a graph and presented in Figure 5.

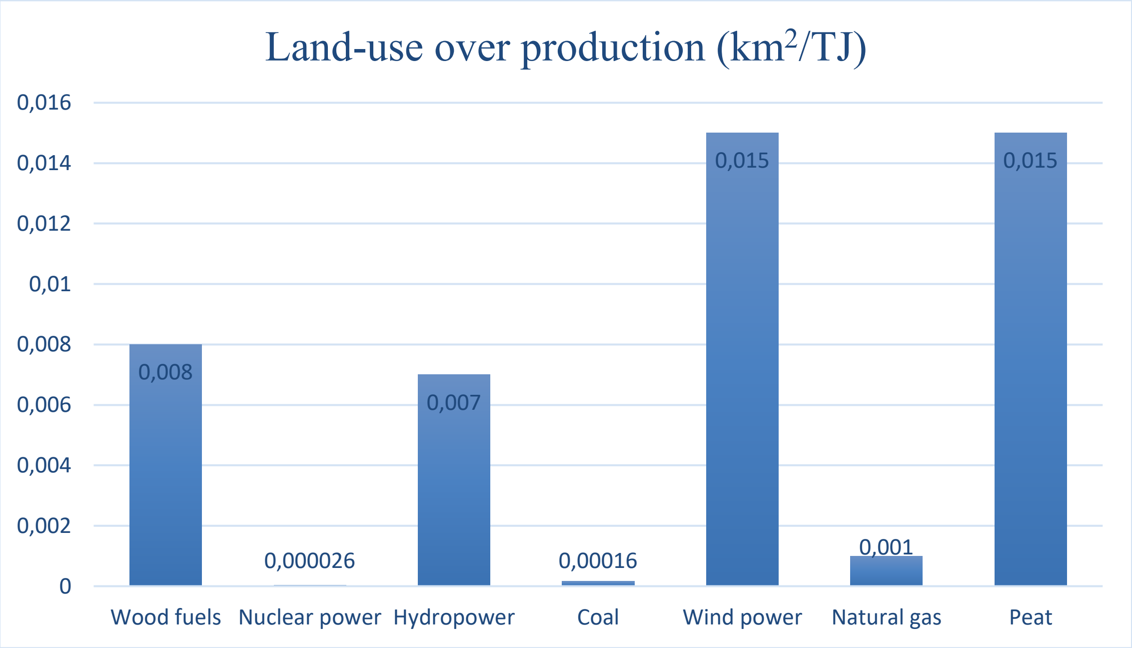

Figure 5. According to the results, peat and wind power require the largest land area in relation to produced TJ in Finland.

The land-use requirements of oil and solar power were not examined in this thesis. However, they were worth mentioning since solar power is quickly gaining popularity among consumers and the importance of oil, although predominantly used to fuel vehicles, rests on reserve power plants and the security of supply.

The results are directional as only a few power plants were used and then extrapolated to calculate land-use over production for each energy source. More precise assessment of land-use would have required more time to examine the land areas occupied by energy production facilities, which was not reasonable in the scope of a bachelor's thesis. The full fuel cycles were not covered in this thesis. Furthermore, the land-use effects outside the borders of Finland were not assessed. However, the results indicate that in general, renewable energy sources tend to require more land area in comparison with non-renewable sources, which is compatible with other studies about the subject, e.g., the report from (STRATA, 2017).

In the future, the need for balancing power is likely to increase due to increasing share of non-dispatchable energy technologies, such as wind power and solar power. Among hydro power and import of electricity, flexible demand and storage technologies are expected to scale up. (ÅF-consulting 2019) Efficient deployment of renewables, e.g., installing solar panels on the roofs or integrating agriculture with wind farms, is one tool to reduce land-use pressure (IRENA, 2017).

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