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Preface

This report reviews the current status of renewable energy hybrids in Finland, in particular those including bioenergy as one energy source. To provide background on market conditions for bioenergy RES hybrids in Finland, the report describes the prevailing situation in the energy sector and renewable energy production. The status of hybrid systems is mainly reviewed through example cases. The future potential of hybrid systems in different applications is estimated and rough quantitative estimates are given. In addition, market barriers for the market growth of hybrid systems are defined. The information provided is based on the literature review, and information provided on the websites and by companies.

The report is part of the IEA Bioenergy's special project "Bioenergy RES Hybrids", carried out during 2016. Participants in the project are IEA Bioenergy, European Commission, Finland, Austria and German. The Finnish part of the project is funded by EC, IEA Bioenergy and VTT Technical Research Centre of Finland Ltd.

Contents

List of symbols

CHP	Combined heat and power
COP	Coefficient of performance
CSP	Concentrated solar power
DAC	Direct air capture
DC	District cooling
DH	District heating
DHW	Domestic hot water
EPC	Engineering, procurement and construction
FiT	Feed-in tariff
GDP	Gross domestic product
KET	Key enabling technology
NG	Natural gas
O&M	Operation and maintenance
ORC	Organic Rankine cycle
PEV	Plug-in electric vehicle
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy source
TRL	Technology readiness level
VRE	Variable renewable energy

1. Introduction

The report is part of the IEA Bioenergy's special project 7 "Bioenergy RES Hybrids" (2016) under Task 41. The main objectives of the report are to review and evaluate the current status of bioenergy RES hybrids in the energy sector in Finland and to find the most potential future hybrid cases. Parallel status reports are generated for Austria and Germany. The Finnish status report is prepared by VTT Technical Research Centre of Finland Ltd.

To provide a comprehensive overview of the status and future perspectives of bioenergy RES hybrids in Finland, the current state of the energy sector and renewable energy utilization is first explained in Chapter 2 and information on market players provided in Chapter 3. In Chapter 4, a review on the status of bioenergy RES hybrids in Finland is presented. Energy sector is categorized in power, heating and cooling, and transport sectors. Hybrid systems are reviewed in different applications and scales: 1) domestic applications, 2) utility-scale applications and district heating and cooling networks, 3) industrial applications, and 4) farm-scale applications. The review mainly consists of example cases of existing or planned hybrid solutions, since there are only a few existing large-scale hybrid solutions. Also on-going and past research activities are introduced. Chapter 5 reflects the potential roles and business cases of hybrid systems and derives rough quantitative estimates for the potential in different applications. Also the benefits and challenges of the technologies are evaluated.

1.1 Definition of bioenergy RES hybrid

Bioenergy RES hybrid is considered as *a process with at least two different renewable energy (RE) inputs, of which one is bioenergy*. However, also some RES hybrid systems comprising other renewable sources than bioenergy are presented, such as a hybrid system combining solar electricity and wind. Virtual power plants, in which the production from different energy sources has a temporal connection, but are not at a single site, are excluded from this review. District heating and cooling networks are considered as large-scale hybrid systems with several heat inputs to the same process. Wood pellet drying by solar energy or by other renewable source represents an integrated process and is considered as a hybrid solution, since the heat capacity of biomass is enhanced by another renewable energy source. Biogas is foreseen as a promising energy source in agriculture and in industry, and is included in this report because biogas production and handling integrates energy production, waste management and circular economy, it bridges energy and transport sectors, and it can be hybridised with other renewable energy sources.

In the renewable energy sector in Finland, the following RE sources can be identified contributing to the energy production in different scales or being under intensive development:

- Bioenergy
- Hydro power
- Wind power
- Solar thermal and electricity (PV)
- Geothermal
- Ground-source heat

Also other technologies, such as low-temperature solar thermal in large-scale and concentrated solar power, and innovative solutions found in other countries similar to Finland are benchmarked in the report as possible future solutions in Finland. For example, Denmark has seen large investments in solar thermal district heat production, whereas in Finland the capacity in commercial scale is still zero, but the potential is high if benchmarked to Denmark.

1.2 Background

The Paris Agreement [1], the European Union's renewable energy targets for 2020 [2] and beyond and the national targets of Finland set demand for the renewal of the energy system with primary intent to decarbonize it. The share of renewable energy of *the total energy consumption* was 34.8% in 2015. Finland's RES target for 2020 under the Renewable Energy Directive is 38% of *the final energy consumption*. This target was exceeded already in 2014. Bioenergy plays a significant role in the Finnish energy system by representing over 80% of the current renewable energy production. In 2015, bioenergy represented 13% of the power consumption and 32.6% of the district heat production, which has a market share of 46.3% in the heating sector. Separate heat production with biomass had a market share of 13.2%. The numbers clearly indicate the strong role of bioenergy in the Finnish energy mix.

The RES target of 20% in the transport sector by 2020, urged forward by national distribution obligation, was exceeded in 2014, and the new goal is 40% by 2030. Transport sector corresponds to 17% of the final energy consumption (2015) and around 40% of the total oil consumption for energy use in Finland. Decarbonization of the transport sector is likely more challenging than other sectors, since there are fewer options to cut emissions. Biofuels represents one natural solution in Finland.

Hydro power is the second largest source of renewable energy production in Finland, and it represented 4.6% of the total energy consumption and 25.1% of the electricity production in 2015, being one of the key elements as balancing power. However, the production is very dependent on the yearly water situation, and the annual variation can be as high as 30–50%. The production from hydro power can hardly be increased in the future, since the available major resources permitted by the current legislation have already been built. [3] Wind power capacity has been gradually increasing in Finland, achieving 2.8% share of the total energy consumption in 2015. However, the growth rate is foreseen to slower, since the Feed-in-Tariff quota for wind power is already fulfilled. Solar electricity has gained interest in recent years, but the share in the total power production figures is still small. Solar thermal installations can only be found in small-scale, whereas heat pumps are spreading also to larger scale.

The government has set a target to significantly increase the use of wood in Finland, 15 Mm^3 per year, and to increase the forest chip utilization in energy production from 54 PJ (15 TWh) in 2014 to 90 PJ (25 TWh) in 2020. Typical characteristic of bioenergy based energy generation in Finland is the high share of forest residues; black liquor alone represents 33.9% of all renewable production. Since around 80% of energy derived from wood is generated and used in forest industry, the future growth of bioenergy in Finland is strongly correlated to the status of forest industry. Forest chips, biogas from biowaste and energy crops, and second generation biofuels are foreseen as major potential resources for growth in bioenergy utilization. [4]

High annual variability in heat and power demand is typical for Finland due to Nordic climate conditions. High efficient co-generation of heat and power dominates the district heating markets (74%), while producing 14.3% of electricity. Electricity generation in industrial combined heat and power plants (CHP) is rather stable over the year, but in the district heating CHP plants the production changes according to heat demand. This causes part of the inflexibility in the power sector and sets new demands for the plant development and operation. Year-round solar energy utilization, in particular solar thermal, is restricted by the varying irradiance conditions due to Northern geographic location. Solar thermal production is focused on the periods with the lowest heat demand.

Next to cutting CO_2 emissions, another motivator for wider implementation of renewable energy technologies is to reduce dependency on import energy. Finland is a net electricity importer. In 2015, 58.68 PJ (16.3 TWh) was imported, mainly from other Nordic countries and Russia. Oil represents 23.9% of the total energy consumption (2015) and is the second largest energy source after wood fuels. Cutting the around 8.5 Mt of import oil (2015) [5] requires significant investments in RE sources.

1.3 Why bioenergy RES hybrids?

The variable renewable energy (VRE) production (e.g. solar electricity, solar thermal and wind) creates need for new flexible energy production balancing the system and for energy storage solutions. Bioenergy is *a storable source of energy*, which can produce *energy on demand*. Energy systems relying more and more on distributed renewable generation instead of traditional centralized production and increasing integration of different energy sectors make the energy systems more complex. In order to increase the share of renewable energy and decrease greenhouse gas emissions, while simultaneously guaranteeing reliable energy delivery with sufficient price, a combination of different technologies is needed. Bioenergy RES hybrids in different applications and scales are part of the solution to respond to challenges in the energy system. Hybrid systems having bioenergy as one component are flexible in the sense of being able to produce both base load and balancing services.

A key action in Finland on its way towards the renewable energy targets is to increase and diversify the use of wood, while increasing the refining value of bio-based end-products. Although a traditional resource in Finland, bioenergy can still be used in many ways to increase the share of RES in the energy system. However, the availability of sustainable bioenergy for all end-uses at a cost-competitive price point needs to be ensured. Implementation of other RE sources can release pressure from bioenergy availability, effectively saving bioenergy for the most valuable end-uses.

Regardless the scale of the hybrid system, one of the main motivators towards using renewable hybrid technologies is to increase the level of self-sufficiency and decrease dependency on purchase prices of electricity and fossil fuels. In particular, the cold winters in Finland offer potential to cut peak prices in heating. At the same time, more energy sources improve system reliability. Renewable hybrid technologies aim to using different energy sources at their best, which can lower the cost of energy and improve system efficiency in respect to using only one energy source. For example, solar thermal is not available during the winter period without a large-scale thermal storage system, whereas biomass can be used with high capacity factor and efficiency. In some situations, hybrid system can even reduce the work load of the system owner/operator and improve the component lifetime.

Bioenergy RES hybrids cover a large number of different technical combinations. **Table 1** shows some of the possible combinations, which were used as the basis for the report.

Table 1. Selected bioenergy hybrid processes described in the form of a matrix.

Process description	**Main product**	**Advantages of integration**	**Market segment**	**Market potential**	**Market uptake**	**TRL of KETs***	**Level of process integration**
Biomass combustion + solar heat collectors	Heat	Increased capacity factor and boiler efficiency, reduced biomass need	Household	Large	Small	9	Medium
Biomass combustion + ground-source heat pump	Heat	Increased capacity factor, reduced biomass need	Household, industry	Large	Small	9	Medium
Biomass combustion + CSP	Power	Increased capacity factor and overall efficiency, wider market area	Utility	Medium	Demo stage	7	High
Biogas + electricity	Bio-methane	Increased carbon utilization, storage	Farm-scale	Medium	Demo stage	8	High
Biomass gasification + electricity	Synthetic fuels	Increased carbon utilization, storage	Industry	Large	Demo stage	6	High
Biomass combustion + Geothermal	Heat	Increased capacity factor and boiler efficiency, reduced biomass need	Utility	Small	Demo stage	9	Medium
CHP networks as RES platforms	Heat	Reliability, storage capacity	Utility	Large	Medium	9	Medium

*TRL of KETs refers to Technology Readiness Level of Key Enabling Technologies. For definitions, see: bit.ly/1TAL0lW

2. Market conditions for bioenergy RES hybrids in Finland

To identify the most promising hybrid solutions, potential market areas for hybrid technologies and the size of the future market, it is important to identify the country specific energy markets and expected changes as well as the trends in adaption of RE technologies.

2.1 Status of energy sectors

The total energy consumption in Finland was 1,301 PJ[1] (361.4 TWh) in 2015, which was 3.3% less than in 2014. The total energy consumption by source is shown in **Figure 1**. The share of renewable resources was 34.8% of the total energy consumption, whereas the share of fossil fuels, oil, coal and natural gas, was 38.0%. Imported electricity presented 4.5% of the total energy consumption. [6]

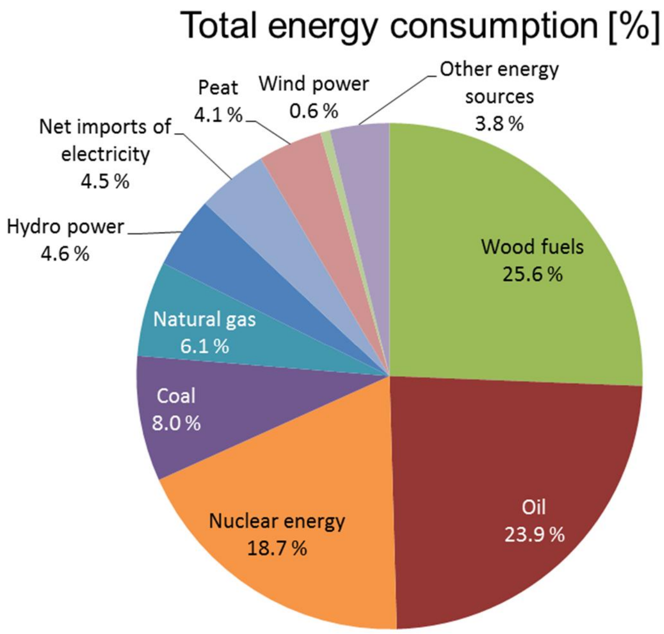

Figure 1. Total energy consumption in Finland in 2015[1]; retrieved from [6].

New Energy and Climate Strategy for the year 2030 is under development in Finland. The National Energy and Climate Strategy was published first time in 2005 and updated in 2008 and 2013. One objective of the update in 2013 included ensuring that the national renewable energy targets for 2020 are achieved. Finland already met the target for RES share of the final energy consumption for the year 2020 (38%) in 2014, and also the target for RES share in transport sector for the year 2020 (20%) was achieved in 2014. [7] The aim of the new Energy and Climate Strategy is to [8]:

- Increase the share of renewable energy in a sustainable way to over 50% by 2030;
- Increase the level of energy self-sufficiency to over 55% by 2030;
- Halve the use of imported oil for domestic purposes;
- Increase the RES share in transport sector to 40% by 2030;
- Cut the coal consumption to zero.

[1] Statistics Finland's preliminary data. Total energy consumption in 2014 was 1,346 PJ (373.9 TWh).

2.1.1 Electricity sector

In 2015, the annual electricity consumption was 297 PJ (82.5 TWh) and the production 238.32 PJ (66.2 TWh) in Finland, leading to net import of 58.806 PJ (16.335 TWh) [9]. Significant share of electricity production, 25%, is based on the combined heat and power (CHP) production (**Figure 2**), which is mainly operated according to heat demand. As a result, power production in the district CHP plants (14.3%) is focused on the winter period. The industrial CHP based power production is rather stable. Hydro power is an important balancing element in the power system. Imported electricity represents almost 20% of the consumption, of which most is imported from the Nordic countries, but also from Russia.

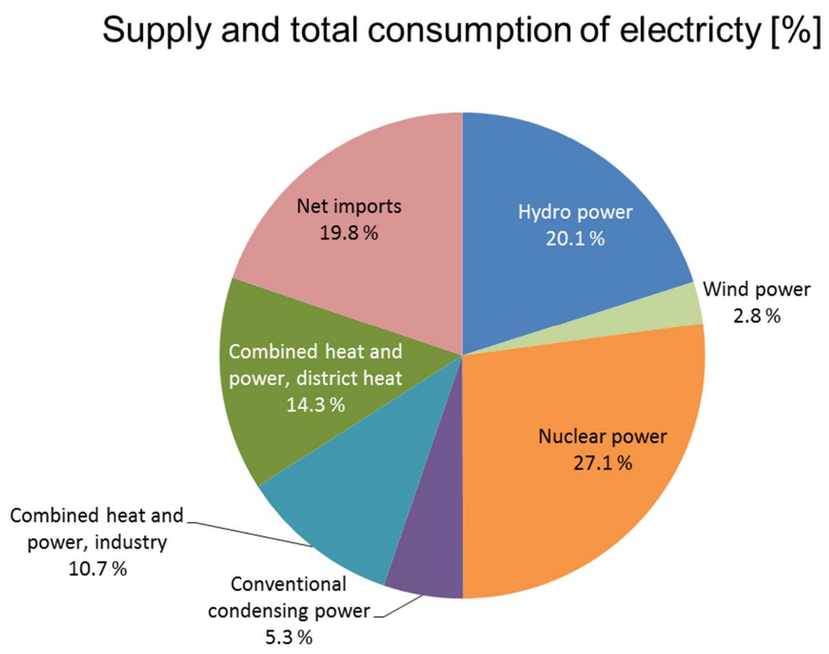

Figure 2. Supply and total consumption of electricity in Finland in 2015[1]; retrieved from [6].

In 2016, the peak consumption was 15.105 GW, which is also the highest measured consumption in Finland. During the peak hour, the import capacity was 4,200 MW. [10] The power generation capacity during peak demand periods is estimated to be 11,600 MW in Finland, which sets the transmission capacity in high importance. The current transmission capacity is approx. 5,100 MW. Discussion on the electricity sufficiency is on-going, since the production capacity is decreasing due to environmental restrictions and economic feasibility of condensing power plants. On the contrary, the wind power capacity has been increasing, but the available capacity during the peak hours is significantly lower than the real capacity. [11] The strength of the Finnish power system, also from the reliability point of view, is its diversity as shown in **Figure 3**. The largest energy sources in power production are nuclear power, hydro power and biomass. The largest renewable resources are hydro power and biomass.

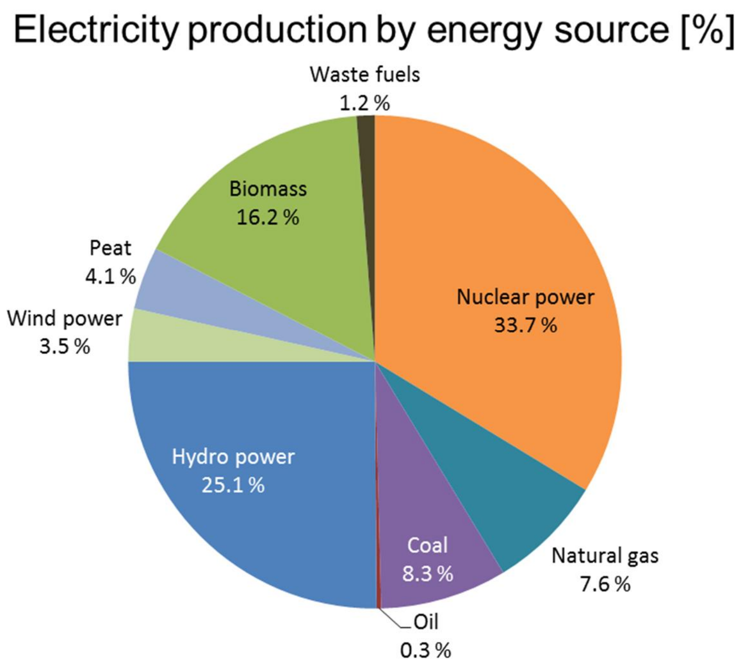

Figure 3. Electricity production by energy sources in Finland in 2015; retrieved from [9].

2.1.2 Heating and cooling sector

Heating solutions in new buildings

In new buildings, district heat (DH) is the most commonly used source of heat. In 2015, 60.9% of new buildings were connected to the district heat network (**Figure 4**), exceeding the 60% for the first time. The share of district heating has undergone steady growth since the end of 1990s. The market share of ground-source heat has been approx. 20% for the past three years. It seems that instead of district heat, the ground-source heat is replacing the use of electricity, wood and fossil fuels. The market share of electricity based heating has been decreasing for years from its top value of approx. 35% in 1980s to just over 10% in 2015. Fossil fuels are fully disappearing in new buildings, and the share of wood-based heating is also decreasing, being currently only approx. 3% in all new buildings. [12]

The market leader in new small-scale buildings with the share of approx. 55% in 2015 was ground-source heat, competing mainly against electricity based heating and district heat (**Figure 5**). However, the market share of ground-source heat has slightly decreased in recent years, while the share of electricity based heating has slightly increased, ending up to approx. 21% in 2015. Reasons for this can be the currently low electricity prices and more energy efficient and smaller houses. Contrary to increasing share of DH in all new buildings, the share has been rather stable and in past two years even decreasing in new small-scale buildings. In the first case, the market uptake of the ground-source heat pumps has not affected the DH demand, but in the latter case, this can be one reason for the slightly reduced DH consumption. [12] The statistics in **Figure 5** do not highlight the market share of other heat pumps than ground-source heat pumps. Fox example, all together over 2,700 air/water heat pumps and over 1,700 ventilation heat recovery pumps were installed in 2015 [13].

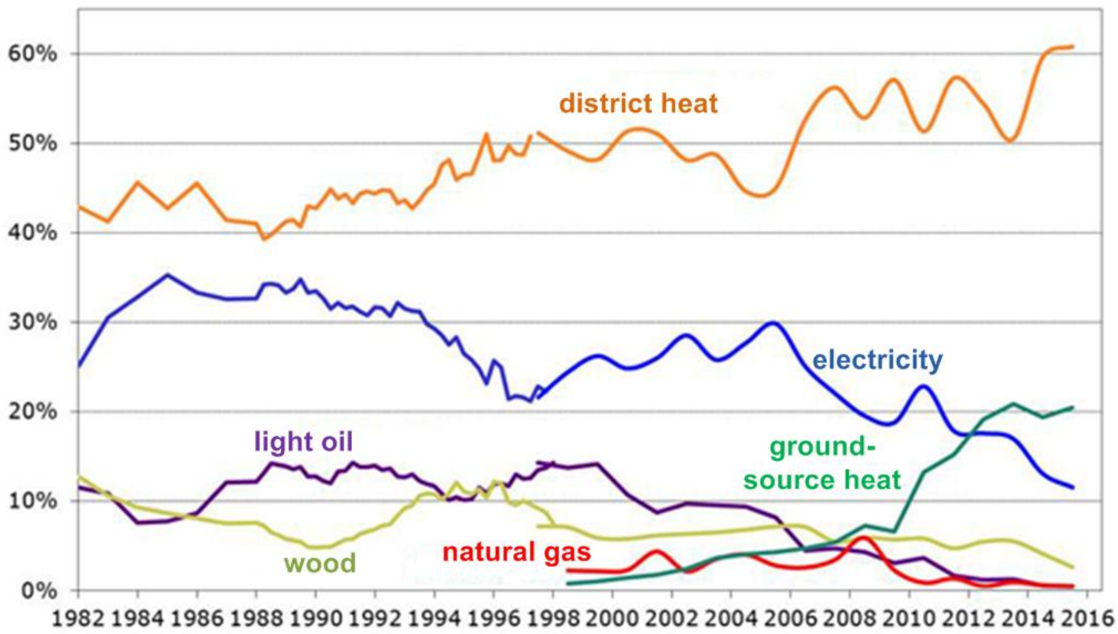

Figure 4. Market share of different heating technologies in all new buildings; retrieved from [12].

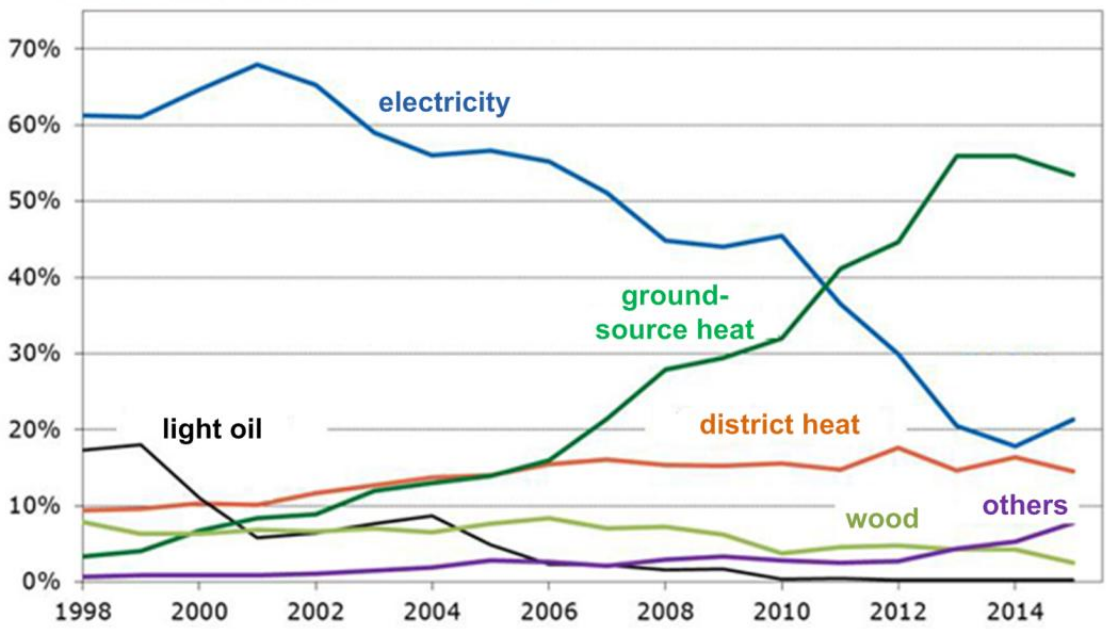

Figure 5. Market share of different heating technologies in new small-scale buildings (i.e. detached houses); retrieved from [12].

District heating and cooling and efficient cogeneration of heat and power

The district heat network has traditionally been strong in Finland, relating to 1950's. As the most common heat source in the country, it should be taken into account in the hybrid technologies related considerations since it:

1) Includes several heat inputs, which, in the future, will be increasingly renewable and waste heat resources;
2) Supports distributed heat generation;
3) Creates flexibility to the power sector, allowing larger share of intermittent RE production.

In 2015, 46.3% of all space heating in residential, commercial and public sector buildings was covered by district heat. A high share of the DH production relies on high-efficient combined heat and power (CHP) production; in 2015, 74% i.e. 87.9 PJ (24.4 TWh). Almost 33% of the DH was covered by biomass (**Figure 6**). The amount of cogenerated electricity was 42.4 PJ (11.8 TWh) i.e. 14.3% of all electricity supply. [9] [14] Due to typical climate conditions in Finland, the monthly distribution of district heat consumption is very uneven (**Figure 7**), leading also to very uneven CHP-based power production. In 2015, the DH consumption was about six times higher in January with respect to summer months, whereas in 2016, the difference will be even higher.

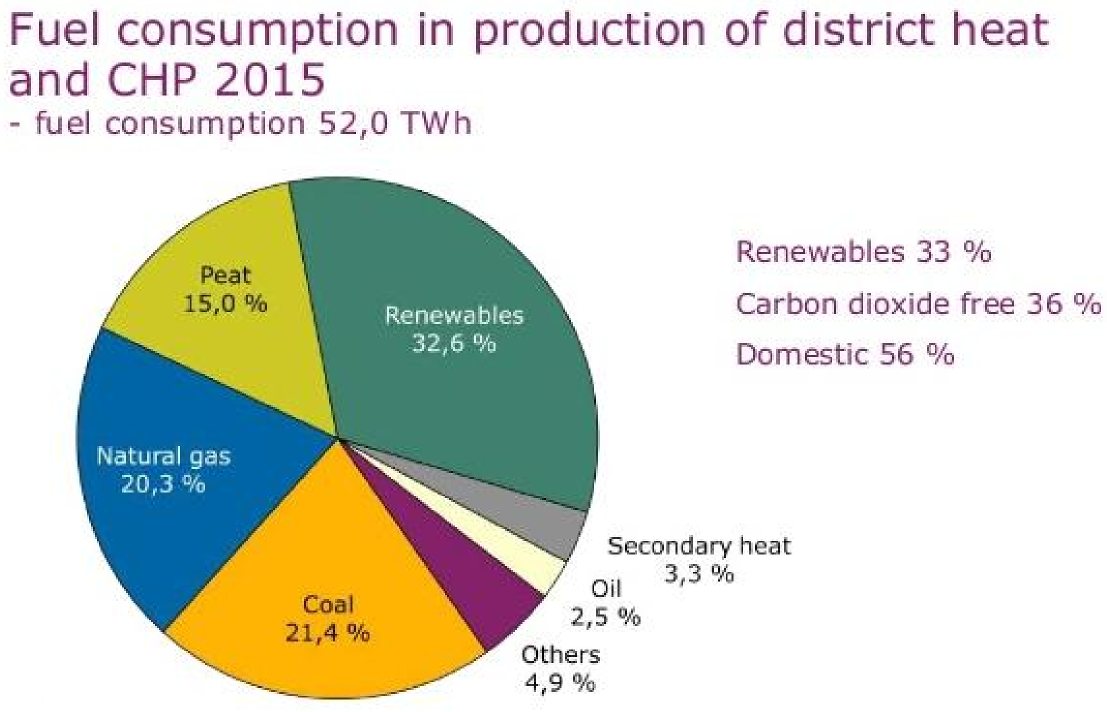

Figure 6. Fuel distribution in DH production; retrieved from [14].

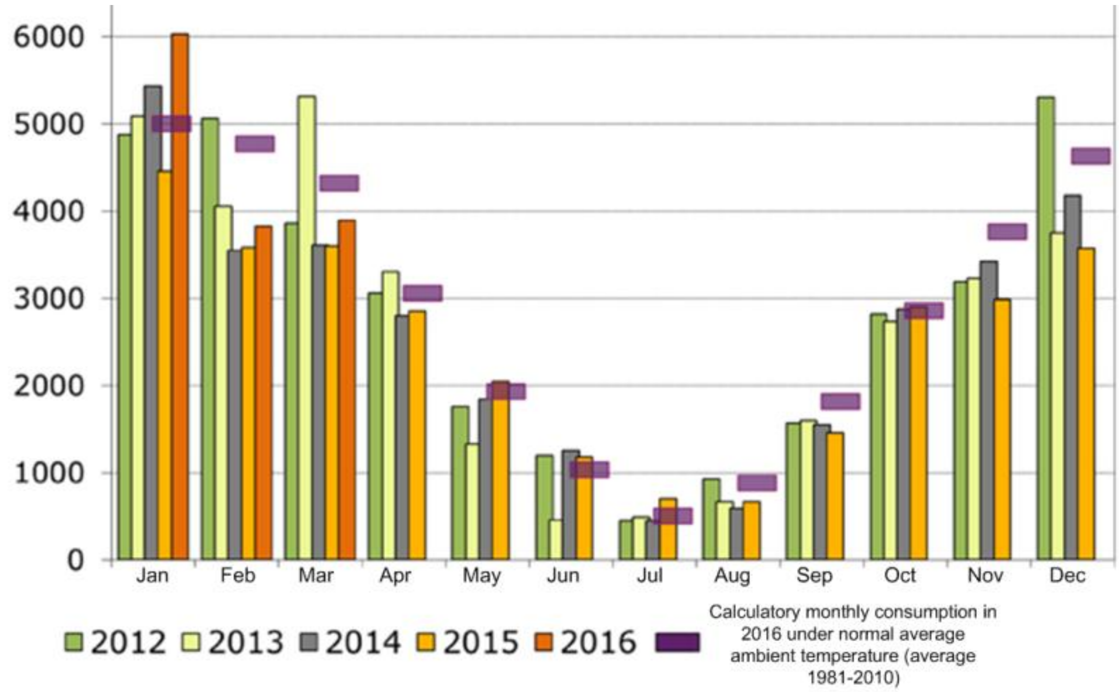

Figure 7. Monthly DH consumption [GWh] in Finland; retrieved from [15].

Currently, CHP plants create part of the inflexibility in the power system while being operated according to heat load. However, DH network with its naturally high storage capacity offers significant potential for increasing the flexibility of the power system. Installation of electric resistance heaters and heat pumps could bridge the heat and power sectors and allow CHP plants to be even shut down during the periods of low electricity prices. In Finland, the low electricity prices become more common with the high share of wind power. Industrial and domestic hot water (DHW) demand is rather stable over the year and can therefore contribute to creating flexibility. [16] Flue gas condensing and development of flexible boilers (e.g. lower minimum load, turbine bypass) are also potential sources of flexibility. Heat storages in the DH network enable higher power production during the periods of high electricity prices [16]. It is evaluated that for example in the HELEN's DH network in Helsinki, the heat storage capacity without any separate storage system is 4.32 TJ (1.2 GWh) [17]. Large share of solar thermal in the DH network would create need for storages and flexible CHP plants especially during the summer period.

The district heat production is already under transition for example in the capital area of Finland, where passive solar energy, heat pumps and waste heat recovery are used to replace coal and natural gas consumption in an energy efficient way (**Figure 8**). Simultaneously, heat pumps create flexibility to the system. The share of bioenergy is continuously increased, and bio-oil can be used to replace heavy fuel oil. The DH demand is foreseen to decrease in some areas due to energy efficient construction, and consequently, lower cost, low temperature DH networks are tested in some new residential areas. [18]

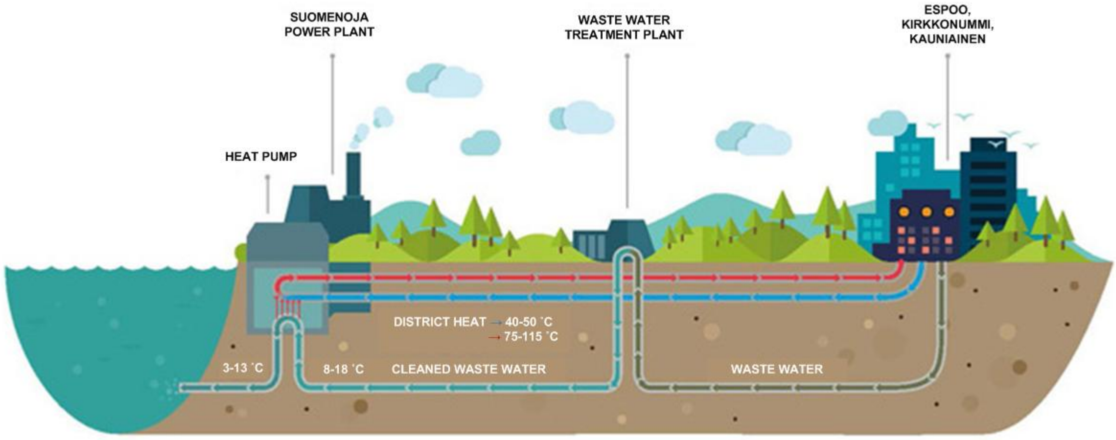

Figure 8. Waste water heat recovery with heat pumps in the district heating system in Espoo; retrieved from [19].

The market share of DH in new construction is foreseen to be 50-75% in the time horizon of 2011–2025, thus increasing the temperature corrected demand from 122.4 PJ (34 TWh) (2015) to 144–151.2 PJ (40–42 TWh) by 2025 [14]. On the other hand, the improving energy efficiency might restrict the need for DH [18]. As the district heat best suits for the urbanized and densely populated municipalities, the urbanization increases the market for DH in the areas with existing networks. Cities with high area density[2] are for example Helsinki (>0.3), Turku, Tampere and Kuopio (>0.15), and there are also more than 250 separate population centers with high area density (>0.1). Also, the market share of district cooling (DC) is increasing. In 2014, the demand was 684 TJ (190 GWh) i.e. more than double the amount in 2011. The market is foreseen to increase by 72 TJ (20 GWh) per year, achieving the market share of approx. 25% i.e. 1,530 TJ (425 GWh) by 2030, while being circa 14% in 2014. [14]

2.1.3 Transport sector

In 2014, the share of transport sector of the final energy consumption was 17% in Finland, which corresponds to 176.12 PJ (48.92 TWh) [21]. The consumption has been in slight increase. Liquid biofuels, biogas and electricity driven vehicles are counted as zero emission vehicles in the transport sector. In 2014, biofuels represented 20.6% in transport sector (double counting), which exceeds the 20% RES target for 2020 [7]. The RES target is urged forward by a national distribution obligation, which increases the target gradually from 6% in 2014 to 20% in 2020. The goal is to increase the RES share to 40% by 2030 [8]. Transport still corresponds to approx. 40% of the total oil consumption for energy use [22].

According to reports by VTT and VATT, the advanced drop-in biofuels would be the most cost-effective way to cut the CO_2 emissions in the transport sector. Biofuels could represent even 40% of the energy use in transport. Biofuels can be flexibly added to the current vehicle stock up to 100% and no changes in the distribution system are required. Biofuel expansion requires investments in biorefineries, increasing the use of domestic resources. The use of both biogas and electric vehicles can increase, but requires renewal of the vehicle stock. The electric vehicles become attractive after the price reduction due to technological achievements. [23] [24]

The electric vehicle stock is still relatively low in Finland: in March 2016, the number of pure electric vehicles was 697 [25].

The increase in transport use of biogas has been fast in recent years as shown in **Figure 9**. In 2015, there were 253 cars driven by biogas and 1,246 hybrid cars in Finland [26]. In 2014, the amount of biogas used in

[2] Area density is defined as the ratio of building area [m^2] to total area [m^2] [20]

the transport was 17 GWh, representing 2.7% of all biogas consumption. The number of public biogas stations increased to 24 during 2014, and further growth in the coming years is expected. The number of stations owners increased to eight and the number of production plants to nine, thus increasing the production from 1,111 Nm^3/hour to 2,731 Nm^3/hour (15 MW_{pa}). Biogas remained the cheapest transport fuel with the lowest price level of 2.41 €cent/MJ. [27] [28]

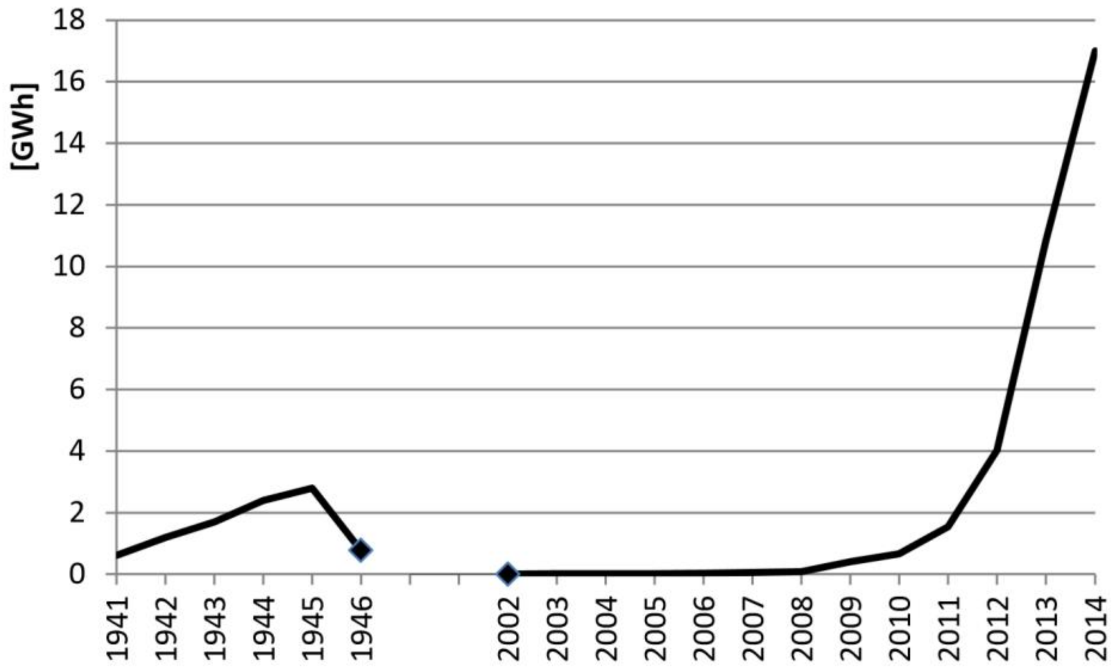

Figure 9. The biogas use in transport 1941–2014 [27]. Data for 1941-1946 is based on archives files, no data for 1947–2001 is available, data for 2002–2013 is based on inquiry and data for 2014 is based on [27].

2.2 Current and projected use of renewable energy resources

The energy markets are in transition as the renewable distributed energy generation, often variable by nature, is gradually increasing its share. At the same time, the role of traditional customers is changing from consumer to also producer, *prosumer*. The energy companies and grid operators are facing a new situation and have to react on the changing trends, such as decreasing running hours of conventional plants and increasing amount of variable power production. One good example of changing business models is Oulu Energy (an energy company in Finland), which has started to deliver excess renewable based power from private distributed micro- and small-scale production units to the grid and customers [29]. Also other energy companies, such as Fortum and HELEN, offer renewable power for the customers.

Renewable energy resources contributed 38.7% to the final energy consumption in 2014 by producing 445.3 PJ (124 TWh) energy [30]. Thus, the target of 38% set for 2020 is already exceeded. The renewable energy contribution by energy source is shown in **Figure 10**. Bioenergy represents over 80% of the renewable energy production (wood fuels: 339.3 PJ i.e. 94.25 TWh) and over 15% of total power production [7]. Solid biomass (incl. industrial spent liquors) represents over 90% of all biomass for energy. The high share of black liquor indicates the strong connection between pulp industry and energy production. The share of biogas is particularly low with respect to EU average.

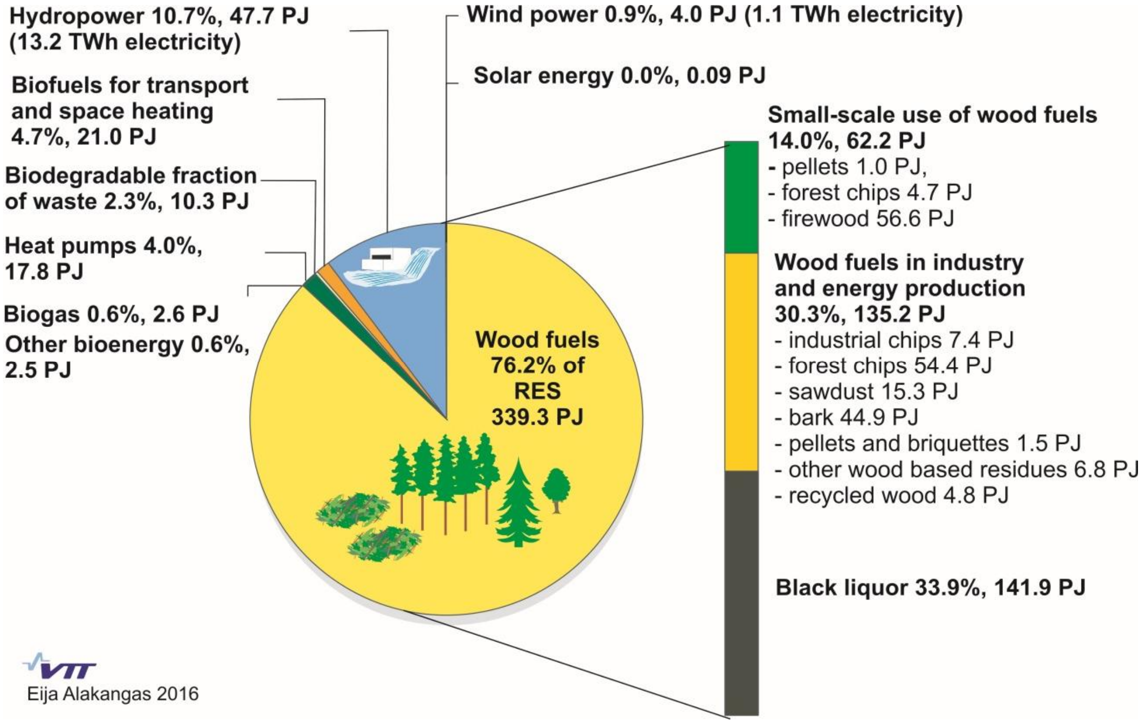

Figure 10. Renewable energy in Finland in 2014 [30].

2.2.1 Bioenergy

The total biomass consumption for energy production in 2014 was 331.2 PJ (92 TWh) i.e. 25.4 million m^3, of which black liquor and other concentrated liquors represented 140.4 PJ (39 TWh), the solid wood fuel use in heating and power plants 129.6 PJ (36 TWh) i.e. 18.7 million m^3 and small-scale use of wood 61.2 PJ (17 TWh) i.e. 6.7 million m^3. Forest chips are the main solid wood fuel with the share of 8.2 million m^3. [31] The goal in Finland is to increase the forest chip utilization in energy production from 54 PJ (15 TWh) in 2014 to 90 PJ (25 TWh) in 2020 [32] and to increase the use of wood by 15 Mm^3 per year [33]. **Figure 11** shows the wood flows in Finland in 2013 and **Figure 12** the trends in forest chip utilization.

Biomass will have a significant role in achieving the RES and self-sufficiency targets set in the government programme. According to studies by Pöyry, the use of solid biomass fuels in centralized energy production will increase by over 54 PJ (15 TWh) by 2030. [34]

Currently, there are about 30 plants producing annually 250,000-300,000 tonnes of wood pellets, resulting to approx. 5.4 PJ (1.5 TWh) energy [35] [36]. However, the total production capacity of the plants is already about 650,000 tonnes [36]. All the produced pellets are not used in domestic energy production; in 2014, the domestic use was 240,000 tonnes, of which 58,000 tonnes were used in buildings and at farms, and 181,000 tonnes in power plants. The consumption in power plants is foreseen to double in the near future. [37] Pellet use is estimated to increase by about 150,000 tonnes by 2017 [36]. As a result, the use is foreseen to be in the range of 400,000–420,000 in a short time frame, corresponding to approx. 7.2–7.6 PJ (2.0-2.1 TWh) energy.

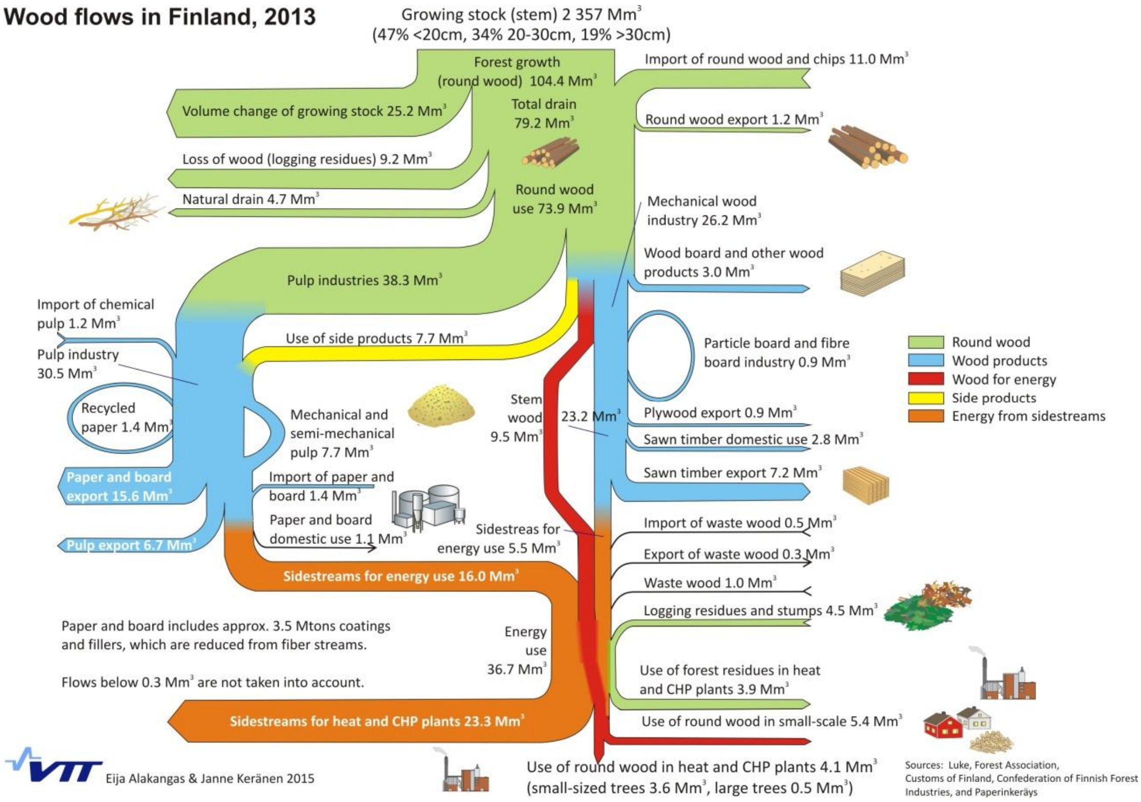

Figure 11. Wood flows in Finland in 2013 [7].

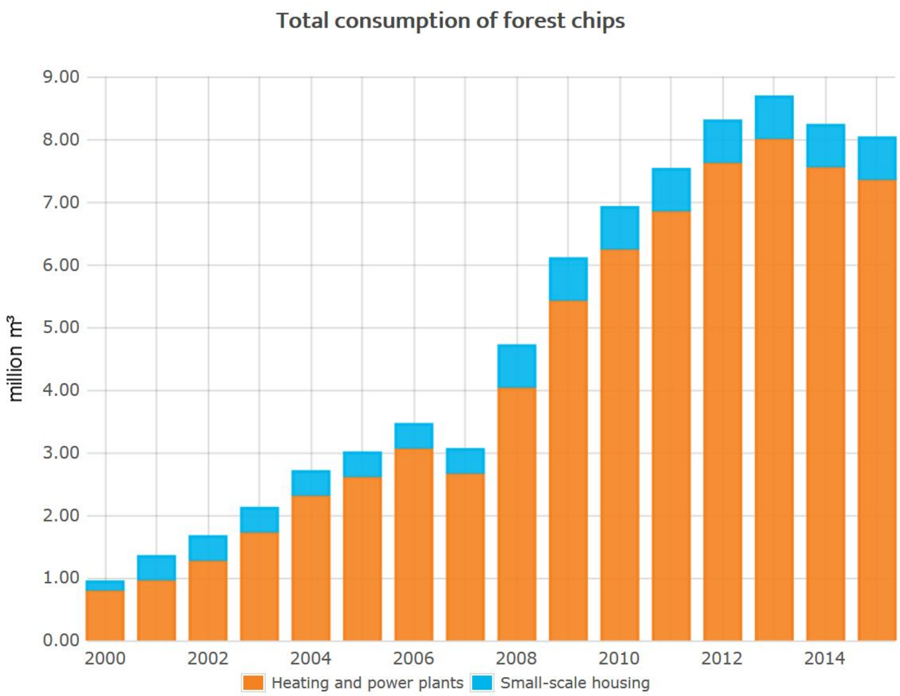

Figure 12. Total consumption of forest chips in heating and power plants and in small-scale housing [38].

Biogas production is not a new technology, but so far, the production and utilization has been very limited in Finland, and the development lacks behind e.g. the Central Europe. However, growth in the production rate has been observed, and the production potential in Finland is stated to be high compared to current utilization. [26] In 2014, biogas reactors produced 1,115 TJ (309.6 GWh) energy (61.5 million m^3) and the production by biogas pumped from the landfills was 94 million m^3, of which 1,093 TJ (303.7 GWh) (74.7 million m^3) was utilized. The produced amount was altogether 155.5 million m^3. The total biogas utilization consisted of 61 TJ (17 GWh) for transport, 1,637 TJ (454.7 GWh) for heat production and 571 TJ (158.6 GWh) for power production (**Figure 13**). The biogas used for energy production represented 0.5% of all renewable based energy production in Finland. [27] [28] The target is to increase the annual biogas utilization to 4.3 PJ (1.2 TWh) by 2020. Biogas production in Finland is subsidised by Feed-in Tariff (FiT). [39] Gasum is one of the biogas producers and distributors, currently feeding 302.4 TJ/year (84 GWh/year) to the grid [40].

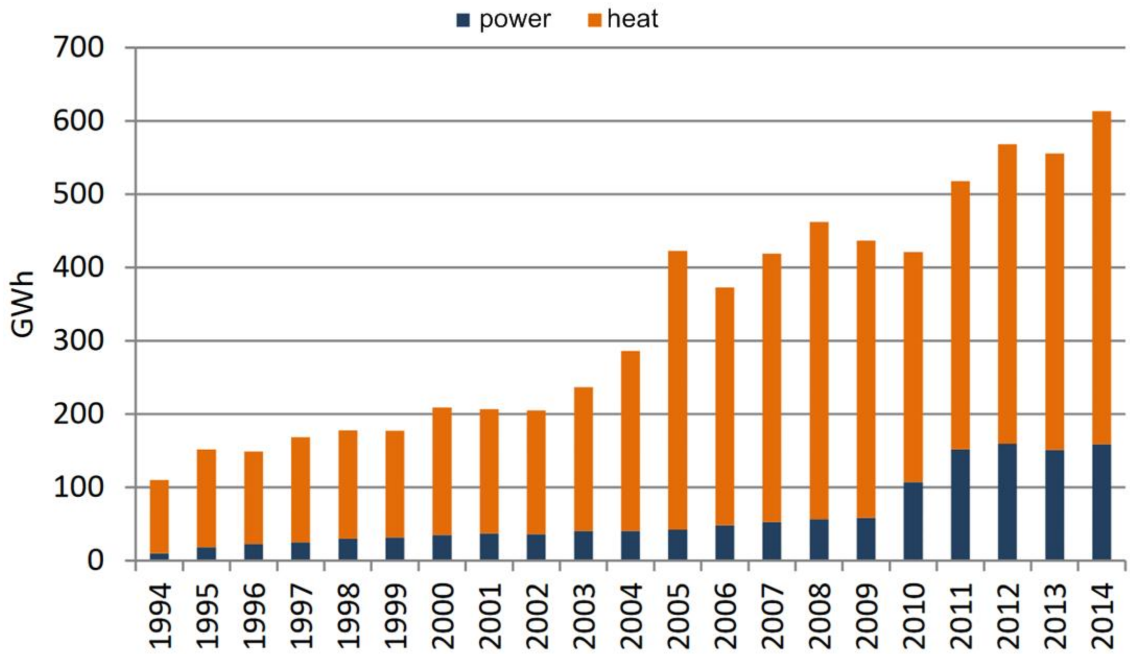

Figure 13. Energy production by biogas in Finland 1994-2014; retrieved from [27].

Table 2 shows the FiTs paid for bioenergy in Finland and the status of the FiT system.

Table 2. Status of the FiT system for bioenergy in Finland in the beginning of 2016 [41] [42].

Fuel	**Capacity limitation [MVA]**	**Quota [MVA]**	**Nr. of accepted plants [-]**	**Capacity [MVA]**	**Annual production [TJ] (GWh)**	**FiT [€/MWh]**
Forest chips	min. 0.1	-	53	3,897	13,726.8 (3,813)	13.13–18.00 [3]
Biogas	min. 0.1	19	3	6	111.6 (31)	83.50 [4]
Wood-based fuels	0.1–8	150	1	1	14.4 (4)	83.50 [5]

[3] The amount depends on the tax for peat and the market price of emission allowance; in 2016, 18 €/MWh.
[4] Target price; incentive paid as the difference of target price and three months' average spot market price of electricity.
[5] Target price as in point 3; max incentive € 750,000 during four consecutive quarters.

2.2.2 Solar thermal and electricity

Any systematic annual process is not yet established to gather statistics about the solar thermal and electricity installations in Finland. According to Statistics Finland, the photovoltaic (PV) capacity was 11 MWp in 2014 and produced 27.9 TJ (7,752 MWh) electricity. From 2015 on, the Energy Authority started to compile statistics of grid connected PV systems. According to questionnaire, the grid connected capacity was 7.9 MW in the autumn 2015. In order to have updated information of the off-grid PV systems and their markets, annual sale statistics should be gathered. [43] Some PV market estimates for recent years are shown in **Table 3**.

Table 3. Current status of solar PV markets in the Nordic countries; retrieved from [44].

	Population [mio]	Cumulative 2012 [MWp]	Market 2013 [MWp]	Cumulative 2013 [MWp]	Wp/habitant 2013	Market growth 2013 [%]
Finland	5.4	11	1.7	12.7	2	15.5
Sweden	9.6	22	18	40	4	81.8
Denmark	5.7	332	216	548	96	65.1
Norway	5.1	10	0.4	10.4	2	4.0
Iceland	0.3	0.9	0.5	1.4	5	55.6
Nordic	26.1	375.9	236.6	612.5	23	62.9
EU28	505.7	69,598	10,374	79,972	158	14.9
World	7,169	100,504	38,352	138,856	19	38.2

The growth rate of solar PV installations has been fast worldwide. In 2014, the worldwide capacity was 183 GWp and, for example, Germany accounted for 38 GWp i.e. about 21%. The technology covered almost 7% of Germany's electricity demand in 2014. [45] The growth rate of PV has been fast in many regions in Europe, but the Nordic countries lack behind. This is not due to the irradiation conditions, but due to a lack of well-adjusted legislation for PV markets and rather low electricity prices. [44] According to calculations of Lappeenranta University of Technology, PV could cover 10% of energy production in Finland by 2050 [46]. **Figure 14** shows the energy pay-back period of multicrystalline silicon PV systems in rooftop use, revealing the reasonable period even in the Nordic conditions.

In Finland, solar thermal technology gains less attention than PV technology, though, in fact, the installed solar thermal capacity is higher, 31 MW_{th} in 2014 [47]. Experts and system suppliers estimate the number of solar thermal installations to be over 1,000 in 2014. IEA's Solar heat worldwide report gives a capacity estimate of approx. 37 MWp in 2013, while Finnish Statistics reports collecting area of 45,000 m^2 in 2014, producing 56.88 TJ (15.8 GWh) i.e. approx. double with respect to PV. [43] Currently 4,000 m^2 of new collector capacity is installed per year [47].

To compare, in the end of 2015, there were 800,000 m^2 of solar thermal collectors installed in Denmark, and the goal for 2020 is 4 km^2, meaning that a fifth fold capacity compared to current would be achieved in five years. The target for the 2030 is 8 km^2 and for the 2050 as high as 30 km^2. The production based on solar thermal energy would be 25.2 PJ (7 TWh) in 2050, covering 40% of the DH demand in Denmark. [48]

According to **Figure 15** based on the data by Finnish Statistics, the growth rate of solar thermal and electricity installations is clearly accelerating. The data for 2015 is not yet available, but even faster growth can be expected compared to previous years. According to results derived in FinSolar project, the domestic market growth in solar energy started in 2014, since the technologies became profitable due to global cost reductions. The investments are economic feasible if the energy is produced for own use to replace higher cost purchased energy and the guarantee period (typically 25 years) is used for the economic evaluation. In the case of companies and municipalities, the prerequisite for profitability is the investment subsidy. [43]

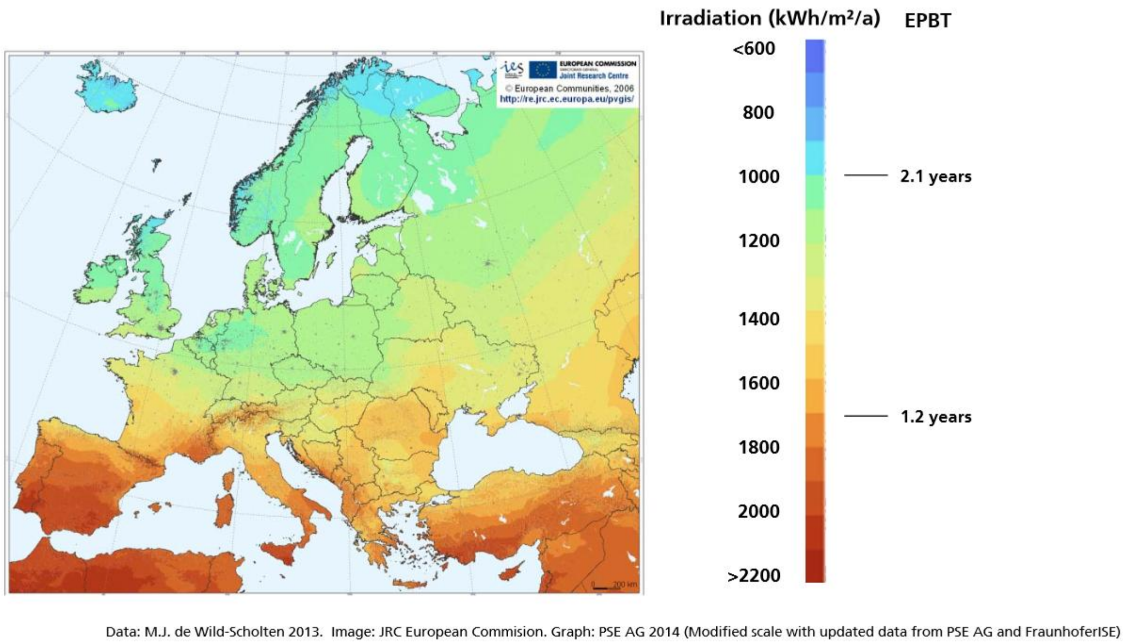

Figure 14. Energy pay-back period of multicrystalline silicon PV rooftop systems – geographical comparison [45].

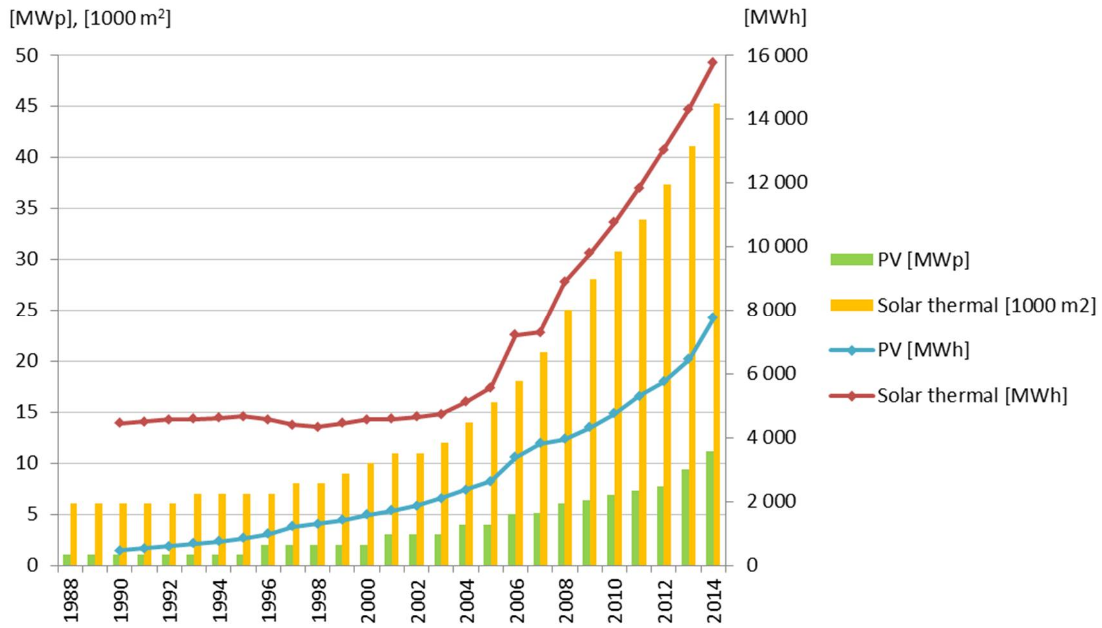

Figure 15. Market development of solar thermal and electricity in Finland from 1988 to 2014. Data is based on the statistics gathered by Finnish Statistics. [49]

Solar thermal installations are still concentrated on small-scale domestic applications, whereas PV systems can already be found in larger scale. The largest installation is placed on the rooftop of a skiing station in Kivikko, Helsinki. The capacity and foreseen annual production of the HELEN's installations are

850 kWp and 2.52 TJ (700 MWh), respectively. The PV panels, 3,000 in Kivikko and 1,194 in another location, are rent for HELEN's customers with fixed monthly price, and the monthly production of the rented panel is compensated in the electricity bill. [50] [51] The business model is easily scalable and gives all the possibility to contribute to penetration of renewable energy. Another example of larger installation is the rooftop of a grocery building in Vantaa. The 503 kWp installation will cover approx. half of the power demand of the building under peak production. Customers can load electric cars with solar power. [52]

On the other hand, small-scale PV systems have gained new boost due to cost reductions. Several companies in Finland, such as Solnet Green Energy, Solarvoima and Areva Solar are delivering PV systems for customers, but also larger energy utilities, such as Fortum, Oulu Energy and Nivos (Mäntsälä Energy) have established a new business model offering PV systems for their customers. SaloSolar as the first company in Finland is manufacturing PV modules. Solar thermal collectors are provided in Finland for example by Savosolar, Ruukki and Sundial Finland.

2.2.3 Wind power

In 2015, the wind power capacity in Finland achieved 1,005 MW with 387 turbine generators, thus producing 8.28 PJ (2.3 TWh) electricity, which represents 2.8% of the total electricity consumption in Finland. The development of wind power capacity from 1997 to 2015 is shown in **Figure 16**. Wind power is a relatively new energy source in Finland, but the growth rate is increasing. In 2015, 124 new wind turbine generators were built, with a combined capacity of 379 MW. In the beginning of April 2016, nearly 13,000 MW of wind power projects were announced, of which offshore projects accounted for 2,000 MW. [53]

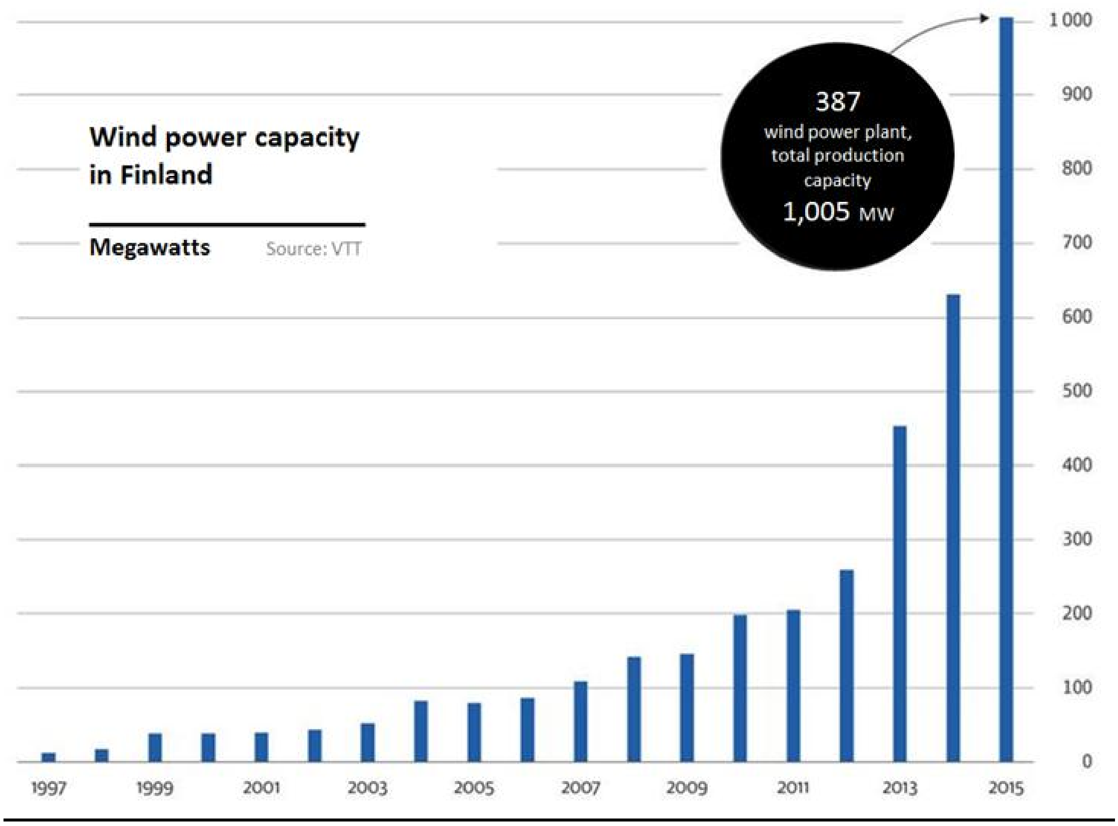

Figure 16. Development of the wind power capacity in Finland from 1997 to 2015; retrieved from [54].

A FiT system for wind power was introduced in 2011 to accelerate the implementation of wind power projects. The tariff level was defined by the ministerial group so as to attract investments needed to meet the 21.6 PJ (6 TWh) annual production target set for the year 2020. In the new Energy and Climate Strategy updated in 2013, the target for annual wind power production by 2025 was set to 32.4 PJ (9 TWh). It is estimated that the target for 2020 requires wind power capacity of 2,000–2,500 MW i.e. around 1,000 wind turbines, whereas around 3,000 MW of capacity is required to achieve the target for 2025. [53] [55] Wind turbines in the FiT system are guaranteed a fixed price of 83.50 €/MWh i.e. the difference between the guaranteed price and market price is compensated for the wind power producer for the length of 12 year. In order to accelerate the development of wind power capacity from the very beginning, a higher guaranteed price of 105.3 €/MWh was paid until the end of 2015 for a maximum of three years. Altogether 2,500 MVA of wind power capacity is set to be accepted to the FiT system. [53] [56]

Currently, there are already almost 1,200 MVA of capacity accepted to the FiT system and approx. 950 MVA belongs to quota, meaning that no new capacity is accepted to the FiT system anymore [57]. It is foreseen that the goal for wind power production by 2020 will be met already in 2018–2019 [58]. As a part of the update of the Energy and Climate Strategy, new support mechanisms for renewable energy technologies are planned by the Ministry of Employment and the Economy [56]. According to the Finnish Wind Power Association, there are currently wind power projects worth of over 12,900 MW and even € 20 billion waiting for the establishment of new incentive system [57].

The Finnish Wind Atlas was published in 2009 to help in estimation of the regional and local wind energy potential in Finland [59]. Since the production is at its greatest during the cold winter months [53], wind power has a good potential to contribute to winter peak demands and simultaneously, it offers good complementary for the solar energy production concentrated on the summer periods.

2.2.4 Geothermal energy

The first geothermal pilot plant for DH production is under construction in Espoo by St1. The drilling of wells to the depth of two kilometers has already confirmed the viability of the project. The final depth of the wells will be seven kilometers. The commercial operation of the pilot plant is scheduled to start in 2017. The heat generation will be even 40 MW and sold to local DH network, thus covering up to 10% of the DH demand of the city of Espoo. [60] The DH network can then be considered as a kind of a hybrid plant combining biomass and geothermal among other heat sources. St1 is planning another plant with capacity up to 40 MW in Turku, where the plant would decrease the emissions in heating and cooling production. [61]

2.2.5 Heat pumps

In 2015, altogether 60,000 new heat pumps were installed in Finland, thereby increasing the amount of renewable energy in domestic heating by 2.16-2.88 PJ (0.6–0.8 TWh). The total amount of heat pumps is 730,000 (2015), of which air-source heat pumps are the most common. Currently, heat pumps produce more than 18 PJ (5 TWh) heat annually. Heat pumps are rapidly replacing oil and electric heating and also district heating in domestic use in old buildings, whereas in new buildings it is the consistently implemented technology. [13]

The use of air/water heat pumps is significantly increasing due to improving technical performance, reliable supply of systems and also due to increasing offering. Strong decrease in construction of small residential buildings and in renovation investments, and low oil prices decreased installations of ground-source heat pumps by 17% in 2015 compared to 2014. Despite small residential buildings, also larger scale buildings (apartment and terraced houses) have started implementing heat pumps, which increases the size of installed pumps. Ventilation heat recovery pumps, already installed to hundreds of apartment houses, are getting more attractive by reducing the heat consumption of the apartment house up to 50%. The potential of ventilation heat recovery pumps is foreseen to be high in Finland since there are over 30,000 apartment houses without any kind of ventilation heat recovery system. Advantages of heat pumps include easy usage, reliability, small space requirement and possibility for cooling, simultaneously achieving even over 10% return on investment. [13] Trends in heat pump installations are shown in **Figure 17**.

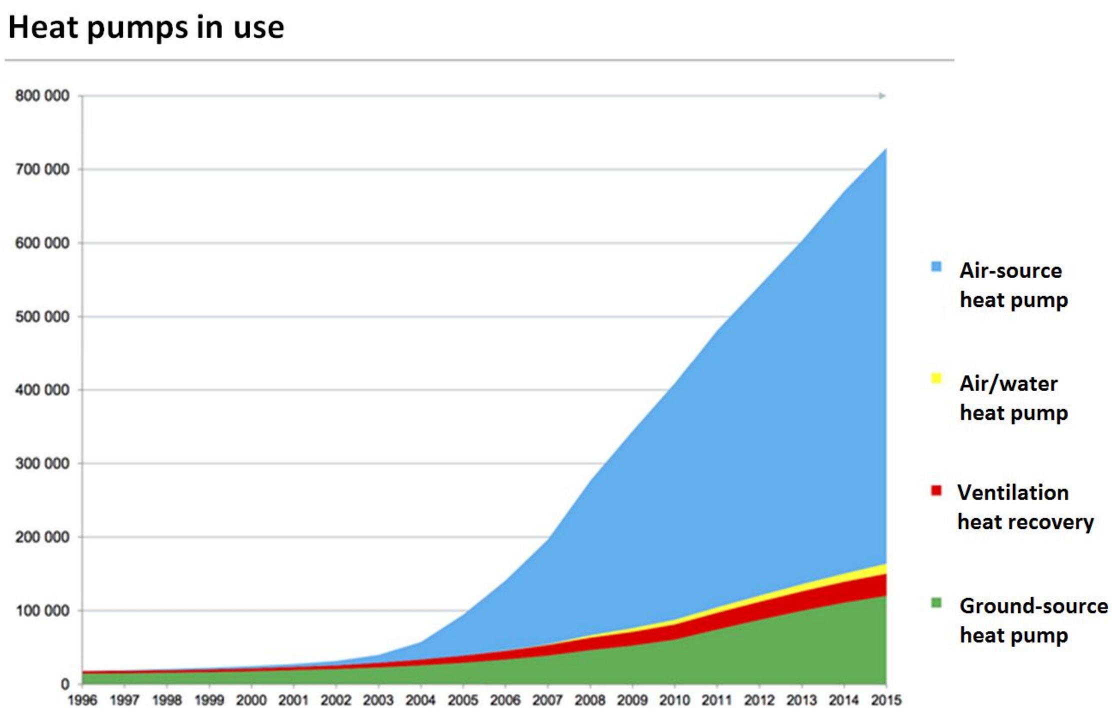

Figure 17. Trends in heat pump installations; retrieved from [62].

According to Gaia Oy, the number of heat pumps in Finland in 2030 will be 1.7 million, producing 54 PJ (15 TWh) energy [13]. With a typical COP value of 3, the power consumption for producing this heat would be 18 PJ (5 TWh). In principle, implementation of heat pumps offers two different basic scenarios for RES hybrid systems:

1) Integration with power sector through renewable electricity utilization – integration level light;
2) Integration with other heat sources – integration level medium.

3. RES and RES hybrid technology market players in Finland

3.1 Active associations in the field of RE technologies

There are several active associations devoted to promotion of RE technologies in Finland. Some of these are listed below. The associations play an important role to bring together renewable energy industries, enhance customers' knowledge on use of RE technologies, set policy recommendations for policy makers and monitor the implementation progress of RE technologies. One recent active association with over 50 members is the Finnish Clean Energy Association, which focus is on renewable energy, smart energy solutions and energy efficiency. The association aims to ease the use of renewable energy and to promote the use of renewable technologies and decisions enhancing their use through proper dissemination.

- Finnish Biogas Association (Suomen Biokaasuyhdistys)
  http://biokaasuyhdistys.net/
- Finnish Clean Energy Association (Lähienergialiitto)
  http://www.lahienergia.org/
- Finnish Fireplace and Chimney Association (Tulisija- ja savupiippuyhdistys ry)
  http://www.tsy.fi/
- Finnish Heat Pump Association (Suomen Lämpöpumppuyhdistys)
  http://www.sulpu.fi/in-english
- Small Hydro Association in Finland (Pienvesivoimayhdistys ry)
  http://pienvesivoimayhdistys.com/en/
- Solar Technology Association (Aurinkoteknillinen Yhdistys ry)
  http://www.aurinkoteknillinenyhdistys.fi/
- The Bioenergy Association of Finland (Bioenergia ry)
  http://www.bioenergia.fi/English
- The Finnish Wind Power Association (Suomen Tuulivoimayhdistys ry)
  http://www.tuulivoimayhdistys.fi/en

3.2 Companies in the field of RE technologies

Some companies providing renewable energy solutions needed in hybrid applications are presented in **Table 4**. In addition to suppliers, there are also consulting services available for high-efficient renewable energy solutions. All the elements needed for implementation of wide variety of hybrid solutions already exist in the markets.

Many of the companies are providing EPC services, especially for domestic applications, and the offering includes different RE technologies, such as fireplaces, heat pumps, solar thermal collectors, PV systems and hot water accumulators, which can be purchased as stand-alone solutions or as flexible case-specific hybrid solutions. Due to strong background in bioenergy utilization, there are several boiler manufacturers in Finland.

Table 4. Examples of renewable energy technology providers in Finland.

Company	Market areas	Technology
Large-scale biomass boilers		
Valmet	Finland, global	BFBs (HYBEX), CFBs (CYMIC), heat boilers (Bioheat RampUp pellet plants), gasifiers, integrated pyrolysis, process automation
Andritz	Finland, global	BFBs (EcoFluid), CFBs (PowerFluid), gasifiers
Amec Foster Wheeler	Finland, global	BFBs, CFBs, grate boilers

Company	Market areas	Technology
Small- and medium-scale biomass boilers		
KPA Unicon	Finland, Russia, South and East Europe	BFBs, grate boilers, pellet boilers
Renewa	Finland, Sweden, France, Latvia, Lithuania	BFBs and CFBs (<50 MW), pellet boilers (<100 MW) and grate boilers (2–12 MW) for heat and power production, utilizing local bioenergy resources
Volter	Finland, Australia, UK, Canada	Wood chip dryer, wood chip gasifier + combustion engine + heat recovery; electric power 40 kW, heating power 100 kW
Gasek	-	Wood chip dryer, wood chip fire-tube boiler + wood gas burner for heat and steam production
Household scale hybrid systems		
Ekolämmöx	Finland	Hybrid heating system for heat and/or DHW production; flexible integration of water circulation wood stove, water circulation sauna stove, heat pump, solar thermal collectors and oil boiler through heat storage
PolarSol	Finland	Hybrid heating system for heat and/or DHW production; system combines flexibly solar, air, ground-source heat, waste heat recuperation and energy storage components; patented flat heat exchanger is utilized for all the components
Kaukora	Finland	Hybrid heating system for heat and/or DHW production; flexible integration of wood, wood chip or pellet boiler, heat pump, solar thermal collectors and oil boiler through heat storage
Solar thermal		
Savosolar	Finland, Denmark, Austria, Germany, Russia	Solar thermal collectors, photovoltaic thermal (PVT) panels
Ruukki	Finland	Ceiling elements including solar thermal or electricity components
Solar electricity		
SaloSolar	Finland	Production of PV panels, daily production capacity 25 kW i.e. 90-100 panels
Areva Solar	Finland	Delivery of PV and solar thermal systems
GreenEnergy Finland	Finland	Delivery of PV systems
Solnet Green Energy	Finland	Delivery of PV systems
Solarvoima	Finland	Delivery of PV systems
Valoe	Finland, India	Delivery of PV systems
Finnwind	Finland	Delivery of PV systems
Virte Solar	Finland	Production and delivery of PV rooftops, in which CIGS thin film panels are directly integrated to the sheet metal ceiling
Heat pumps		
Nibe	Finland	Delivery of heat pumps, PV systems, solar thermal systems and wood and pellet burners
LämpöYkkönen	Finland	Delivery of heat pumps
Wind power		
Finnwind	Finland	Delivery of small-scale wind power systems
Geothermal		
St1	Finland	Pilot system on geothermal energy
Biogas		

Company	Market areas	Technology
BioGTS	Finland	Biogas reactors and upgrading units, biodiesel production units
Metener	Finland, China	Biogas reactors and upgrading units
Watrec	Finland	Biogas reactors
Liquid biofuels*		
UPM	Finland	Renewable diesel (BioVerno) production from tall oil
Neste Oil	Finland, US	Renewable diesel (NEXBTL) production
Fortum	Finland	Bio-oil Fortum Otso® for energy production and industry

*Existing liquid biofuel production plants

4. Status of hybrid technologies in Finland

4.1 Current hybrid applications and concepts

Based on the renewable energy companies in the markets and existing knowhow in Finland, all the elements needed for implementation of RES hybrids in heating and cooling, power and transport sectors exist. Since the number of existing hybrid solutions is modest in Finland, except to some extent in domestic use, the status of bioenergy RES hybrids is reviewed through case examples identified in Finland (Chapters 4.1.1–4.1.4) and through on-going research activities (Chapter 4.2).

4.1.1 Domestic applications

Some bioenergy RES hybrid solutions found and proposed in Finland for domestic use are shown in Appendix A. The list includes also some solutions not using bioenergy.

Overview on current status

RES hybrids in domestic applications are mainly found in the *heating sector*. The utilization is not yet very wide, but is becoming more common. Usually detached houses, especially outside the DH network, have a hybrid heating system based on multiple energy sources, such as oil, biomass, electric resistance heater or heat pump. In 2015, hybrids covered almost 8% of the heating markets in small-scale buildings; some examples are integration of air-source heat pump and electric heating or ventilation heat recovery pump and solar heat [12]. In new apartment houses, ground-source heat and ventilation heat recovery are becoming common, even in DH network areas, and electric heating or district heat is usually chosen to complement the production.

Many Finnish companies providing stand-alone renewable heating solutions have already included flexible heating solutions in their offerings, e.g. solar thermal collectors can be integrated to a wood pellet burner, a biomass burner or a heat pump. There can be already found a view companies offering entire hybrid heating systems as “a product", enabling the use of multiple heat sources to DHW and/or space heating: systems typically include a heat storage and flexible connection for several heat sources, such as bioenergy (stove or wood pellet burner), solar heat, heat pump and waste heat recovery (**Figure 18**). Oil consumption of existing oil boiler in detached house can be either fully or partly cut by integrating renewable energy sources through heat storage. Domestic RES hybrid heating system is mature as a technology and the main challenge is the selection of technologies and their proper dimensioning. A hybrid system including solar thermal collectors is not yet a “standard” in Finland like in some countries.

Figure 18. Ekolämmöx's hybrid solution for DHW and space heating; energy sources are selected case by case; retrieved from [63].

Investments in domestic scale RES hybrid heating systems are fully market driven in Finland, since the only support is the tax reduction in the installation work. One indicator of the growing market is given by the district heating providers; for example HELEN and Savon Voima give services for their customers to design a building-specific heating system, in which other heat sources are integrated in parallel to the district heating. The district heating contract requires the permission from DH provider, when changes in DH components are made in the building connected to the DH network. [64] [65] While the hybrid solutions are being introduced to offerings of technology providers, faster growth rate can be expected.

Finnish companies, such as PolarSol, Ekolämmöx and Kaukora, provide full hybrid systems for domestic heating. PolarSol's basic concept is shown in **Figure 19**. The concept is built around the PolarSol's heat exchanger, made of thin stainless steel and having large heat transfer area, which can be found in every heat source integrated to the heating system. An innovative product based on the PolarSol's heat exchanger is the heat collector combining the solar thermal collector properties with the air heat pump; the system is able to both collect the solar irradiation and recover heat from the building exhaust air and outside air. It is stated that the annual collected energy in South Finland is approx. 3,500 kW/m^2, whereas the corresponding figure for regular collectors is around 600 kW/m^2. [66]

Figure 19. The basic hybrid concept for domestic applications by PolarSol: the components, which can be flexibly connected to heat exchanger [66].

Background and need for hybrid technologies in domestic applications

With relatively high investment cost, ground-source heat pump, air/water heat pump and biomass boiler are usually considered as alternative base load heat sources in domestic applications. In Finland, approx. 60,000 heat pumps are sold annually, mainly to replace oil and direct electricity based heating [67]. Due to increasing share of electric heating, heat pumps and district heating, biomass is nowadays seldom the only heat source, but its role as an additional heat source is emphasized [32] [68]. In 2008, it was estimated that there were approx. 2.9 million fireplaces in Finland[6], of which 1.55 million are located in detached houses. Approx. 86% of detached houses have a fireplace. The number of wood-fired sauna stoves is approx. 1.1 million. Annually, 70,000 new fireplaces are installed. [68] The amount of pellet boilers in buildings is 27,000 [37].

The investments in heat pumps and biomass boilers can be partially explained by the fact that customers protect themselves against the foreseen future increase in purchase prices of oil and electricity. Wood pellet and wood based heating can partially or fully cut the power consumption in electric heated buildings, whereas in the buildings with DH or heat pump, peak heat demand can be covered with biomass. Also heat pumps reduce electricity consumption with respect to direct electric heating, and the investment is shown to be beneficial, especially during the high electricity prices [67].

The efficiency of heat pump decreases in the cold winter period, and the typical dimensioning of the heat pump requires another parallel heat source to cover the peak heat demand. Both heat pump and wood pellet burner are very user friendly, whereas the traditional heating with wood requires more effort. One idea behind the hybrid system is to use different heat sources at their best. This approach is illustrated in **Figure 20**. The ventilation heat recovery included in the hybrid system can be used during the whole year, whereas solar heat is not available during the winter months. As a result, the benefit of the hybrid system in annual level is based on the complementary nature of its components.

[6] Excluding wood-fired sauna stoves.

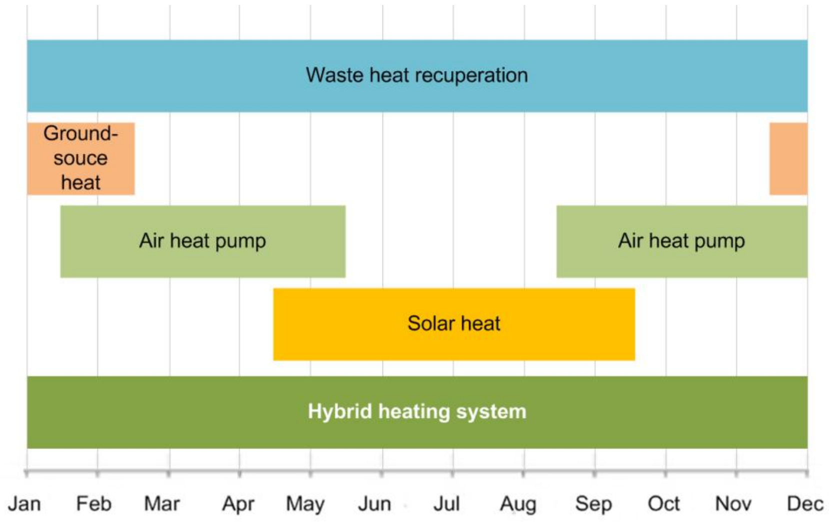

Figure 20. Schematic of the annual utilization of different energy sources in domestic scale heating system by PolarSol; retrieved from [66].

Ground-source heat pump is shown to be more economical in large-scale residential buildings than smaller ones. If stove or fireplace is installed anyway, it can complement the ground-source heat during the coldest winter months, thus reducing the electricity consumption. If the hybrid system relies on regular biomass based heating, it is shown to be more beneficial from the point of view of reliability and life time to complement the system with solar collectors rather than with air/water heat pump. If the share of biomass in the heating system remains small, air/water heat pump makes more sense than solar collectors. [63]

Solar heat integration

Solar heat collectors are able to complement both ground-source heat and biomass based heating (or any other heat source) through thermal storage (**Figure 21**). The benefit of integrating solar collectors to the biomass based heating system is the reduced need for biomass and boiler maintenance, especially during the summer period. The economic benefit is rather small in small installations, but effort is avoided. The integration is easy to implement and solar heat can be stored, since biomass based heating system typically includes rather large thermal storage. In the case of integration to the ground-source heat pump, the life time of the pump can be enhanced. The use of the pump is focused on rather short time periods during the hot summer months, and solar energy can partly avoid these start-ups. Other reasons discovered for solar thermal installation in households are cost savings in fuel or electricity costs, scalability to customer needs, effortless use and minor O&M costs, long life time and desire to contribute to CO_2 cuttings in a simple way [69].

In the case of ground-source heat pump integration, solar heat can be utilized to support the heat pump by upgrading the temperature of the ground cycle liquid before input of the heat pump in spring and autumn. Surplus solar heat in summer can be load to boreholes after DHW heating for using in autumn and winter through upgraded water temperature of the boreholes. [70] Solar thermal integration to heat pump can even double its efficiency (COP) [43].

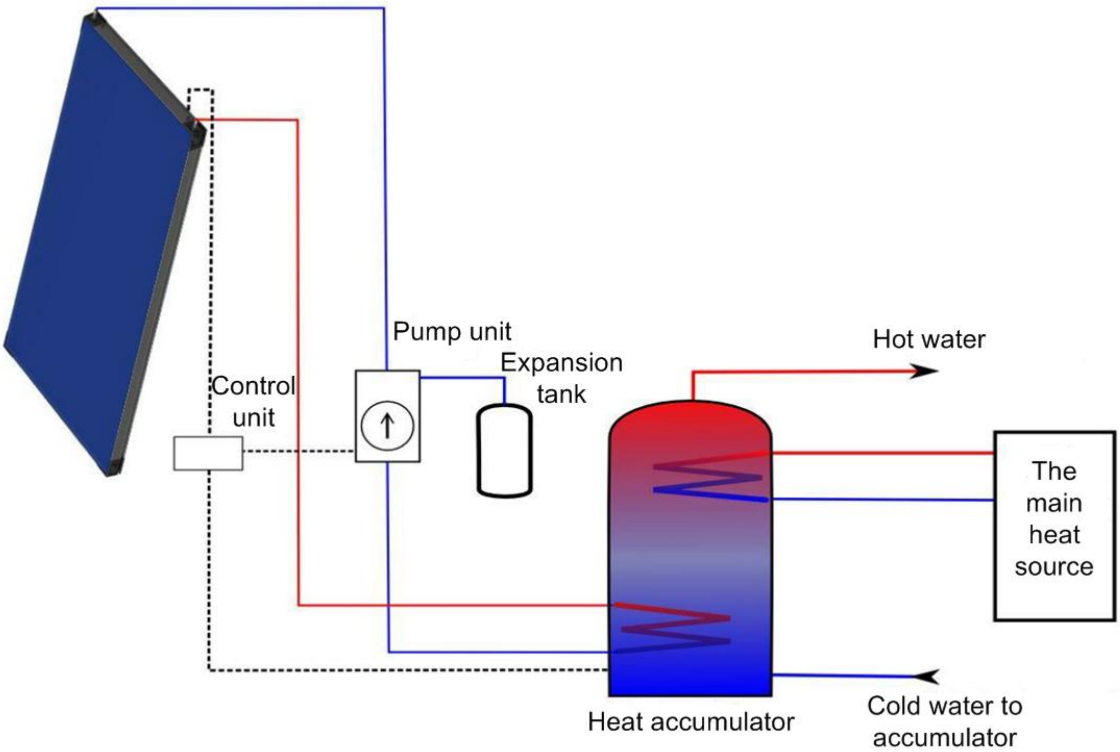

Figure 21. Integration of solar heat collector to the heating system through thermal storage; retrieved from [69].

Hybrid system in relation to district heating network

The increasing district heat prices have encouraged customers, even in the case of existing buildings, to reduce their district heat consumption with other energy sources. Under the Finnish climate conditions, solar thermal system always requires another parallel heat source (hybrid system). Consequently, solar thermal suits well for the DH connected building. Even a hybrid system having more heat sources than only solar thermal can make sense in the DH connected building, for example in terms of dimensioning of the system. From the heat provider point of view own production reduces the DH sale, but on the other hand, new service businesses might arise.

Jyväskylä Energy, an energy company in Central Finland, has demonstrated first time in Finland a two-way DH network connection in a pilot single family house in Jyväskylä as shown in **Figure 22** [71]. The estimated annual heat production by solar heat collectors (2 kW, 4 m^2) delivered by a Finnish company Ruukki is 7.2–10.8 GJ (2-3 MWh). Solar heat is primarily utilized in the building and complemented by wood stove and district heat. In the case of surplus solar heat production, heat can be fed to the DH network. Water fed to the DH grid has to be >75 ˚C and the pressure is raised higher than in the DH feed water line by a pump. The system does not include any thermal storage, since the DH network brings the required flexibility. The building has an energy measuring for both directions, and the same price is paid of the solar thermal energy than the customer pays for the district heat. [72] Similarly, backup heat by DH network could be provided to a building with other heat sources than solar thermal as well.

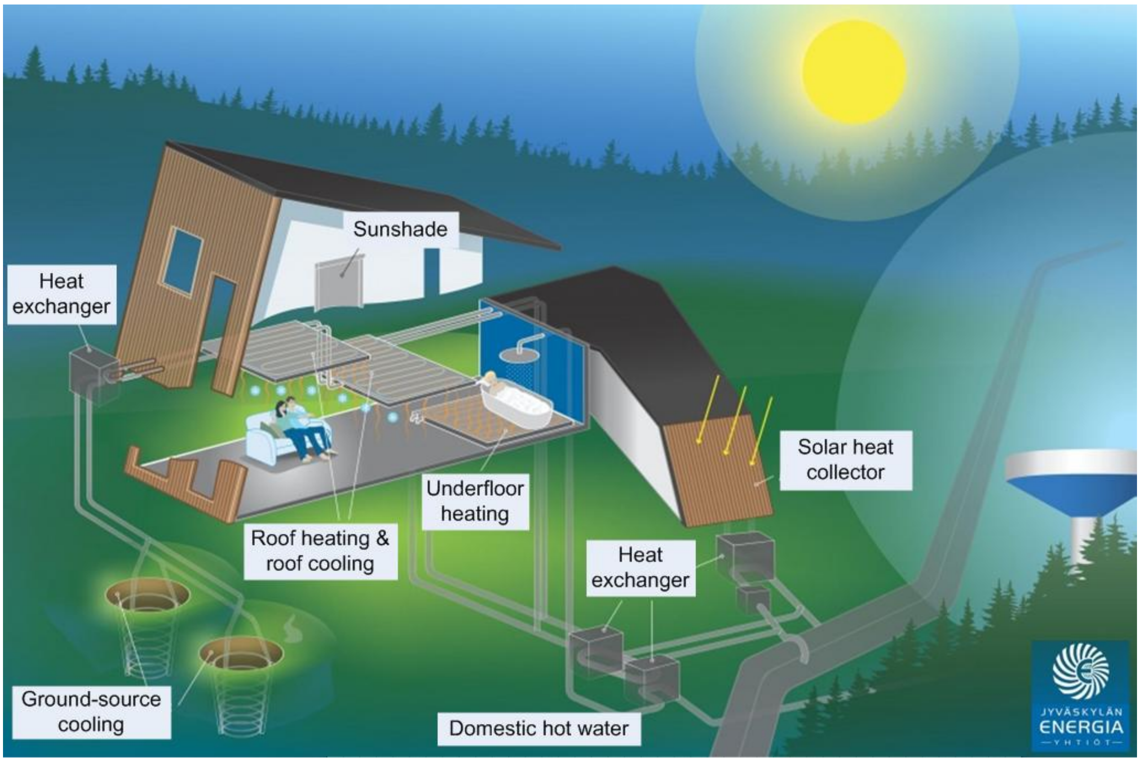

Figure 22. Schematic of pilot building having two-way district heat network connection; retrieved from [71].

4.1.2 Utility-scale applications and district heating and cooling networks

Examples on utility-scale bioenergy RES hybrid solutions and hybrids related to district heating and cooling networks are shown in Appendix B. Some of the cases are presented in this chapter.

Commercial buildings

A nursing home in Lahti is first of a kind in Finland utilizing both solar thermal and electricity in significant quantities to complement DH and grid power consumption in the near zero energy building. Solar thermal can cover 20-30% of total energy demand with collectors delivered by Savosolar [73]. On annual level, this means most of the DHW from spring to autumn. The nominal capacity of solar collectors is 120 kW and the estimated annual production 432 GJ (120 MWh). The 50 m^2 PV system produces power with approx. 7 kW capacity for the pumps and other power consumers of the solar thermal installation, making the system self-sufficient. [74]

Solar-based heating and cooling is studied with the 180 m^2 solar collector installation on the rooftop of a commercial building, Löfbergs' office, in Karlstad, Sweden within SunCool project. ClimateWell has developed a thermal heat pump component, CoolStore^{TM}, which is directly integrated into solar collectors to provide heating during winter, cooling during summer and hot water every day. The CoolStore tubes combine as first collectors in the world heating, cooling and energy storage. [75] Rest of the heat demand of the building is provided by ground-source heat and district heat. With similar climate conditions, the technology could be adaptable also in Finland. A cooling system utilizing solar heat is installed to Savosolar's production facility in Mikkeli within a project carried out by Savosolar, VTT Technical Research Centre of Finland Ltd and ZAY Bayern.

School building as a pilot system

One example of utility-scale RES hybrid system is the school building of “Sakarinmäki” in Helsinki, implemented by HELEN. Sakarinmäki is a pilot project and a part of the larger vision of renewable residential area. The energy consumption of the building is distributed between space heating (~74%), domestic hot water (~6%) and electricity (~20%). Before, the heat production was covered by fossil light oil. With the hybrid heating system built, the goal is to cover at least 80% of the building’s heat demand by renewable sources. However, it seems that in the end at least 85% will be achieved. The hybrid system consists of ground-source heat, solar thermal, oil boilers and heat accumulators (**Figure 23**). [76] [77] [78]

Figure 23. The hybrid heating system in Sakarinmäki school building [69].

Heat produced by Savosolar’s collectors is used when available, whereas ground-source heat is the main heat source. Two heat accumulators were installed to store the solar heat. The existing oil boiler units are used in the case the demand cannot be covered with solar and ground-source heat, and the oil used is mainly bio-oil. Nominal capacity of oil boilers is 1,500 kW and consequently, the whole heating demand of the building, 1,200 kW at maximum, could be covered by oil. The hybrid system is evaluated to save approx. € 70,000 in heating costs. Data of hybrid system components and their production is given in **Table 5**. The daily production by different heat sources can be followed at HELEN’s website (**Figure 24** and **Figure 25**), and the data is also used for educational purposes. [76] [79]

Table 5. Technical data of the HELEN’s hybrid heating system for a school building.

Component	**Capacity [kW],[l]**	**Area [m^2]**	**Annual production [GJ] (MWh)**	**Share of the total production [%]**
Ground-source heat	275 kW, 21 bore-holes, 300 m each	-	3,441.6 (956) (in 2014)	75
Solar heat collectors	150 kW	160	432 (120) (estimate)	5
Bio-oil boiler	1,500 kW	-	-	20
Heat accumulator	2 x 4,000 l	-	-	-
Hybrid system, annual	Max demand 1,200 kW	-	3,240 (900)	100

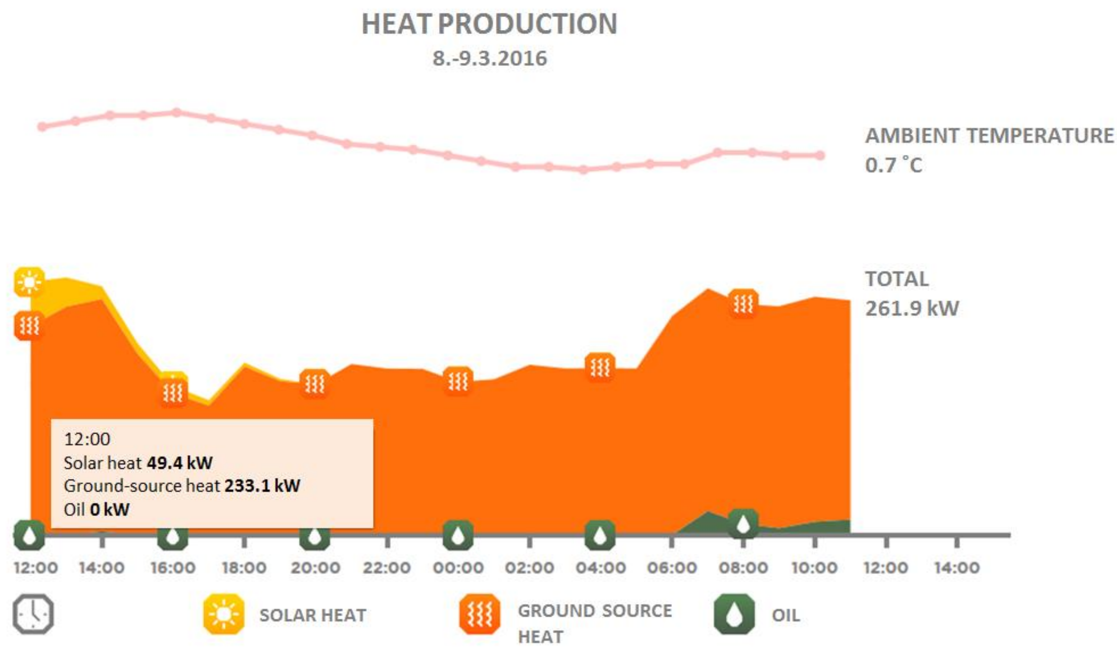

Figure 24. Production figures of a hybrid heating system in a school building at example winter day; retrieved from [76].

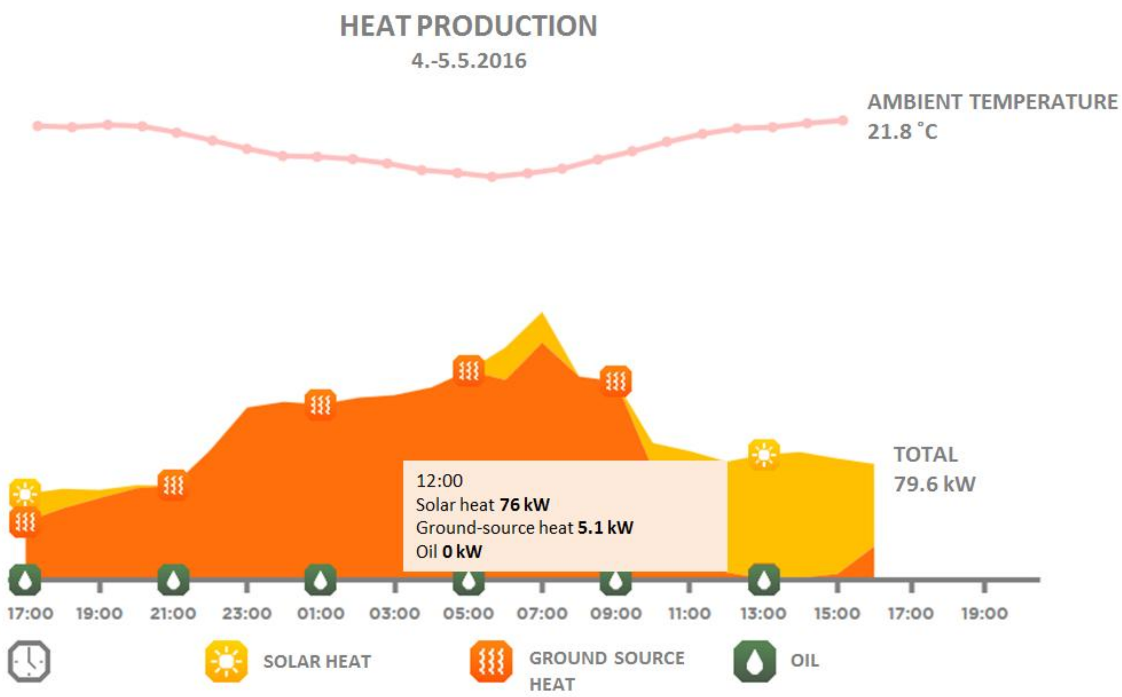

Figure 25. Production figures of a hybrid heating system in a school building at example spring day; retrieved from [76].

Case Sakarinmäki represents a part of the larger renewable energy vision by HELEN. HELEN offers as a first energy company in Finland possibility for its customers to by district heat with guaranteed production by renewable energy (wood pellets), and the company has pledged to increase the renewable based production in accordance to demand [80].

CHP networks as RES platforms – a large scale hybrid system

A good case example of the large-scale hybrid platform is HELEN's concept based on trigeneration of heat, power and cooling for dense urban area [81]. HELEN's goal is to be CO_2 neutral energy utility by 2050, and wider utilization of biomass plays a key role in the transition. About 90% of the annual district heating in Helsinki (24.8 PJ i.e. 6,888 GWh in 2014) is produced by efficient CHP production. Key actions made or decided to increase the share of bioenergy in DH production are wood pellet co-combustion with coal, distributed heat production with bioenergy and the use of biogas. In 2015, HELEN used about 5,800 tonnes i.e. 100.8 TJ (28 GWh) of wood pellets through co-combustion with coal in its CHP plants. The goal is to replace 5–7% of coal by wood pellets. An investment decision in a 100 MW wood pellet boiler to replace an old oil boiler is made. [82] Biogas based DH production will be delivered to large customers willing to buy renewable district heat [83].

HELEN seeks for new heat sources, such as heat pumps, solar thermal and geothermal. HELEN's Katri Vala heat pump plant co-generating district heating and cooling is the largest of its kind in the world. The plant is highly efficient since it takes advantage of waste heat streams by recovering heat from the return water of district cooling and from purified sewage water (**Figure 26**). In 2015, the heat pump plant covered 7% i.e. 1,519.2 TJ (422 GWh) of HELEN's DH production and 60% i.e. 324 TJ (90 GWh) of DC production. HELEN's district cooling system is the third largest in Europe, and expanding rapidly. The heating and cooling capacity of the plant, produced by five heat pumps, is 90 MW and 60 MW, respectively. During the summer period, almost all of the heating demand of the centre of Helsinki and about half of the entire city can be covered by the Katri Vala plant. Second heat pump plant will be built in the centre of Helsinki, consisting of two heat pumps (2 x 7.5 MW cooling, 2 x 11 MW heating). District cooling is also produced at Salmisaari CHP plant through absorption cooling and, during winter, from cold sea water. [84] [85] [86]

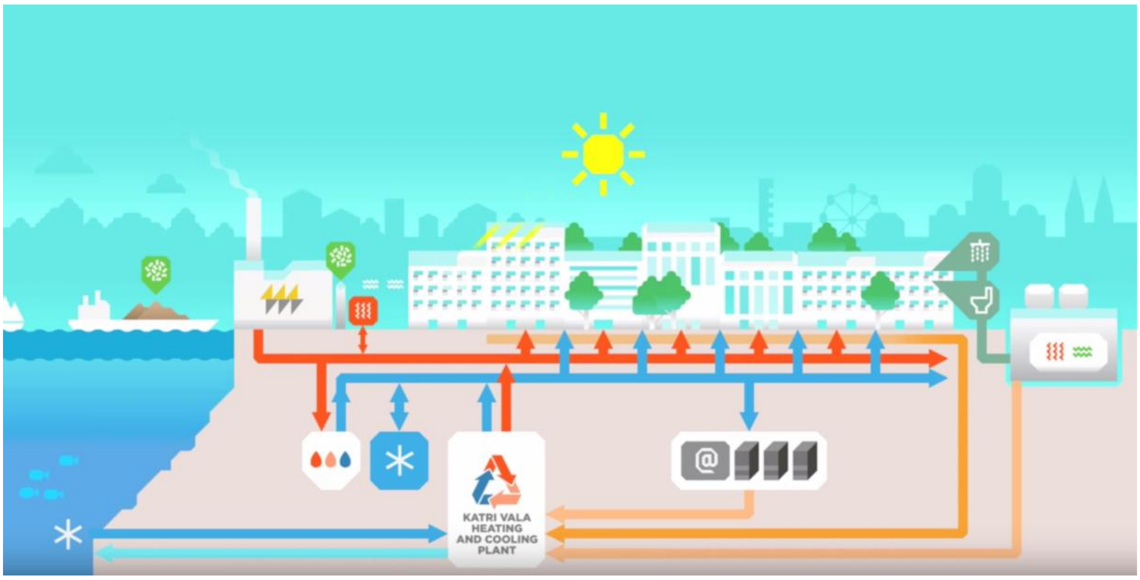

Figure 26. HELEN's integrated district heating and cooling system based on multiple heat sources [87].

Passive solar energy is already widely used for DH production in Helsinki through recovery from district cooling network; during the summer period, up to 2.88 TJ (800 MWh) of heat can be recovered from district cooling in a day. Heat and cooling storages are essential to balance the production and demand; large heat accumulators are installed in connection to power plants and cooled water is stored in underground chilled water storages, 11 million liters in Pasila and 38 million liters under a park in the centre of the Helsinki. [84]

Benchmark from Denmark to utilize Finnish knowhow in district heating networks

Many cities and district heating companies in Finland are interested in integrating solar heat to DH network in order to increase the share of renewable energy and to cut emissions in the heating sector. Solar thermal utilization reduces the consumption of biomass and other fuels. For example in Denmark, solar thermal integration in the district heating plant, typically using also biomass, is getting common rapidly. **Figure 27** shows a hybrid DH plant, producing also some electricity in Løgumkloster in Denmark. The plant produces 108–115.2 TJ (30–32 GWh) energy annually, wood pellets as the base producer (3 MW). Solar collectors (15,300 m^2) produce approx. one-fourth of the total production (28.8 TJ i.e. 8,000 MWh). Peak solar field power is 13.5 MW, and 7,400 m^3 heat storage is able to dispatch 400-500 MWh. Other heat sources are natural gas, absorption heat pump and electric heat pump. [48] [88]

In Vojens in Denmark as much as 45% of the total annual heating is covered by solar energy by using effective solar collector area of 70,000 m^2. The peak capacity of the solar installation is 49 MW, and calculated annual production is 100.8 TJ (28 GWh). Solar heat can be stored from summer period to winter period with the help of a 200,000 m^3 thermal pit storage. The rest of the annual heat demand is covered by three gas engines, a 10 MW electric boiler, an absorption heat pump and gas boilers. [89]

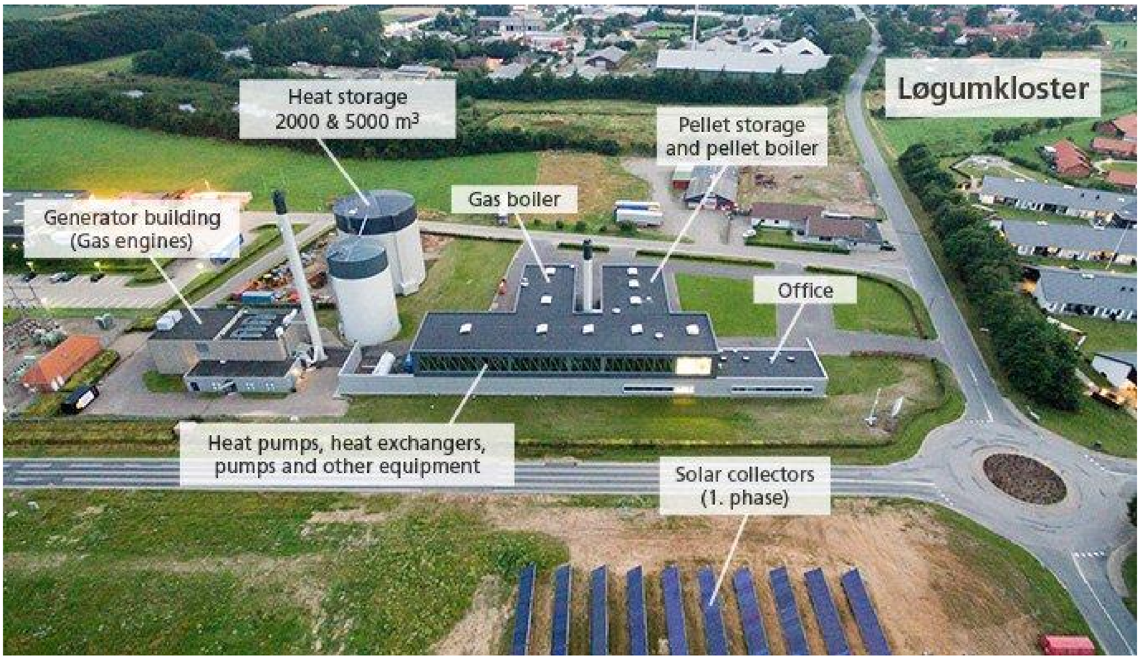

Figure 27. Hybrid district heating plant (CHP) combining wood pellets, solar thermal energy and natural gas in Løgumkloster in Denmark [48].

Currently, large-scale hybrid systems combining biomass, solar thermal and heat storage system cannot be found in Finland. However, the future pathway towards these kinds of hybrid solutions looks feasible in terms of rather similar climate conditions to Denmark. The technology is not foreseen to include any major technical barriers, and the factors slowing the development and implementation in Finland are rather the lack of knowledge (e.g. costs, integration) and economic uncertainties.

Know-how and manufacturing base related to the bioenergy based energy production is strong in Finland due to the long history in bioenergy utilization. Also advanced technical know-how related to the solar thermal technology and integration to the DH network can be already found; the Finnish company Savosolar has delivered its solar thermal collectors already to 18 different countries (as of 4/2016) and stepped on the Danish district heating markets. The company has delivered 15,300 m^2 of solar collectors for the before mentioned Løgumkloster DH plant in Denmark. [69] In order to cover 50% of the total heat demand by solar energy in the future, the solar field is planned to be extended to a size of 50,000 m^2 and a seasonal heat storage of 150,000 m^3 is planned to be implemented (**Figure 28**) [90]. Savosolar has had also other large-scale deliveries to Denmark, but the domestic markets have remained rather small until today.

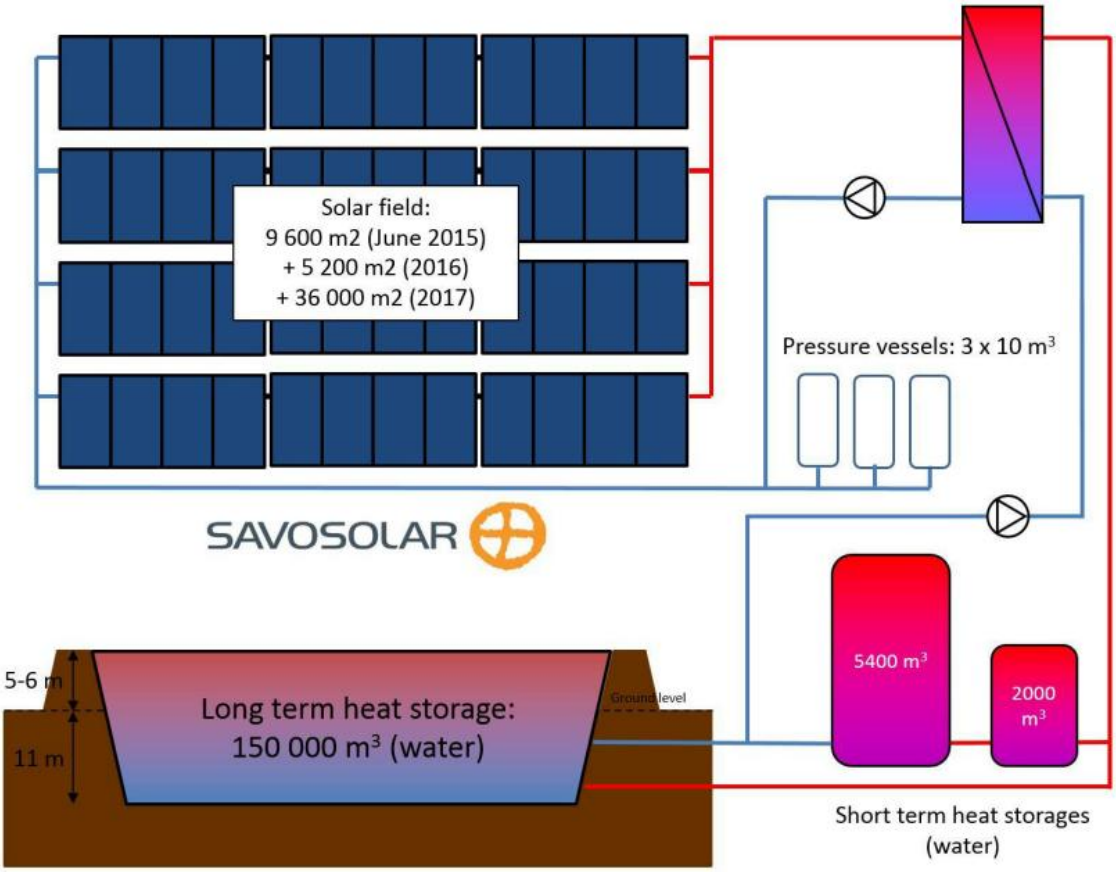

Figure 28. Schematic of the Løgumkloster district heating plant in Denmark, showing the schedule of solar thermal collector installations delivered by Savosolar [69].

Pilot-scale integration of solar thermal and bioenergy for heat production

Savon Voima Oyj is the first example in Finland replacing fossil fuel based DH unit with hybrid system combining biomass and solar thermal (**Figure 29**). The DH unit using heavy fuel oil to produce heat for the area in Tahkovuori was replaced by a pilot system consisting of wood pellet burner, electric heater and solar heat collectors (**Table 6**) in the end of 2015. Solar collectors are used to preheat the return DH water before its heating to final temperature in the pellet boiler or electric heater. This arrangement guarantees better efficiency for the collectors. Solar heat is available from the beginning of February until October, but during the remaining period, other heat sources are needed to cover the heat demand. During the summer period, heat is produced with collectors and electric boiler, since current electricity prices are low. This combination has also the advantage of not undergoing any disturbances. [91] [92] [93]

Figure 29. Savon Voima's pilot DH plant combining wood pellets, solar thermal and electric heater [94].

Table 6. Technical data of the Savon Voima's hybrid district heating system.

Component	**Capacity [kW]**	**Area [m^2]**	**Annual production [GJ] (MWh)**	**Share of the total production [%]**
Wood pellet burner	500			
Electric heater	70			
Solar heat collectors	8	12	10.8–14.4 (3–4)	0.3–0.4
Hybrid system, annual			3,600 (1,000)	

The annual solar share is rather low and the production is focused on the summer period (from June to August) with estimated production of 9–10.8 GJ (2.5–3 MWh), representing approx. 2.5% of the total production during the same period. The system does not include any heat storage system, which reduces the investment cost, but limits the achievable solar share. With the current arrangement, the solar heat is able to replace even one fifth of the peak heat demand during summer days. By dimensioning solar collectors to summer period demand (approx. 40 kW) annual solar thermal production would be approx. 20 MWh and solar share of approx. 2% could be achieved, requiring sophisticated control system. [92] [93]

The hybrid system is a pilot project investigating the use of solar heat in parallel with other heat sources in DH production and technical and economic feasibility of scaling up the system. The project allows developing the control of the solar collector system to better fit in parallel with other heat sources. The main goal is to gather operational experience of the hybrid system and simultaneously, the fuel consumption is decreased and the heat production from domestic renewable sources increased. The investment cost of the new DH system was € 350,000, of which 15% was covered by the investment subsidy. [93] [95]

PV integration to district heating system

In Hämeenlinna, PV panels with 15 kW capacity were recently connected to the DH system in a pilot project. The energy produced is used to run the pumps circulating water in the DH network. At the same time, the local energy utility Elenia is able to gather data of solar electricity utilization. [96]

Regional hybrid heating solutions

The Finnish One1 offers solutions for regional energy production based on distributed renewable energy sources and also hybrid solutions combining e.g. heat pumps, solar thermal and bioenergy. Their hybrid heating unit, utilizing ground-source heat, solar thermal and natural gas, to produce heat for a residential area is shown in **Figure 30**. In 2012, such a unit was implemented in Lappeenranta in housing fair area. They have also delivered a hybrid system with a capacity to cover heat demand of about 60 buildings in a district area in Myrskylä. The heat production is based on ground-source heat (approx. 800 meters of piping) and solar thermal collectors with capacity of 55 kW. In the centre of Artjäri, even 80% of the heat demand is covered by One1's hybrid unit by combining biomass and ground-source heat. [97]

Figure 30. One1's hybrid heating unit combining ground-source heat, solar thermal and natural gas as energy sources [97].

Innovation in solar thermal integration to bio-based district heating network

In Lerum in Sweden, solar thermal integration to the DH network in an innovative way is investigated in the NOISUN project financed by the EU. The project demonstrates the use of noise barriers that simultaneously produce solar energy to local district heating system (**Figure 31**). [98] Flat plate collectors with collecting area of 857 m^2 were installed for the length of 400 m. The results expect annual solar thermal production of 250–400 MWh and an annual saving of 275–440 m^3 of wood chips. [99] The base heat production is covered by district heating boilers burning biomass, such as wood chips, wood pellets and vegetable oil. The annual solar share with current collector installation remains low (from May 2015 to April 2016 >0.5%). However, during the summer period larger amounts of biomass can be replaced (in August 2016 >3%), and momentarily, all the production can be covered by solar thermal energy. [100] With similar irradiation conditions with respect to Sweden and high length of motorways and railways passing residential areas, the technology has potential also in Finland after proved to be technically and economic sound.

Figure 31. Solar heat collectors acting as a noise barrier in Lerum in Sweden [101].

New hybrid solution to Nordic countries

A first case of implementing concentrated solar power (CSP) technology in Nordic conditions can be found in Denmark. Danish Aalborg CSP supplies a 16.6 MW parabolic trough solar field to be integrated with a biomass-fuelled organic Rankine cycle (ORC) plant for CHP generation. The plant is able to produce both electricity and district heat. This will be the first large-scale system in the world to demonstrate the capability of CSP technology to optimize the efficiency of ORC in the areas of lower direct normal irradiance. The project shows the potential of CSP technology in the European climate when integrated with other technologies. [102] This kind of development steps for hybrids have not been identified in Finland yet.

Intermittent hybrid system

A hybrid power plant combining variable wind and PV resources for electricity production is under construction in Hamina (**Figure 32**), expected to be in operation already in summer 2016. A PV system consisting of 2,784 PV panels, with total capacity of approx. 745 kW, is erected in an existing wind power plant consisting of four wind turbines with a nominal capacity of 2 MW, providing approx. 72 TJ (20 GWh) annually. The estimated annual PV production is 2.448 GJ (680 MWh). The investment cost of the PV system is over one million euros, of which 30% is covered by the investment subsidy. The plant represents the first utility-scale wind-PV hybrid system in Finland, and one reason for the construction is to study the solar energy potential in Finland and the complementarity of wind and PV production. Wind production is typically better during the wind period with respect to summer period in Finland, when PV production in turn is weaker. [103] [104] [105] The results of the complementarity of two different intermittent source of energy will also reveal the need for the balancing power. The complementarity between wind and PV production and also between wind and CSP production has been studied before for example for the area of Iberian Peninsula in Spain having good wind and solar resources [106] [107].

Figure 32. Wind-PV hybrid power plant in Hamina [104] [108].

4.1.3 Industrial applications

“GeoBio” hybrid solution

Adven (Advanced Energy Solutions) has delivered an industrial scale “GeoBio” hybrid solution for a logistic center in Sipoo to fulfill its heating and cooling demand. The hybrid system produces almost fully CO_2-free energy by utilizing ground-source heat and wood pellets as the main energy sources. RE sources will cover 95% of the final energy consumption. The use of heat pumps, used as base producer, is prioritized in order to guarantee the maximal capacity factor. Pellets are used during the winter period with increased heat demand, whereas heavy fuel oil serves as backup fuel. In the end, approximately half of the annual heat demand is covered by ground-source heat and the other half by wood pellets. In addition to ground-source heat, heat is recovered from the cooling system, and the total heat production capacity is 6.0 MW. Ground-source heat is collected with 150 bore holes, each 300 m in length, and the system is one of the largest heat pump plants in Finland. [109] [110] Modular design probably brings benefits for the system in terms of optimizing the efficiency. Technical details of the plants are shown in **Table 7**.

Table 7. Technical data of the Adven’s “GeoBio” hybrid system.

Component	**Capacity [MW]**	**Share of the total production [%]**	**Temperature [˚C]**
Wood pellet burner	4 (2 x 2 MW)	close to 50	max 120 ˚C
Ground-source heat	2 (2 x 1 MW)	close to 50	max 50 ˚C
Heavy oil boiler	6 (2 x 3 MW)	under 5	-
RES hybrid	-	95	-

It is concluded that the hybrid solution offers savings in heat production with respect to e.g. district heating. The cooling demand is covered by free cooling from the rock ground and with heat pumps if needed. [110]

Biomass to replace fuel oil in food and beverage industry

Snellman is a good example within food industry about oil replacement by renewables. The company has replaced all of its over 1,000 tonnes of oil consumption by biogas, which is partly produced from its sludge and sewage, to produce heat and steam. Biogas production and utilization creates new local networks; Snellman’s biogas is produced in nearby production unit in Jepua, and biogas is also used in other local industries. Approx. half of the 72 TJ (20 GWh) annual production is used at Snellman. Ventilation heat recovery is used to produce heat, and the payback period of two years was achieved for the investment. Interest in PV installation exists, but for now, the investment has not been considered beneficial enough. In the future, also electricity demand of the facility could be covered by biogas. [111] [112] [113]

Similar approaches to replace oil consumption can be found elsewhere in the food industry. Adven has delivered a 5 MW biomass boiler (wood chips, other wood-based fuels and milled peat) for CHP production to Valio's facility in Oulu to replace heavy fuel oil and a 11 MW wood chip boiler to Altia's facility in Rajamäki to replace oil and coal. The old oil boiler capacity will be remained for backup and peak use. [114] [115] This kind of biomass plants are potential ground for bioenergy RES hybrids, since biomass could be saved from summer period to winter period with solar thermal integration as an example.

Efficiency improvements through waste heat recovery

In Mäntsälä, heat from outlet cooling air from Yandex's data centre is recovered to district heating network owned by Nivos. This new solution has not only reduced the natural gas consumption for DH production, but also lowered the purchase price of district heat for customers by 5% and decreased DH production related CO_2 emissions by 40% in the centre of Mäntsälä. The data centre produces heat at 37 ˚C (inlet air 20 ˚C) with power demand of 15 MW. The outlet heat is recovered to DH network by a heat pump. The capacity of heat recovery system is 4 MW, producing annually 72 TJ (20 GWh) district heat i.e. approx. half of the annual DH demand of the centre of Mäntsälä. [116] [117]

The ecosystem created by the energy company and the private company in Mäntsälä is globally first of a kind large-scale project [117]. Waste heat from several other industrial processes could be recovered to district heating networks as well. This would not only decrease the amount of wasted heat, but also decrease the investments in new capacity in DH network.

PV systems to industry

A Finnish food industry company Atria is planning to invest in a 6 MW PV system in its production facility in Nurmo. The system would consist of 24,000 PV panels installed both on the rooftop and on the ground released from the composting use. The annual power production of the plant is estimated to be 20.16 TJ (5,600 MWh), corresponding to approx. 5% of the facility's power consumption. Since the cooling need of the facility is high, PV production is well-adaptable to the system. The profitability of the investment is dependent on the investment subsidy. [118] Similar PV installations in industrial scale have not been seen in Finland before, but interest in this kind of installations is increasing. Oil consumption in heat and steam production at Atria's facility was recently replaced by peat. The 13 MW boiler can also utilize wood and produces approx. 252 TJ/year (70 GWh/year). [119]

4.1.4 Farm-scale applications

Examples on farm-scale bioenergy RES hybrid solutions found in Finland are shown in Appendix C. Some of those are highlighted more closely in this chapter.

Biomass in agriculture

Agriculture has traditionally utilized a lot of biomass for energy production, in particular for heating, since biomass, especially wood chips, is easily and widely available, and the trend is foreseen to continue. The biomass availability, desire to increase *energy self-sufficiency* and the foreseen increase in purchase price of oil and electricity can be identified as the main motivators for renewable energy investments. The high energy demand and its rather even distribution over the year together with wide utilization of biomass and large rooftop areas available for solar energy harvesting create a promising ground for bioenergy RES hybrids at farms, and a few show cases can be already found.

In 2013, bioenergy represented 16.2 PJ (4.5 TWh) of all energy consumption in agri- and holticulture i.e. 45% [120], whereas in 2010, the number was 14.76 PJ (4.1 TWh) i.e. 41%. Bioenergy is mainly used for heating in wood chip and wood pellet boilers and, for example, the peak heat demands can be covered with bioenergy. [121] Small-scale CHP installations have been seen as a good choice for farms, if the investment subsidy is received and all the produced heat can be utilized, since the profitability of the investment is highly dependent on the level of heat utilization [122]. Biogas production and consumption at farm-scale is modest, but gradually increasing.

Technology providers

Small-scale CHP systems utilizing locally available wood chips are delivered for example by Finnish companies Volter [123] and Gasek [124]. Volter offers modular, easily scalable system producing power and heat 40 kW and 100 kW, respectively. The technology is based on combined wood chip gasification and power production in gas motor. In addition, the company provides wood chip dryers, which can utilize the waste heat from the gas engine. Volter's technology is well suitable for farm-scale applications, but for industry and districts as well. In addition to domestic markets, technology has already been delivered to e.g. Australia, UK and Canada. A schematic of the integrated gasifier and gas motor is shown in **Figure 33**. Gasek's technology combines conventional fire-tube boiler and wood gas burner. The benefit of the technology is that also existing oil boilers can be retrofitted for the wood gas burner.

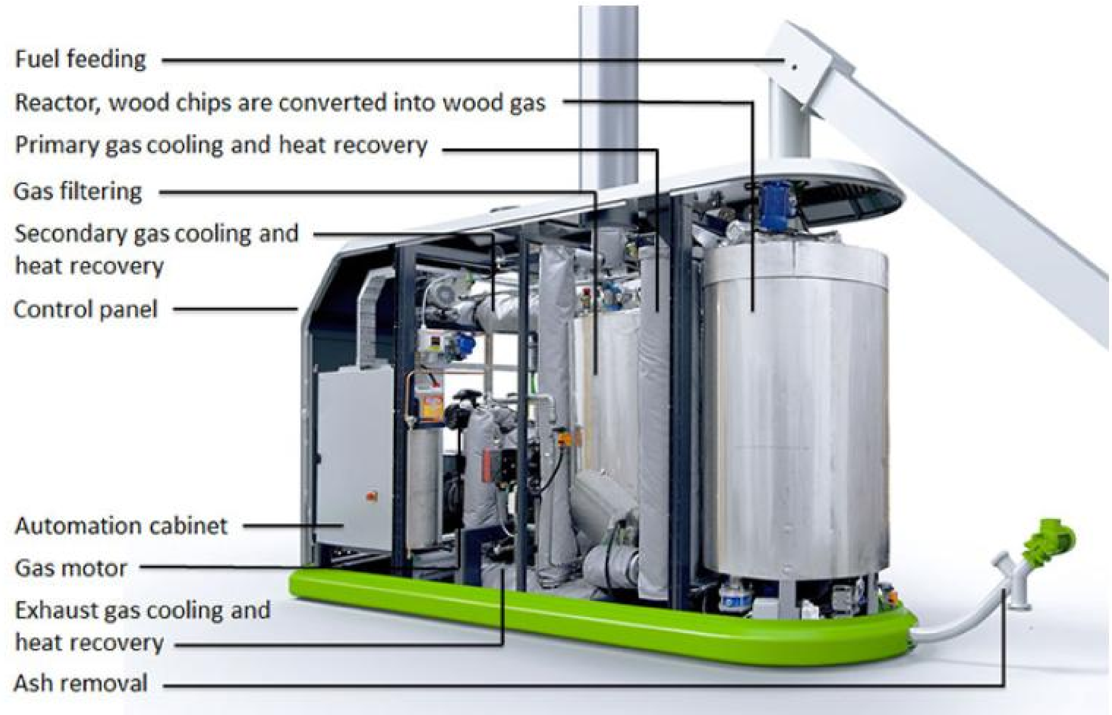

Figure 33. Schematic of Volter's technology for heat and power production [123].

Biogas production and upgrading technologies are provided for example by Finnish companies BioGTS [125] and Metener [126]. The biogas reactors can utilize wide range of raw material, such as biodegradable waste and biomasses from municipalities, industries and agriculture. The compact and modular biogas plant of BioGTS has treatment capacity of about 600–1,000 tonnes/year of biomass feedstock. In addition, organic fertilizer is produced as by-product and can replace chemical fertilizers. BioGTS's upgrading technology is based on Pressure Swing Adsorption. The smallest unit capacity provided by BioGTS is 20 Nm^3/h of raw gas, and the capacity is easily scalable. The capacity of the largest unit is 200 Nm^3/h of raw gas. Metener offers upgrading units with capacity of 10–100 Nm^3/h of raw gas. In addition to domestic markets, Metener has already delivered a biogas plant to China.

Renewable intermittent power production to complement bioenergy

At a farm in Nurmes, bioenergy is complemented by PV system, resulting in 100% self-sufficiency in heating and 55% self-sufficiency in electricity (**Figure 34**). Wood chips are utilized through gasification and small-scale CHP to produce heat (100 kW) and power (40 kW). Annual heat production has been in the range of 1,350 GJ (375 MWh) and power production 540 GJ (150 MWh), while the theoretical maximum is approx. 4,320 GJ (1,200 MWh). During the summer period, surplus heat is used to dry the wood chips needed during the year, 1,400–1,500 i-m^3. The consumption of grid sourced power is further reduced by a 50 kW PV system, which is expected to produce 144 GJ (40 MWh) annually. [127] [128] [129] Since the energy consumption at farm is rather constant and almost half of the power is still purchased from the grid, the variable PV production most likely does not cause any flexibility requirements for the CHP system.

Similar approach at another farm in Sukeva leads to a 100% self-sufficient energy system. The production curve of the 15 kW PV system has a good match with the increased power demand for cooling during the summer months. The gasification and CHP (heat 80 kW, power 30 kW) based on the wood chips is taken into use in the summer, when both power and heat demand increases. To increase the overall efficiency, waste heat from CHP is used for wood chip drying. [130] Indicative energy production and consumption distribution of farms in Nurmes and Sukeva is shown in **Figure 34**; the energy consumption in a farm in Sukeva, focused on growing berries, is much lower than in the other farm focused on livestock farming.

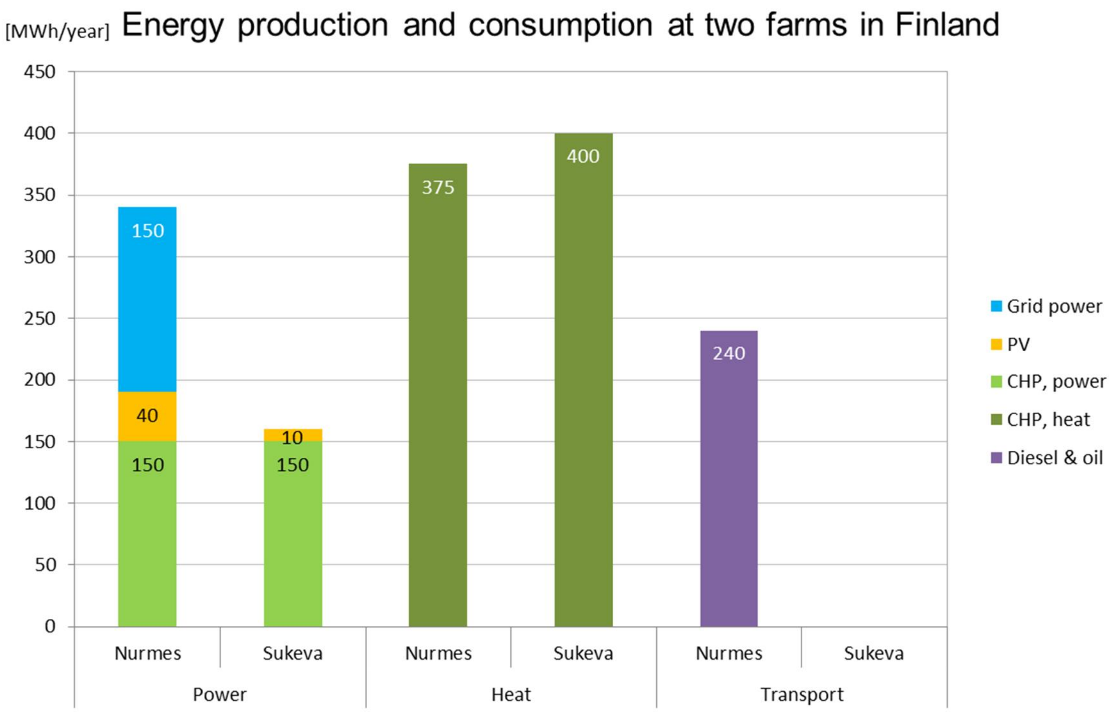

Figure 34. Distribution of energy production and consumption by energy source at two farms in Finland; transport consumption unknown in the case of Sukeva [127] [130].

Traditional wood combustion for heat is complemented by air-source heat pump and light fuel oil at a farm in Pieksämäki. Both wood (70.2 GJ/year i.e.19.5 MWh/year) and heat pump directly reduce the oil consumption (54 GJ/year i.e. 15 MWh/year), leading to a self-sufficiency of 57% in heating. The grid sourced power consumption is reduced by at least 12% by own PV system (19.8 GJ/year i.e. 5.5 MWh/year). Rather constant daily PV power is achieved with different installation directions. [131]

At a farm in Tuuri, grid sourced power consumption is reduced by a 600 kW (1,260 GJ/year i.e 350 MWh/year) wind mill. The power is also used to run the ground-source heat pump (468 GJ/year i.e. 130 MWh/year). Rest of the heat is produced by burning wood chips (612 GJ/year i.e. 170 MWh/year). The system (**Figure 35**) achieves 100% self-sufficiency both in heat and power on annual level. [132] Both in the case of Pieksämäki and Tuuri, own power production can be used to drive the heat pump, which, in a well-controlled system, gives an opportunity to balance the power production through heating system and thus reduce interactions with power grid.

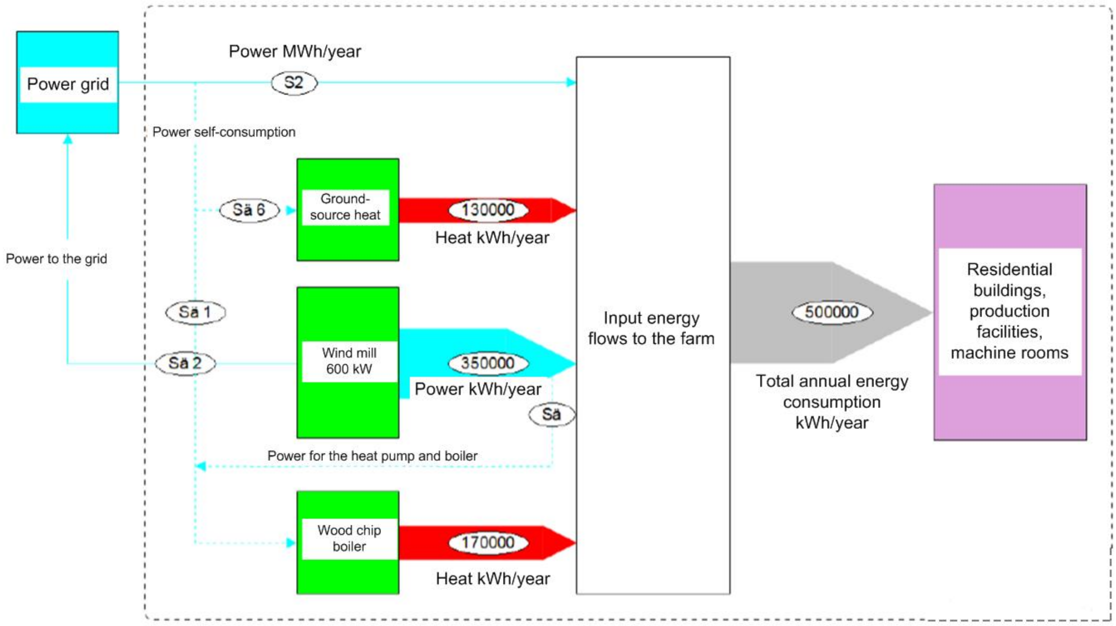

Figure 35. Hybrid power and heating system at a farm in Tuuri; retrieved from [132].

There has been identified a growing trend towards installing PV systems at farms (**Figure 36**). This can be seen for example in the joint purchases of PV panels: in Lappeenranta, three purchase rounds have resulted in installation of 120 PV systems. Farm-scale PV installations are entitled to 35% investment subsidy. The PV production allows reducing the amount of power purchased from the grid. A large electricity consumer at farms is for example grain drying (on average 19%). Due to imbalance between power demand and PV production, the possibility to sell surplus production to the grid is important, if no battery storage is installed. Advantages of PV panel installation are rather carefree nature, which is a clear benefit at the work-intensive farms, and ability to act as back-up power. [133] [134]

Also wind power production has gained more interest in recent years in farm-scale. For example, a farm in Sastamala has installed a wind mill with the peak capacity of 225 kW. The annual wind power production is 720–900 GJ (200–250 MWh), which covers on annual level the whole power demand of the farm growing chickens. To reduce the investment cost, the wind mill was purchased from second-hand markets with an investment cost of approx. € 130,000. The investment received an investment subsidy of 25%. The wind mill has shown to be reliable and requires maintenance only seldom. [135] The power production by wind mill, or by PV system, do not always match with the demand. One solution to utilize excess electricity, without an investment in battery system, is to convert the excess electricity to heating system through an electric boiler.

Figure 36. A PV system (peak power 11 kW) in the rooftop of a farm in Lappeenranta. The system produces approx. 20% of the annual power consumption of 180 GJ (50 MWh). [133]

Biofuel production in farm-scale

Agriculture offers a good environment for biofuel production, since resources are locally available and the product can be utilized locally, replacing oil and power from the grid. A farm in Iisalmi, concentrated on grain growing, has implemented a hybrid system including wind (5 kW) and PV (10 kW) power, ground-source heat pump and production of biodiesel. An indicative energy flow chart is shown in **Figure 37**. Biodiesel, produced from waste vegetable oils gathered from nearby restaurants and canola oil, is used for power (not shown in **Figure 37**) and heat production and as vehicle fuel at the farm. The annual production capacity is 500,000 liters. Remaining heat demand is covered by ground-source heat and by feeding wind power to the heating system through an electric boiler. Part of the power from the grid is replaced by solar power. [136] The hybrid system, which also integrates different energy sectors, leads to a higher degree of energy self-sufficiency. The farm is 100% self-sufficient in heat, whereas the numbers for power and transport fuels are 5% and 50%, respectively. [137]

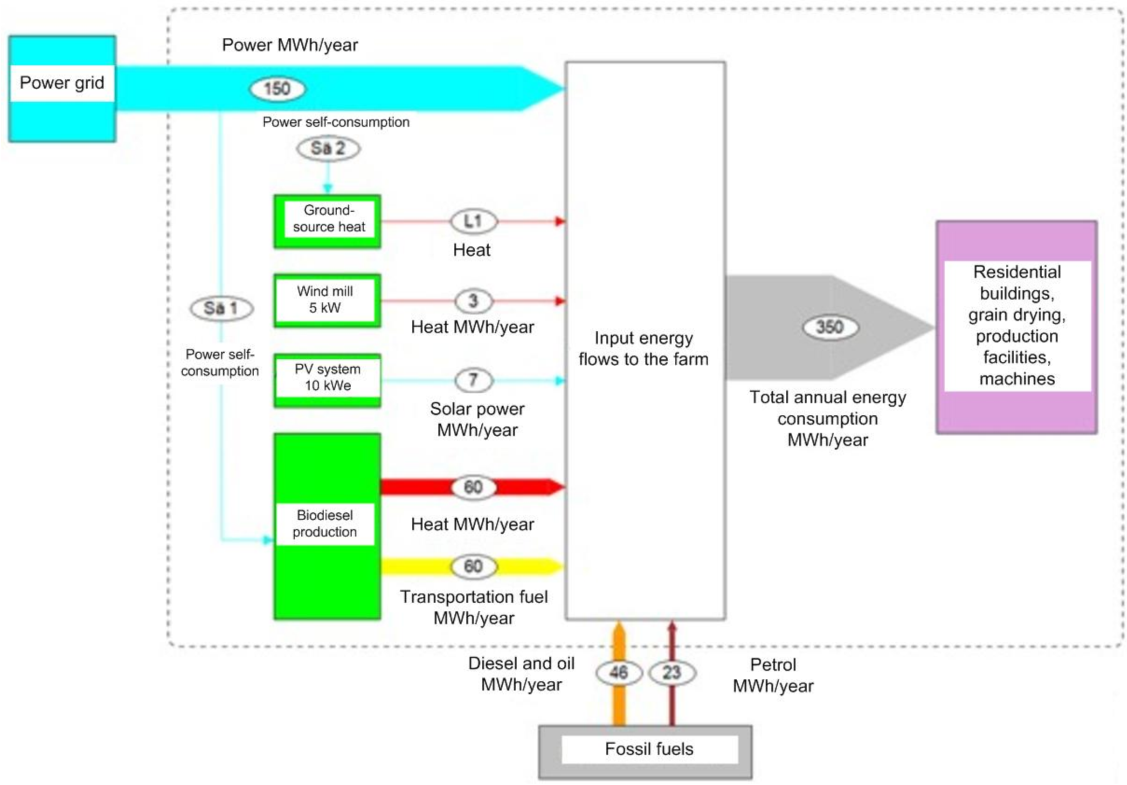

Figure 37. Energy flow chart of a hybrid system of a farm in Iisalmi; retrieved from [137].

Biogas production in farm-scale

In Denmark, quite a many hybrid systems combining a central biogas plant with solid biomass boilers can be already found, and there has been already seen a growth in farm-scale biogas production: farmers collect and treat biogas and compress it into the natural gas grid. [138] To give an example, the Danish Ammongas provides an amino-based system for removal of CO_2 from biogas. The process offers great integration possibilities in the heating sector, since the process consumes heat, which can, however, be reused at 75 ˚C or higher e.g. as district heat. [139] The biogas production and consumption in agriculture has gained more interest also in Finland in recent years (**Figure 38**). In 2014, the total heat and power production from biogas in farm-scale was 14.96 TJ (4,155 MWh) and 3.98 TJ (1,106 MWh), respectively. This was produced in 13 farm-scale biogas reactors, whereas at least 15 were under design or construction [27] The production figures still cover only an insignificant share of the total energy consumption in agriculture, but high potential exists. The plants under design or construction have potential to increase the production capacity from 1,020 m^3 to at least 4,324 m^3 in the next few years.

Most of the biogas produced in farm-scale is utilized for CHP production. One of the reactors can be found in Suomussalmi. The reactor utilizes manure and silage to produce annually 489.6 GJ (136 MWh) power and 705.6 GJ (196 MWh) heat. Over 85% of the power consumption can be covered by biogas. During the changes in power demand of the farm, the system takes use of the grid with two-way connection. The heat production by biogas is larger than the demand. The payback period of the biogas system is evaluated to be 11 years with initial investment of € 262,000. [27] [140]

One of the existing farms producing biogas, Kalmari farm, refines biogas for transport use in addition to use for heat and power production. The farm is fully energy self-sufficient, and the main income of the farm comes from the vehicle biogas. [141] The main parameters of the farm are shown in **Table 8**.

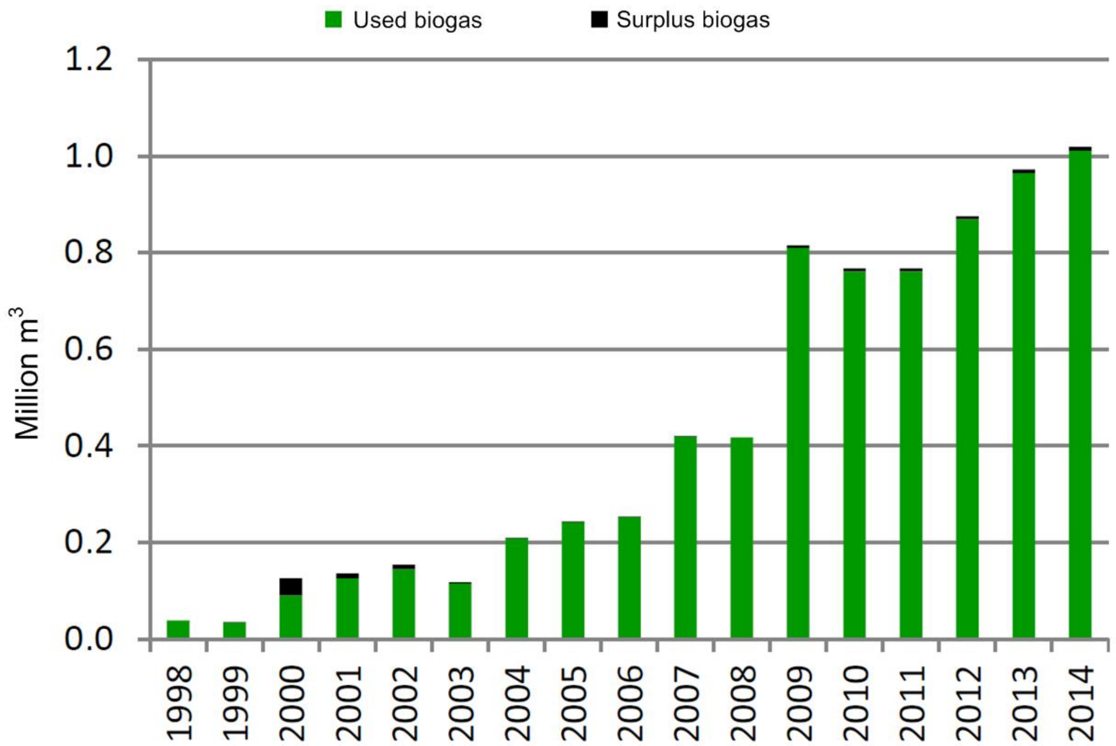

Figure 38. Biogas production and consumption in agriculture in Finland 1998–2014 [27].

Table 8. The main parameters of the Kalmari biogas farm [141].

Biogas reactor	Reactor volume	1,000 m^3
	Cow manure	2,000 m^3/year
	Confectionary by-products	200 m^3/year
	Fat	600 m^3/year
	Post-storage tank	1,500 m^3
Biogas (raw)	CH4 content	62–64%
CHP		25 kW_{el}
		50 kW_{th}
Gas boiler		80 kW_{th}
Upgrading to traffic fuel	Capacity	50 Nm^3/h of raw biogas
	Electricity consumption	1.2–1.4 kWh/kg
	Water consumption	10 liter/kg
	CH4 content	95% ± 2%
End-products	Electricity	270 GJ/year (75 MWh/year)
	Heat	540 GJ/year (150 MWh/year)
	Biomethane for traffic fuel	3,600 GJ/year (1,000 MWh/year)

In addition to farm-scale biogas production plants, 14 larger scale facilities for treatment of municipal solid waste can be found in use and 19 under construction or design. In 2014, these plants handled 152,000 tonnes of bio-based waste in addition to 245,000 tonnes of sludge, producing altogether 428.4 TJ (119 GWh) heat and 115.92 TJ (32.2 GWh) power. [27] One example is BioKymppi in Kitee, which uses annually 15,000–19,000 tonnes of waste streams, such as domestic biowaste, biowaste from food industry, manure, and sewage and fat sludge, to produce energy and nutrients. BioKymppi is self-sufficient in energy and it also sells heat to the local DH network and power to the national grid. In addition, the plant produces useful nutrients for the agriculture. [142] In the future, the BioKymppi plant will also produce gas for the needs of transportation [143].

Biogas reactors do not only produce energy and vehicle fuel, but also produce nutrients and dispose waste, thus enhancing circular economy and improving waste management at farms, in industry and in municipalities. The interactions and stakeholders of the biogas economy are shown in **Figure 39**.

Figure 39. Stakeholders and interactions of the biogas economy [144].

Biomass drying with solar energy and waste heat

Wide biomass utilization in agriculture, large potential rooftop areas for solar harvesting and waste heat streams typical during the summer period create great potential for wood and wood chip drying in farm-scale, increasing the heat capacity of biomass. Small-scale wood chip utilization requires moisture content of 15–25%, while natural drying leads to a content of 30–50%. [129] [145] Usage of hot air or steam, significantly reducing the time required to achieve a certain moisture content [146], and relatively high power consumption of drying offer great preconditions for hybrid systems and process integrations at farms. One realized case to dry wood with solar energy is shown in **Figure 40**. The hybrid system built in Saarijärvi takes use of old, currently empty cow house. The thermal power of the solar thermal air heater is approx. 50 kW, whereas the power consumption is less than approx. 10 kWh/i-m^3. [146]

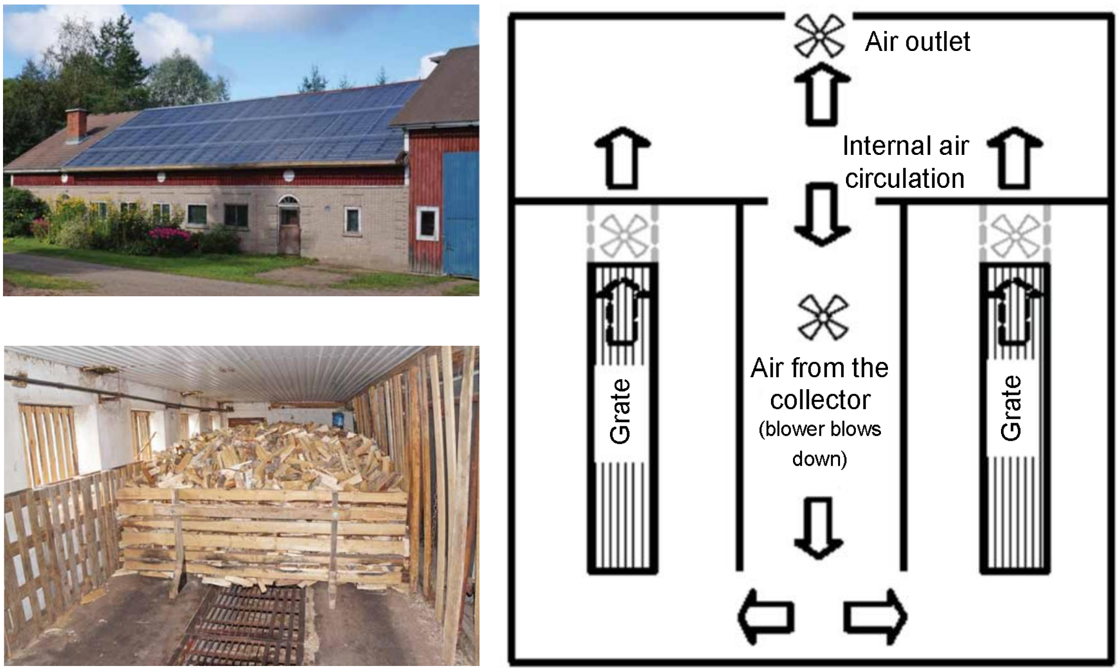

Figure 40. Left: Cow house with rooftop solar heat collectors to dry wood. Right: Schematic of the wood dryer system; retrieved from [146].

Solar thermal wood chip drying is technically scalable to large-scale power plants as well, but the space required by the solar collectors sets a restriction. However, distributed wood chip drying at farms, based on waste heat and/or solar heat utilization, would allow taking advantage of the technology in large-scale and also enhances energy efficiency in transportation by avoiding the transport of the water content. This becomes significant in the case of long transport distances; the average road transport distance in Finland is over 100 km [147]. Distributed wood chip drying would create new business opportunities for farmers, since their heat production units are typically operated with partial load most of the year and surplus heat is available especially during the summer period [146]. In addition, the solar thermal production is concentrated on summer months.

In order to advance solar thermal wood chip drying technology for example in the sense of process efficiency and controllability, a pilot-scale test facility (**Figure 41**) is under construction at VTT Technical Research Centre of Finland Ltd. A solar heat collector system will be installed on the office rooftop to produce solar heat for the existing biomass dryer. The solar heat will also be usable for the recently installed direct air capture (DAC) system. The controllability issues include for example the trade-off between the required pumping power and reduction in relative humidity of biomass.

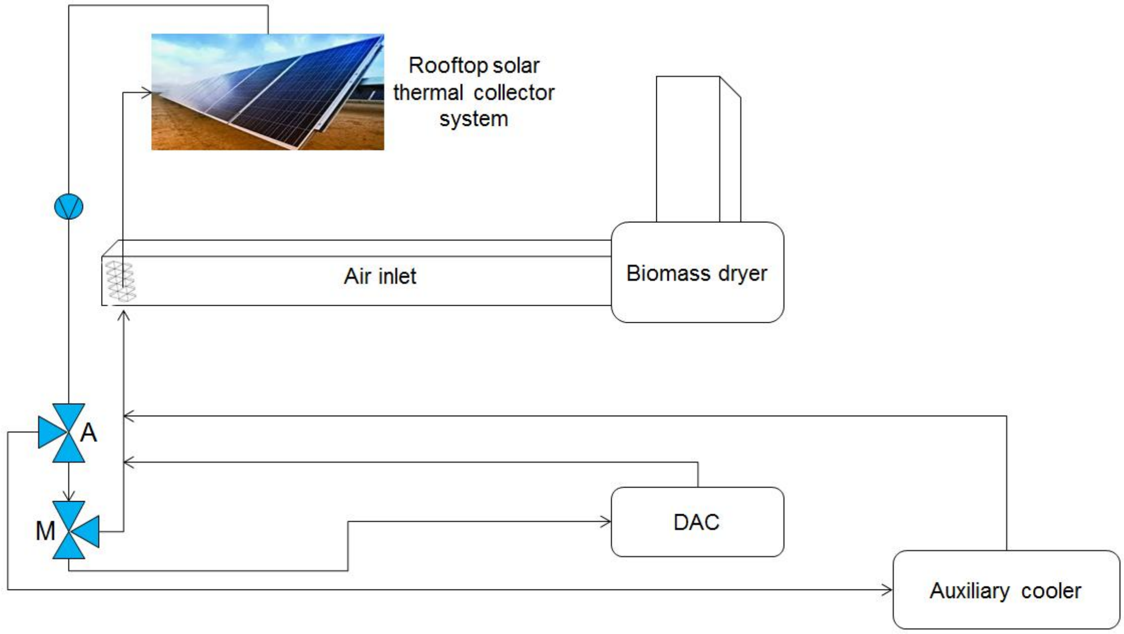

Figure 41. Solar thermal wood chip dryer for pilot-scale testing (VTT).

4.2 R&D on hybrid technologies

This chapter presents example projects, both on-going and completed, and research topics related to hybrid and renewable energy technologies.

COMBO-CFB – Combination of Concentrated Solar Power (CSP) with Circulating Fluidized Bed (CFB) Power Plants

The main objective of the project, led by VTT Technical Research Centre of Finland Ltd and funded by Tekes (the Finnish Funding Agency for Innovation), was to develop innovative hybrid concept integrating high temperature solar heat into conventional power plant to produce centralized renewable energy. The plant can be utilized either as base load producer or as load-following producer balancing variable renewable generation. In addition to integration of two different technologies, concentrated solar power (CSP) and fluidized bed technology, upper level coordination of the plant together with weather forecasts were included in the final concept.

Different technology options for integration and different integration strategies were searched and analyzed in the project. Detailed analysis of selected integration strategies was carried out through dynamic simulations, which revealed the process behaviour in the whole operational area of the plant and the restricting issues for achievable efficiency and solar share. Since the integration of two dynamic energy production technologies changes the operational conditions and thermal balance of the system, interactions between the subsystems need to be studied. For example, concept with the highest solar share does not necessarily lead to the best thermal and net efficiencies.

By integrating solar field into a biomass combustion plant, a wider market area for both technologies can be provided; CSP technology can be brought to areas with lower direct normal irradiance, whereas areas with poorer bioenergy resources can be utilized in a sustainable manner. The concept produces fully renewable and dispatchable energy by taking advantage of the storable nature of bioenergy. In the case of coal-fired power plant, the integration restricts the consumption of coal and related CO_2 emissions. The hybrid concept benefits from the joint use of equipment, such as turbines and generator, which reduces the levelized cost of electricity produced by CSP technology. This can enhance the implementation of capital cost intensive CSP projects.

DESY – Distributed Energy Systems

The project researched locally distributed energy production and related investments, and was led by VTT Technical Research Centre of Finland Ltd within the CLEEN Ltd's research programme. The goal was to produce energy near the consumption by using hybrid solutions producing heat and/or electricity to the building. Locally available renewable sources, such as solar thermal, solar electricity, wind power, bioenergy or heat pump, were added in parallel to the existing primary energy source, such as electricity, district heat or oil. [148] The main project results are presented in [149].

The results revealed that solar energy, both solar thermal and solar electricity, is a beneficial way to reduce purchase power for ground-source heat pump. In particular solar thermal integration is a wise investment in terms of profitability of the investment. The pay-back period of the investment is 5-6 years with respect to costs of for example oil or electric heating. In the case of using solar electricity, the pay-back period of the investment is around 9 years. Benefits of solar energy are environmental friendliness, easy and quiet utilization, and connectability to all primary heating technologies. [148]

Solar thermal integration in parallel to district heating is also profitable, if solar energy is used to replace a heat source with higher operation cost for the period from spring to autumn. The local DH network could also be utilized to store excess heat from households for short time periods. In the case of close to zero energy building, solar thermal and electricity are needed as supplemental energy sources, leading to 50% lower environmental emissions compared to district heat or electric heating. [148]

The project showed that currently it is not profitable to add more than one local energy source to the energy system of a building from the point of view of the investment cost. The project was carried out by developing simulation models, which were applied to selected cases, through measurements and by arranging expert panels. [148]

ENPOS – Energy Positive Farm

The project was funded by the EU's Central Baltic INTERREG IV A –programme. The project aimed to define the possibilities to reduce or step down the fossil fuel consumption at farms, and example case farms for used for this. The main results of the project are presented in [150]. The project provided new information and suggestions to enhance energy saving and energy self-sufficiency at farms, which are important issues in the future farming, since the potential of RE production is rather high at farms. The self-sufficiency was studied in heat and power production, transport and fertilizer production. [151]

FinSolar

FinSolar is a project funded by Tekes within Groove programme and led by the Aalto University School of Business. The project brought together around 50 companies and organizations, which represent different stakeholder groups interested in solar energy, such as technology suppliers, consults, financing institutes, municipalities and housing cooperatives. The aim of the project was to accelerate the solar energy markets in Finland and increase solar energy export activities. The project created new models for collaboration, procurement and finance of solar energy investments by facilitating cooperation with experts, companies and public organizations. In addition, legal and governance barriers for market growth were recognized. These are presented more closely in [43]. Within the project, a database of solar energy markets in Finland was created, including for example solar energy statistics and solar actors in Finland. [152]

Neo-Carbon Energy

The project is one of the Tekes' strategic research openings and carried out in cooperation with VTT Technical Research Centre of Finland Ltd, Lappeenranta University of Technology LUT and Finland Futures Research Centre FFRC at University of Turku. The project presents a new solution for Finnish energy system based on solar and wind alongside other renewables, such as hydro power, geothermal and sustainable biomass. The energy system is based on emission-free, cost-effective and independent energy production. [153]

The future energy system is foreseen to rely on solar and wind, which, however, are variable sources of energy. In order to build an energy system tolerant for this variability, bridging of different energy sectors and energy storages are needed. The project suggests that there is a continued need for carbon as energy carrier for fuels, chemicals and materials also in the future. The primary solution for decarbonization is to use the atmospheric CO_2 as a source of carbon for synthesizing hydrocarbons. The future energy system requires storages, and the amount of storage and combinations of technologies is researched in Neo-Carbon Energy. [153]

Research on district heating networks

Globally, 4th generation district heating is a widely research topic. One advantage of reducing the hot water temperature in the DH network from current 115 ˚C to 60-80 ˚C would be improved possibility to integrate distributed energy resources, such as heat pumps, geothermal energy, solar thermal and recovered waste heat, into DH network [20] [154]. This could also allow reducing the need for traditional power plants in the network. The development pathway is already becoming reality for example in Denmark, where a number of district heating companies have started projects aiming to reduce the temperature significantly [155].

The efficiency of solar thermal production decreases at the higher temperatures (**Figure 42**), which makes the lower temperature DH networks more favourable for solar collectors. Centralized solar thermal plants feeding the DH network can achieve significantly higher efficiency than distributed systems in buildings. [154] Balancing heat sources, such as biomass, can be easily integrated in large-scale to the centralized plants.

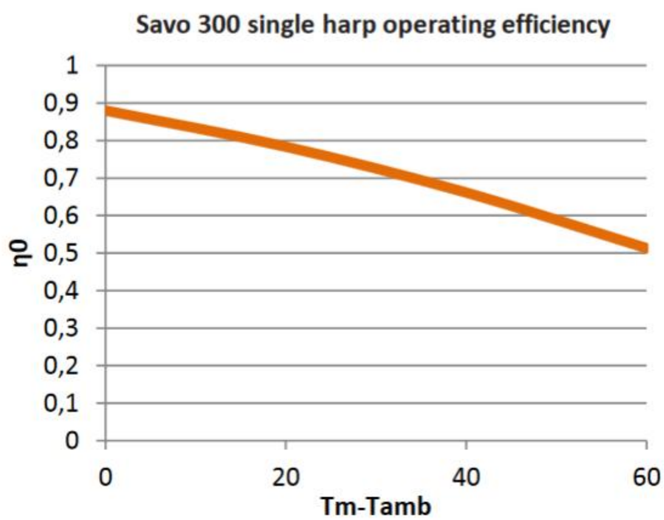

Figure 42. Solar collector efficiency as a function of temperature difference [156].

5. Future perspectives and markets of bioenergy RES hybrids in Finland

5.1 Potential market areas and expected market sizes for RES hybrids

The increasing amount of distributed renewable energy production and the change towards more versatile and complex energy system reflect the future markets of bioenergy RES hybrid solutions. It has been shown that the system comprising several energy inputs is more reliable with respect to the system with only one energy input. In the energy system with increasing amount of variable RE generation, this feature becomes of great interest.

5.1.1 Domestic applications

The largest potential for domestic hybrid applications lies in the heating sector, the main motivators being reduction in energy costs, increased self-sufficiency and user friendliness. Many detached houses already have one renewable energy resource to produce heat (i.e. wood stove or heat pump) and a hot water tank, which helps the further integration of other RE sources. In the case of new buildings, water circulation based heating system is getting more common [157]. In the power sector, hybrid solutions remain rare due to the fact that majority of buildings are connected to the power grid. However, market growth in PV installations to reduce grid sourced power consumption has been detected.

The replacement potential for renewable energy and hybrid technologies is high in Finland: 200,000 oil boilers, 100,000 other water circulation based systems, 500,000 directly electric heated systems, 500,000 summer cottages and 100,000 premises outside the DH network [158]. Altogether, 1.4 million buildings could either use RE technologies or be integrated to DH network. Currently, approx. 5,000 oil boilers are replaced annually by non-fossil heat sources, such as heat pump, biomass and also solar thermal. By replacing 20,000-30,000 boilers annually, the oil consumption of 500 million liters/year (18 PJ/year i.e. 5 TWh/year) for heating could be cut well before 2030. [159]

The largest potential for domestic hybrid solutions lies in the buildings outside the DH network, where it is challenging to economically cover the whole heat demand with a single heat source. A hybrid system combining for example heat pump or wood stove as a base producer and oil boiler or electric resistance heater as a topping is already common in detached houses. In a fully renewable hybrid system, potential base load producers are ground-source or air/water heat pump, wood pellet burner or fireplace with water circulation. Depending on the household's heating behaviour, the role of biomass in a RES hybrid system can be roughly divided in two categories:

1) Biomass as the base load producer: The consumption, operation costs and work load can be reduced by the integration of other heat sources;
2) Biomass to complement other heat sources (e.g. heat pump as base load producer): Peak demand and electricity costs can be cut and over dimensioning of the heat pump avoided.

It is estimated that at least 100,000 wood pellet burners could be installed in Finland, mainly to replace direct electric heating and oil boilers [35]. The current wood pellet production capacity is about 650,000 tonnes [36], representing approx. 11.7 PJ (3.25 TWh) of energy. Of this, approx. 273,000 tonnes i.e. 4.896 PJ (1.36 TWh) could be utilized in buildings and at farms in the future[7]. Approx. 1.55 million fireplaces are already located in detached houses out of 2.9 million in all buildings, and the potential annual growth is 70,000 fireplaces if historical trends are followed [68]. The potential for heat pumps is 1.7 million by 2030 [13], and it is foreseen that by 2020 there could be over one million heat pump installations with capacity of over 6,000 MW (production over 36 PJ i.e. 10 TWh) [160]. As smaller detached houses are getting common,

[7] Calculated assuming 27,000 wood pellet boilers in buildings and consumption of 58,000 tonnes, and future investments in 100,000 wood pellet boilers.

electric heating is a potential competitor or complement for heat pumps and bioenergy during low electricity prices.

Solar thermal market development has been rather slow in Finland, though, high potential exists due to wide heating markets. Solar thermal integration can reduce the fuel consumption and maintenance of the biomass or oil boiler. This is significant especially during low heat loads in spring, summer and autumn. In the case of heat pump, solar thermal integration improves the life time of a pump, since running hours and the number of start-ups are reduced. By storing solar heat to bore holes, the efficiency of a heat pump can be increased. [43] Both solar thermal and PV reduces the demand for purchase electricity. Solar thermal always requires a parallel heat source, since the production during the winter months is minimal.

The economic feasibility of a hybrid system is based on the usage of each heat source at their best. The hybrid system, for example by PolarSol, can fully replace the traditional ground-source heat pump, with even smaller investment of approx. € 15,000 [161] with respect to investment cost of ground-source heat pump of € 14,000–20,000 [162]. Ground-source heat is typically the most feasible heat source in large-scale residential buildings (>200 m^2). In smaller ones, the hybrid system might be more beneficial, especially if a fireplace or stove is installed anyway. [63] The report by the Bioenergy Association shows that wood pellet based heating is economically competitive with oil and electric heating both in the existing and new residential buildings (**Figure 43**). The customer price of pellets is approx. 5.8 c/kWh as of 2015. [35]

Due to high investment cost of district heat connection, continuously increasing district heat price [163] and reduced heat demand in energy efficient buildings [18] there has been identified minor transition from district heating to other heat sources also in the DH areas. Biomass, heat pump and solar thermal are potential heat sources to cut the DH consumption and related costs.

In apartment buildings belonging to DH network, significant annual savings in heating (even 50%) can be achieved by implementing ventilation air heat recovery system. There are about 30,000 apartment buildings where ventilation air heat recovery could be implemented [13]. DH consumption can be further reduced by adding solar collectors to the system. PV system can be implemented to cut the grid power consumption. Most likely the first investment in a PV system by a housing cooperative in Finland was done in 2016 in apartment building in Helsinki and potential for such, profitable investments is high [164].

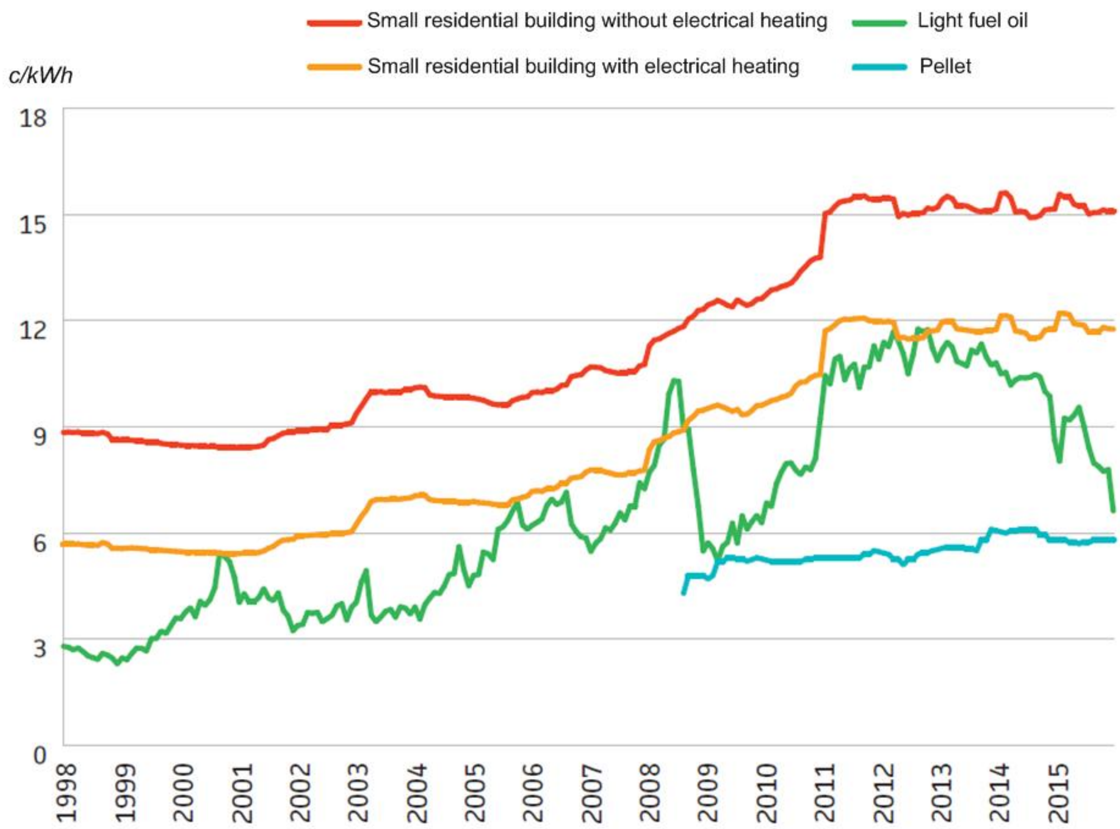

Figure 43. Purchase price of electricity, wood pellets and oil from 1998 to 2015 in Finland; retrieved from [35].

Bioenergy RES hybrid potential in domestic applications:

- RES hybrids to replace oil and electric based heating in the non-DH buildings
- Biomass to cover peak demands and heat pump as the base producer
- Biomass for base load production and other heat sources to complement the production
- Solar thermal to reduce biomass consumption, operation costs, work load and need for boiler maintenance
- Solar thermal to lengthen the lifetime of a heat pump and to improve the heat pump efficiency
- Biomass, heat pump or solar thermal to decrease DH related costs
- PV to reduce grid sourced power

Potential in numbers:

- 200,000 oil boilers to be replaced; annual replacement potential 20,000-30,000 boilers
- 100,000 other water circulation based systems to be replaced
- 500,000 directly electric heated systems to be replaced
- 500,000 summer cottages to be equipped with a hybrid heating system
- 100,000 buildings outside the DH network
- 2.9 million fireplaces (1.55 million in detached houses) to be complemented with other RE sources; annual growth about 70,000 fireplaces
- 27,000 wood pellet boilers to be complemented with other RE sources; potential addition at least 100,000 boilers, corresponding consumption ~4.896 PJ (1.36 TWh)
- Heat pump potential 36 PJ (10 TWh) by 2020 (>1 million) and 54 PJ (15 TWh) by 2030 (1.7 million), to be complemented with other RE sources
- 30,000 ventilation heat recovery pumps to apartment buildings
- 500 PV systems (15 kW) to housing cooperatives during the next two to three years, corresponding production 21.6 TJ (6 GWh)

5.1.2 District heating and cooling networks

DH network can be found in 166 municipalities of slightly over 300 in Finland [18]. The total length of the DH network was approx. 14,300 kilometers in the end of the 2014, and the annual expansion is 250–500 km [165]. The market share of district heating is foreseen to increase from 122.4 PJ (34 TWh) in 2015 to 144–151.2 PJ (40–42 TWh) by 2025 through urbanization, mainly in the areas with existing network [14]. On the other hand, energy efficient construction and high DH prices are foreseen to diminish the DH demand. In 2012, district cooling was provided by eight energy utilities [18]. The demand in urban areas is foreseen to further increase from the 684 TJ (190 GWh) in 2014 to 1,530 TJ (425 GWh) by 2030 [14].

District heating and cooling networks offer a great potential for efficient utilization of renewable energy and waste heat sources [166]. In 2013, biomass, mainly wood chips, became the largest source of district heat (29%), overtaking natural gas (26%), coal (26%) and peat (13%) [18]. There is transition towards wider utilization of biomass and waste streams. Thanks to typically large storage volumes in DH and DC networks, there is potential to integrate variable RE sources (wind and PV) to DH network, which simultaneously increases flexibility in the power system (**Figure 44**). Since the amount of variable production in Finland remains low, this possibility has not been widely utilized yet.

Bioenergy plays a key role in fast transition towards CO_2 neutral DH production. Bioenergy is available around the year, but in order to guarantee its availability and sufficiency to all end-uses with cost-competitive price, it is beneficial to release the pressure from biomass utilization in energy production with other heat resources. As described in Chapter 4.1.2, for example HELEN is planning to increase its bioenergy share through distributed energy production model, by co-combustion of wood and coal and by biogas utilization. Also in Turku, a multi-fuel CHP plant is under construction to replace coal. The target is to increase the biomass share from the initial 40% to 60-70%. The fuel flexibility allows using different fuels according to their costs. [167]

In the future, bioenergy is foreseen to enable renewable balancing services in the energy system with increasing amount of variable renewable generation and serve for the peak loads. An example of recent bioenergy investments in flexible capacity is Fortum Värme's new biomass CHP plant (wood chips and wood residues) in Stockholm, Sweden [168]. In Finland, there have already been some investments in pulverized wood pellet burners, which can cover the peak heat demand periods with rather fast response time, thus replacing oil and natural gas in peak production.

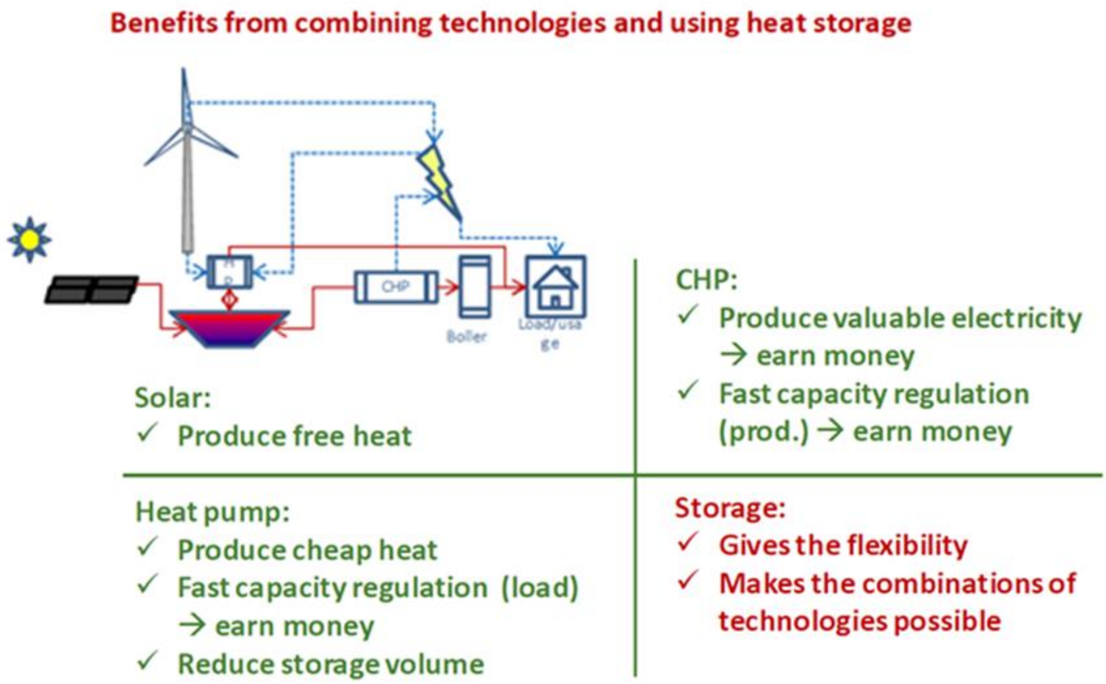

Figure 44. Integration of DH network and CHP (bioenergy) with power sector [169].

Solar thermal with low operation costs is an attractive way to cut CO_2 emissions in the DH production. Bioenergy is foreseen to be a good complement to variable solar thermal production due to its easy storability and balancing ability. Reference cases of solar thermal integration to district heating biomass boilers can be found for example in Denmark (Chapter 4.1.2). So far, solar fractions of 5-25% (i.e. ~10,000 m^2, ~7 MW_{th}) are most common, but even larger systems are foreseen to be cost-effective [169]. Large-scale heat storages, usually found in the DH system, improve the usability of the solar heat. In the DH area, centralized solar heat production is identified to be more beneficial than building-scale production due to economies of scale [47].

The economic feasibility of solar thermal and biomass integration depends on the price of the fuel replaced[8]. Solar heat price in Denmark has fallen down to 30 €/MWh, average price being around 45 €/MWh [169]. The cost-competitiveness is foreseen to further improve along the reduction in collector prices. In existing large solar thermal installations in other applications, investment decisions have mostly been made based on economic benefits. Solar thermal can bring also operational benefits: the minimum heat load covered by biomass boiler with rather poor part load efficiency or by fossil oil can be avoided during the summer period. However, the reduced operating hours of boiler, CHP based power production and faster achieved minimum load of the boiler are potential barriers for large-scale solar thermal investments.

There is active on-going research on solar thermal integration into the district and regional heating networks, and the first pilot system combining wood pellet burner and solar collectors is running (Chapter 4.1.2). Districts utilizing solar resources are under planning for example in Helsinki (Östersundom) and Turku (Skanssi [170]). However, the first large-scale showcase plant is still lacking. Typical solar field size in a regional heating plant is in the range of 40–200 m^2 and in a DH plant 5,000–150,000 m^2. Assuming the solar thermal capacity currently existing in Denmark to be built in Finland within the next five years, the solar thermal market in large-scale applications would increase from practically zero to 800,000 m^2 i.e. the annual production could be in the range of 1,440 TJ (400 GWh)[9].

[8] For example in Denmark, the household gas price (2012, 2nd half) was close to 110 €/MWh [169].
[9] Assuming 1,000 kWh/m^2 annually in Finland and collector efficiency of 50%.

Passive solar energy is already utilized for DH production in HELEN's district heating and cooling system. Since the DC network is continuously expanding, the passive solar energy potential for DH production increases. Currently, even 2.88 TJ (800 MWh) of solar energy can be covered to DH network in a day in Helsinki. If roughly estimating the same production from June to August, annual passive solar energy contribution of 262.8 TJ (73 GWh) to HELEN's DH network can be derived. Similar trend in all the DH and DC network development in Finland would give a theoretical potential of 1,584–1,656 TJ (440–460 GWh) for passive solar energy utilization.

Bioenergy RES hybrid potential in district heating and cooling networks:

- Bioenergy as a fast pathway to increase the RES and cut emissions in DH production
- Bioenergy as a balancing element in the DH network and to cover peak loads
- Waste streams, passive solar energy and heat pumps to increase the system efficiency
- Waste heat recovery to reduce investments in generation capacity
- DH networks balancing the intermittent power production
- Solar thermal to save biomass resources and cover part loads during the summer period

Potential in numbers:

- Potential of renewables in DH network 144–151.2 PJ (40–42 TWh) by 2025 (122.4 PJ i.e. 34 TWh in 2015)
- Potential of renewables in DC network 1,530 TJ (425 GWh) by 2030 (684 TJ i.e. 190 GWh in 2014)
- Potential of solar thermal in DH network 1,440 TJ (400 GWh) within the next few years
- Potential of passive solar energy in DH network 1,584–1,656 TJ (440–460 GWh) by 2030

5.1.3 Industrial applications

The energy consumption in industry was 521 PJ (144.7 TWh) in 2014, representing 47% of the final energy consumption [171]. The largest energy source is wood fuels with the share of close to 35% i.e. 182.4 PJ (50.6 TWh). Oil, natural gas and coal still represent 12%, 8% and 7.5%, respectively, meaning a potential of 143.3 PJ (39.8 TWh) for renewables. The largest energy consumers were forest industry, chemical industry and metal industry. One example of bioenergy RES hybrid system in food industry is Snellman's facility combining biogas combustion and ventilation heat recovery for heat production (Chapter 4.1.3). The total potential of hybrid systems in food product manufacturing industry is 16.2 PJ (4.5 TWh) and in beverage manufacturing industry 2.07 PJ (0.57 TWh), altogether 18.3 PJ (5.08 TWh). [172]

High industrial energy consumption, still high share of fossil fuels and availability of different waste heat resources create potential for hybrid systems in industry. Grid sourced power can be replaced by own power production, but the largest potential exists in the heating and cooling sector. Potential heating and cooling sources in addition to bioenergy are solar thermal energy, heat pumps and different waste heat sources, which are typical in industry.

In many countries, solar energy is already utilized in industrial heating and cooling applications. For example, PepsiCo's Tolleson facility in Arizona uses solar thermal collectors to produce hot water, thus reducing natural gas consumption of the facility (7% annually), and Heineken Breweries installs solar thermal collectors to all of its facilities to produce process heat. In Europe, food industry has started to use solar energy for process heat production. [173] [174] In Finland, the challenge in industrial solar thermal utilization is the mismatch between production and demand. However, the already wide utilization of bioenergy offers potential complement to solar thermal due to its storable nature.

Waste heat recovery plays an important role in industry to increase the overall energy efficiency. This, combined with bioenergy, offers a good base for renewable heating and cooling solutions. For example a food industry company Saarioinen has invested in solutions recovering waste heat from the cooling system to heating system. While bioenergy and ground-source heat are typically alternative heat sources in household scale, in industrial scale the integration can achieve economic feasibility.

Bioenergy RES hybrid potential in industrial applications:

- Bioenergy RES hybrids to reduce energy costs, reduce biomass consumption and replace oil
- Better waste management through biogas production
- PV to reduce grid sourced power and increase self-sufficiency

Potential in numbers:

- Potential of renewables in industry 521 PJ (144.7 TWh)
- Potential in food products manufacturing industry 16.2 PJ (4.5 TWh)
- Potential in beverage manufacturing industry 2.07 PJ (0.57 TWh)

5.1.4 Farm-scale applications and biogas

The direct energy consumption in agriculture was 36.108 PJ (10.03 TWh) in 2013, thus representing approx. 3% of the final energy consumption in Finland. Of the total consumption, bioenergy covered 45% i.e. 16.2 PJ (4.5 TWh), whereas the light and heavy fuel oil represented 34%, electricity 15% and peat 6%, respectively. [120] The numbers roughly indicate a 19.8 PJ (5.5 TWh) potential for renewable energy in agriculture.

The main motivators for renewable energy implementation at energy-intensive farms are reliable energy delivery, energy self-sufficiency and minimized energy related costs. The number of farms in Finland was 50,999 in 2015 [175], leading to an average annual energy consumption of 709.2 GJ (197 MWh) at a farm. The constantly decreasing number of farms and increasing unit size create greater potential for hybrid systems. Since the energy consumption is high, it is challenging to economically cover all the demand with a single energy source. Different process integration options become interesting in order to reduce waste energy, which is produced due to mismatch between demand and production over the year. Currently, the utilization of RE at farms aims to reduce the consumption of oil and grid power. When bioenergy utilization becomes wider, variable RE sources can either decrease the biomass consumption and use it rather for balancing, or increase the amount of further refined biomass based products.

The distribution of energy consumption highly depends on the type of agriculture, but on average the distribution is as presented in **Table 9**. High oil consumption as vehicle fuel opens potential for liquid biofuels and also for biogas. Approx. one-third of the oil i.e. 4.176 PJ (1.16 TWh) is consumed for heating and drying, and could be covered with renewable sources. The highest electricity consumption can be found in sow farms, in which the consumption varies between 20–30% of the total consumption. In chicken farms, the heat demand can be even 79% of the total consumption. [121] [176]

In addition to 36.108 PJ (10.03 TWh) consumption in agriculture, 6.48 PJ (1.8 TWh) of energy is consumed annually in greenhouses (size >1,000 m^2) [176].

Table 9. Distribution of average energy consumption in agriculture in 2012 [176].

Energy use	Share of the total energy consumption [%]	Energy consumption [PJ] (TWh)
Agri- and holticulture	**100**	**43.2 (12)**
Heating	28	12.096 (3.36)
Grain drying	17	7.344 (2.04)
Vehicle fuels	33	14.256 (3.96)
Electricity	22	9.504 (2.64)
Greenhouses	**100**	**6.48 (1.8)**
Heating	64	4.147 (1.152)
District heating	8	0.518 (0.144)
Electricity	28	1.814 (0.504)

Wood and wood chip drying can reduce the required amount of raw material for energy production and lead to annual savings of thousands of euros [129]. Potential heat sources for the drying are waste heat from CHP production and solar thermal, which both are focused on the summer period, when also the drying is most efficient. If expecting average wood chip utilization of 120 i-m^3 at a farm [177], the theoretically potential wood chip consumption would be 15.42–22.03 PJ (4.3–6.1 TWh) and the energy required for the drying 2.048–3.481 PJ (0.57–0.97 TWh), depending on the time of the year (consumption 93 kWh/i-m^3 in the summer and 158 kWh/i-m^3 in the winter [146]). The annual use of wood in small residential buildings (incl. buildings at farms) is in the range of 5 million k-m^3. Of this, 1 million k-m^3 is sold on the markets (6.12–9.36 PJ i.e 1.7–2.6 TWh), and could be theoretically dried. [178]

The highest biogas production potential in Finland is estimated to be in agriculture [26]. Biogas technology efficiently combines, at its best, energy production, waste treatment and nutrient recycling at farms, simultaneously increasing the self-sufficiency and incomes of the farm. The annual manure production from domestic animals is over 17 million m^3, leading to techno-economic potential of 3.24–6.48 PJ/year (0.9–1.8 TWh/year). The biogas potential from the fields is estimated to be approx. 16.92 PJ (4.7 TWh). [179] However, the market uptake of the technology has been slow, and the share of farm-scale biogas production of all production is rather small (<1%). Restricting issues are the high initial investment, rather case-specific subsidy policy and the expected work load for the farmers. However, in recent years, market growth has been seen.

With the current policy framework (investment subsidy and FiT) it is clear that all the farms are not able to invest in an own biogas reactor and the biogas production is not shown to be feasible in small-scale [26] [39]. Since the storing of biogas is challenging, the utilization is beneficial if the biogas can be constantly used [179]. It might be challenging to find use for the heat especially during the summer period; one solution is to use it for wood chip or grain drying. One way to increase the profitability is to refine biogas for transport, which approx. doubles the benefit with respect to power and heat production. [180] Transport gas production at farms and in larger reactors improves the gas availability in the locations outside the natural gas grid. In the case of own electricity production, the most benefit is gained by utilizing it at the farm, since the transport and tax in the electricity price are not paid when power is sold to the grid.

In Finland, natural gas grid is strong and connects the biogas sources and demand [180]. Feeding to the gas grid also neglects the challenges in storing gas. Waste streams from forest industry offer great potential for biogas production [181]. According to Gasum, the annual potential wood based biogas production could be 54 PJ (15 TWh) [181], thus corresponding to almost half of the current (2014) natural gas demand [171] and significantly contributing to CO_2 reductions (**Figure 45**). Sitra's estimate for annual techno-economic biogas potential based on biomass waste (excl. synthetic biomethane) is 18.36–50.04 PJ (5.1–13.9 TWh) [113]. By replacing natural gas, which represented 7% of the total energy consumption in 2014 [171], higher degree of self-sufficiency could be achieved in Finland.

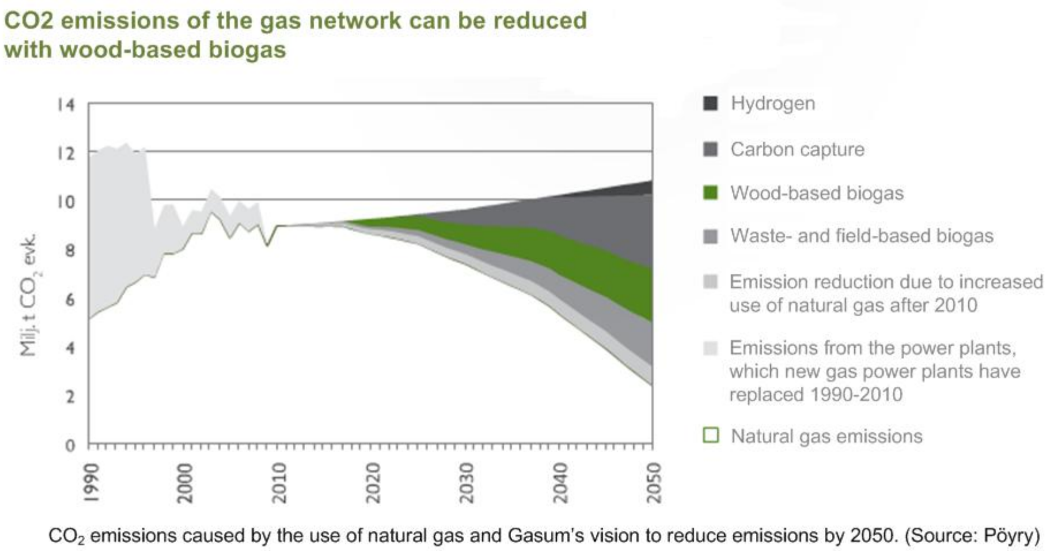

Figure 45. Gasum's vision to reduce CO_2 emissions with biogas [181].

Bioenergy RES hybrid potential in farm-scale applications:

- Solar thermal and ground-source heat to complement bioenergy in heat production
- Solar thermal and waste heat for wood and wood chip drying
- PV and wind power to complement bioenergy and grid power, and for biofuel production, also for heat production through electric boiler
- Biogas from waste resources to replace oil in heating and grid power
- Biogas to grid or transport to increase the incomes
- Fertilizers from biogas production to replace commercial fertilizers
- Liquid biofuels from waste resources to replace oil as vehicle fuel and oil and grid power in energy production

Potential in numbers:

- Potential of renewables 19.8 PJ (5.5 TWh) in agriculture and 6.48 PJ (1.8 TWh) in greenhouses
- Potential of wood chips 15.42–22.03 PJ (4.3–6.1 TWh)
- Potential of wood chip drying 2.048–3.481 PJ (0.57–0.97 TWh) with waste heat and solar thermal
- Potential wood for drying 1 million k-m^3, corresponding to 6.12–9.36 PJ (1.7–2.6 TWh)
- Theoretical potential of biogas 93.6 PJ (26 TWh) i.e. the current natural gas consumption (2014)
- Techno-economic potential of manure-based biogas 3.24–6.48 PJ (0.9–1.8 TWh)
- Potential of field biomass based biogas ~16.92 PJ (4.7 TWh)
- Techno-economic biogas potential based on biomass waste 18.36–50.04 PJ (5.1–13.9 TWh)
- In total, wood based biogas potential ~54 PJ (15 TWh)

5.1.5 Summary of foreseen bioenergy RES hybrid potential in Finland

Table 10 summarizes the directional estimations on potential of different RES hybrid technologies in Finland identified in Chapters 5.1.1–5.1.4. In addition to bioenergy RES hybrids also some other RES hybrid technologies are presented.

Table 10. Hybrid systems identified in Finland and estimations on their market potential.

Application	Main product	Advantages of integration	Market potential	Market uptake	TRL [1)]	Level of integration
Heat pump + renewable electricity [2)]	Domestic and industrial heat, district heat	Increased self-sufficiency, cut in peak electricity prices	Medium; 730,000 buildings with heat pump	Small	9	Low
Bioenergy + heat pump	Domestic and industrial heat, farm-scale heating	Increased self-sufficiency, cut in peak electricity prices, less work and maintenance, smaller heat pump	Medium; 1.4 million households, 50,999 farms	Medium	9	Medium
Bioenergy + solar thermal	Domestic and industrial heat, farm-scale heating	Increased self-sufficiency, less work and maintenance	Medium; 1.4 million households, 50,999 farms	Small	9	Medium
Heat pump + solar thermal	Domestic and industrial heat	Increased self-sufficiency, increased heat pump lifetime and efficiency	Medium; 1.4 million households	Small	9	Medium
Bioenergy + solar thermal (passive & active) + waste heat (heat pumps) + geothermal	District heat	Reduced emissions, lower operation costs, cut in oil and bioenergy use during the summer period, longer period available for boiler maintenance, reduced investments in production capacity, no need for thermal storage	High; 40–42 TWh in DH by 2025, 425 GWh in DC by 2030, 400 GWh solar thermal in DH within the next few years	Medium	7 / 9 [3)]	Medium
Bioenergy + solar thermal + waste heat recovery + ground-source heat	Industrial heat e.g. food product and beverage manufacturing, logistic centers	Cost-effectiveness, reduced emissions, better waste management (biogas), local labor	High; 144.7 TWh	Small	9	Medium
Bioenergy + PV + wind + biogas/ biodiesel	Farm-scale heating, electricity and transport	Increased self-sufficiency, cut in peak electricity prices, reduced purchase of oil and electricity, additional incomes	Medium; 10 TWh, 50,999 farms	Small	8 / 9 [4)]	Medium / High
Bioenergy + solar thermal + waste heat	Biomass drying at farms	Increased heat capacity and reduced biomass consumption, waste heat utilization, additional incomes	Small; 0.6–1.0 TWh for wood chip drying in small-scale	Small	7	Low
Biogas	Farm-scale CHP, large-scale energy production, transport	Reliability, emission reductions, utilization of waste streams, self-sufficiency, nutrients, biogas to areas without NG grid	High; current NG use 26 TWh (2016), biogas potential: wood based ~15 TWh, manure based ~1.4 TWh, field biomass based ~4.7 TWh	Small	9	Low

[1)] TRL of KETs refers to Technology Readiness Level of Key Enabling Technologies. For definitions, see: bit.ly/1TAL0lW[10]
[2)] Most likely not a bioenergy RES hybrid
[3)] Passive solar thermal and waste heat recovery integration to (bioenergy) DH network at TRL 9, active solar thermal and geothermal integration at TRL 7
[4)] Biodiesel production at TRL 8

5.2 Incentives and challenges for bioenergy RES hybrid technologies

5.2.1 Incentives for renewable energy technologies

Renewable energy is promoted in Finland through different policy measures and instruments. Some of these are shortly introduced below. More information about measures and instruments having impact in particular on the mobilization and utilization of bioenergy for bioeconomy can be found in [7]. Likewise single RE technologies, also RES hybrid technologies are affected by the measures and instruments.

Production subsidy for renewable electricity

Wind power (see Chapter 2.2.3), biogas, forest chips and wood-based fuels (see **Table 2**) can be approved to the FiT system for a maximum of 12 years while meeting the prescribed preconditions. The production subsidy in the FiT system is based on sliding premium, which is paid for produced electricity in accordance to three-month electricity price or market price of emission allowance and peat tax. In the case of a power plant using wood based fuel or biogas, an increased FiT is paid as standard heat premium, if the plant produces heat for utilization and the plant overall efficiency meets the required standards. The objective of the FiT for wood chip based electricity production is to retain the competitiveness of forest chips in the cogeneration of power and heat. There are plans to cut the aid level for forest chips produced from the industrial roundwood by 40% from the full premium tariff in order to address potential distortion of wood competition in the future. The FiT system is operated by the Energy Authority. [3] [7]

Investment subsidy for renewable energy

The Ministry of Employment and the Economy can grant investment subsidy for companies, municipalities and other communities for such investments and surveys that promote the production and use of renewable energy, efficient energy production or consumption, or reduction of environmental hazards arising in energy production or consumption. The primary aim of the subsidy is to enhance the profitability of early-stage investment and to minimise the risks associated with the introduction of new technologies. Investment subsidies are considered on a case-by-case basis. For the year 2016, M€ 35 is allocated for the investment subsidy. The maximum support for investment is 40% of the eligible investment costs. Typical investments granted in the electricity sector are small-scale hydro power, and solar electricity- and landfill gas projects, whereas in the heating sector, for example biomass fuelled heating plants, and heat pump- and biogas projects are granted. [3] [7] [41] In 2016, the investment subsidy for solar electricity is 25% and for solar thermal 20% [43]. In 2015, the subsidy for small-scale hydro power and landfill gas projects was 15–20%, for biomass fuelled heating plants, 10–15%, for heat pump projects 15% and for biogas projects 20–30% (see more about the preconditions in [182]).

Distribution obligation for biofuels in transport

A distributor of transport fuels liable to pay taxes must distribute biofuels for consumption. The required share of energy content of biofuels of the total energy content of petrol, diesel oil and biofuels delivered by

[10] For example, TRL 7 refers to system prototype demonstration in operational environment and TRL 9 to actual system proven in operational environment.

the distributor steadily increases to 20% by 2020. However, the distribution obligation does not apply to a distributor, who delivers less than one million liters of petrol, diesel oil and biofuels for consumption during a calendar year. The energy content of the biofuel is calculated to fulfil the distribution obligation twofold, if the biofuel is produced from waste, remains or inedible cellulose or lignocellulose (double counting). [7] [41]

Production subsidies in rural development programme

The investment subsidy aims to increase the share of energy production based on RE sources at farms, whereas entrepreneur subsidy can be approved to enhance business opportunities related to renewable energy in rural areas. Renewable energy investments at farms are able to receive a 40% investment subsidy of the eligible investment costs. The subsidy excludes the part of the investment, which produces energy for continuous selling. The maximum investment grant of the entrepreneur subsidy is 30% of the eligible investment costs for the renewable heat and power production and for biogas production sold for transport or vehicle fuel. The investment must be either new infrastructure or significant expansion in existing infrastructure. [41]

Discretionary energy subsidy for small-scale residential buildings

The investment subsidy can be approved for private small-scale residential buildings, which are in year-round use. The investment must either improve the energy efficiency of the building and reduce the energy use related emissions, or implement ground-source heat pump system, air/water heat pump system, pellet or other biomass boiler, or hybrid heating system to produce renewable heat. The maximum amount of the subsidy is 25% of the investment costs approved by the municipality. In 2015, the total amount of the subsidy was M€ 2, which was used to around 650 buildings, leading to average subsidy of € 3,000. [41]

Enhancing distributed electricity production

Barriers slowing the development of small-scale distributed electricity generation have been taken down in recent years in the electricity market legislation. Renewable and distributed electricity has similar access to the grid as other production according to non-discriminatory criteria. Some facilitation giving also economic benefits are applied to small- and micro-scale electricity producers: [41]

- Operators of plants with capacity <2 MW are not obligated to pay for a grid upgrade possibly needed to connect the plant to the grid;
- Operators of plants with capacity <1 MW are not obligated to generate hourly production forecasts;
- All the production connected to the 110 kV distribution grid is obligated to a maximum annual average distribution fee of 0.07 €cent/kWh.

The most benefit in small-scale production is gained by using the produced electricity to replace purchase electricity. This requires the production unit to be placed within the same premise or group of premises as the consumption. By replacing purchase electricity, not only the energy component of the purchase price, but also the tax[11] and distribution components are avoided. The number of energy utilities buying the excess electricity from small-scale producers in growing. Typically, the price for electricity sold to the grid is the hourly spot price. However, the revenue does not include the distribution and tax components. [41]

Households investing in renewable energy systems are entitled to apply domestic tax reduction. The reduction is calculated of the labor expenses, which include for example the installation cost. The amount of domestic tax reduction is 45% of the eligible costs. [43]

[11] A system with capacity of ≤100 kVA and a system with capacity of >100 kVA, but producing ≤800,000 kWh/year, are tax-free.

Energy taxation

Energy taxes are excise duties levied on both traffic and heating fuels, coal, natural gas, fuel pellet, tall oil and liquid fuels, and on electricity consumption. In addition, a security of supply fee is charged for energy products. The energy tax is divided into two components; the energy content component and the CO_2 tax component. The taxation of peat is separated from taxation of other fuels and effects on the subsidy for forest chips. Biogas and solid biomass fuels are charged neither as transport nor heating fuel. Sustainable first generation bio-oil has 50% lower CO_2 tax and second generation bio-oil is tax free. Tall oil is charged as heavy fuel oil in order to lead the utilization to refining instead of combustion. [3] [7] [41]

For the fuels used in combined heat and power production, CO_2 tax component is 50% lower than in the separate heat production in order to improve the cost-competitiveness of CHP production. [41]

Electricity is taxed at its consumption stage and fuels used for power production are exempt from the tax. On the contrary, fuels used for heat production are subject to taxation. The tax on electricity is divided into two classes: the lower is subjected to industry and agriculture, whereas the higher is charged for other consumers. [3] [7]

Emission trading

The emission trading system is implemented by the Ministry of Employment and the Economy, and the Energy Authority acts as Finland's national Emission Trading Authority. The emission trading system covers approx. half of the GHG emissions in Finland. The total volume of allowances for the period 2013-2020 accounts to approx. 18 million tonnes, leading to 37.6 million tonnes per year. Emissions allowances will be allocated to a total of 566 installations. In accordance to effort sharing decisions, Finland's target is to decrease emissions by 16% by 2020 from the level in 2005 in the non-emissions trading sector. [7] [183]

The total CO_2 equivalent GHG emissions in 2015 were 55.7 million tonnes[12] (**Figure 46**). Emissions fell by six per cent compared to 2014 and 22 per cent compared to 1990. The biggest reason for the fell was the decrease in coal and natural gas consumption in the energy sector. Emissions in the non-emissions trading sector went down by a half per cent. They were 0.8 million tonnes of CO_2 equivalent below the annual emission allocation set by the EU. [184]

[12] Statistics Finland's instant preliminary data.

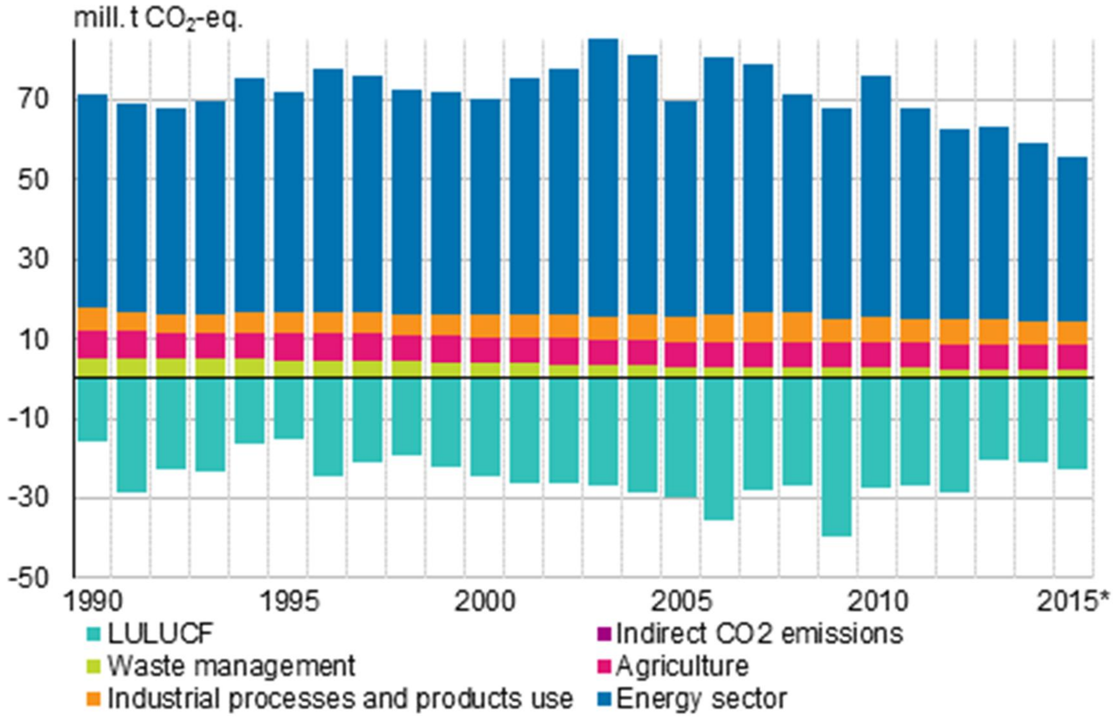

Figure 46. Development of GHG emissions by sector in Finland from 1990 to 2015[12] [184].

5.2.2 Challenges and market barriers for bioenergy RES hybrids

In recent years, the low market prices of oil and electricity have challenged the deployment of renewable technologies in heating markets, and the competition between different heat sources has hardened. In 2015, the average spot price of electricity was approx. 30 €/MWh in Finland. However, heat pump solutions have benefitted from the low electricity prices especially in detached houses. In new buildings, the share of oil based heating has been minor for years, but the low market prices slower the replacement in existing buildings. District heat is still the market leader in apartment buildings and in larger buildings, but increasing district heat prices reduce its competitiveness. [41] In the power sector, competitiveness of small-scale PV investment producing electricity for own use is not highly affected by the electricity market price, since the share of taxes and distribution of the total price can account for even two-thirds of the total price. Policy measures, especially the increased taxes on fuels for DH production and taxes overlapping with emission trading have increased the DH prices [41]. The emission allowance prices remaining at low level do not push for the renewable investments in the emission trading sector.

The deployment of bioenergy is strongly affected by the political decisions in the EU and national level. The sustainable criteria might affect the biomass availability and increase the price for energy use. Such decisions are critical for bioenergy markets, but create need for other RE technologies and hybrid systems. It is foreseen that the share of RE could rise to over 50% by 2020 in DH production. Preconditions for this development pathway are competitiveness of district heating with respect to other heat sources, active wood markets and development in terms of availability and mobilization of forest energy. [41]

FinSolar project [43] estimated that around 100 companies are active within the field of solar energy in Finland. The global market potential of renewable technologies is huge. References are a precondition for succeeding in the export businesses, and one challenge for Finnish companies, for example in the field of solar energy, in getting to the export markets is the lack of domestic references. To enhance domestic investments, a stable investment environment should be created and political risks associated to investments should be minimized through guidance by the government. [43]

Slow technical developments, bureaucracy and residents' lack of wide knowledge of options have retarded efficiency improvements and renewable implementation in private housing. As an example of technical developments, over 80% of district heating customers have nowadays a smart metering system, which increases the possibilities of the customer to choose other heat sources in parallel the DH, and in the future, enables two-way district heat markets [41]. In the case of solar energy systems, there is not a common national regulation about the subject to license. Instead, the rules are determined in the municipality level, and the differences between municipalities can be large. Differences increase the uncertainties in the profitability estimations and risks for the product suppliers. The permission process can affect the investment profitability especially in the case of a consumer. [43] **Table 11** summarizes some of the foreseen market barriers for different specific hybrid solutions.

Table 11. Foreseen market barriers for hybrid solutions identified in Finland (see also Table 10).

Application	Barriers for market uptake
Heat pump + renewable electricity [1)] (domestic, industry, district)	• Investment cost of heat pump and PV/wind power • Mismatch in power production and demand (PV) for heat production
Bioenergy + heat pump (domestic, industry, farms)	• Investment cost • Competitive technologies in base load production
Bioenergy + solar thermal (domestic, industry, farms)	• Investment cost • Attitudes & lack of knowledge
Heat pump + solar thermal (domestic, industry)	• Investment cost • Attitudes & lack of knowledge
Bioenergy + solar thermal (passive & active) + waste heat (heat pumps) + geothermal (district)	• Investment cost • Minimum heat demand required for economic operation of CHP plant • Mismatch in production and demand (solar thermal) • Land-use requirement of solar thermal • Risks in the pilot phase of geothermal solar thermal utilization • Lack of operation experience of complex system
Bioenergy + solar thermal + waste heat recovery + ground-source heat (industry)	• Investment cost • Attitudes • Lack of local stakeholders to build up the local biogas economy
Bioenergy + PV + wind + biogas/biodiesel (farms)	• Investment cost • Additional work load • Attitudes • Technology readiness
Bioenergy + solar thermal + waste heat (biomass drying at farms)	• Investment cost • Work load • Hard to scale up
Biogas (farms, utility, transport)	• Investment cost • Work load

[1)] Most likely not a bioenergy RES hybrid

6. Summary and conclusions

Bioenergy is the main renewable energy source in Finland with the share of 25.6% of the total energy consumption. Its consumption in energy production has been rather stable over the last years. Residues from forest industry are a typical bioenergy source in Finland, for example black liquor represents 33.9% of RES. However, the national Energy and Climate targets for 2030 and new pathways for bioenergy use, such as processing to biofuels for transport, set new questions of sufficiency of sustainably and cost-effectively available bioenergy resources. In addition to wide bioenergy utilization, typical characteristics for Finnish energy system are the high annual variability in heat demand due to climate conditions, the strong role of district heating in the heating sector and large contribution of CHP to heat and power production.

The status of renewable technologies (Chapter 2.2) shows that the technological background for bioenergy RES hybrids already exists. No major technical challenges for different hybrid schemes can be found, though development steps are still required in advanced processes, such as in Power-to-Gas technology, and in the operation of complex systems. Most of the hybrid schemes identified in the report already have reference cases in Finland or in similar countries. The main findings are summarized in **Table 12**. However, since the number of large-scale references is still low, the status of bioenergy RES hybrids is mainly reviewed through examples in this report (Chapter 4.1).

Table 12. Summary on existing and developed bioenergy RES hybrid solutions in Finland.

	Domestic scale	**Utility-scale and DH/DC networks**	**Industry**	**Farm-scale**
On market/ Implemented	• Biomass + solar thermal • Biomass + ground-source heat • Biomass + waste heat recovery • Biomass + electric heating • Biomass + DH • Biomass + PV	• Biomass + waste heat recovery • Biomass + passive solar energy • Co-combustion of biomass and coal	• Biomass + ground-source heat • Biomass + waste heat recovery • Biomass + PV	• Biomass + ground-source heat • Biomass drying • Biomass + PV • Biomass + wind • Biogas production
Ongoing developments	• Two-way DH connection	• Biomass + solar thermal • Biomass + geothermal • Hydrogen boosted biofuels • Waste heat utilization from new sources	• Biogas related networks	• Biomass + solar thermal • Liquid biofuel production

Domestic scale RES and non-RES hybrids are common heating solutions in detached houses outside the district heating network. Typically, it is not cost-competitive to rely only on one energy input due to high annual differences in heat demand in Finland. The main driver for RES hybrids is to increase the level of energy self-sufficiency, to cut oil and electricity related costs and to use single heat sources at their best. There are for example 200,000 buildings heated by an oil boiler, which could be replaced by bioenergy RES hybrid systems. Wood is a traditional source of heat in detached houses in Finland, though the use as the only heat source has decreased. In RES hybrid system, the role of biomass depends on the heating behaviour of the resident. Typically, biomass and heat pump are considered as alternative base load producers due to relatively high investment cost. Solar thermal technology is favorable together with bioenergy in terms of savings in fuel, work load and maintenance, or with heat pump in terms of lengthened component life time and improved efficiency. Domestic hybrid systems do not carry major technical risks; the challenge is rather in the proper selection and dimensioning of integrated technologies. Hybrid system offering as “product” is foreseen to speed up the markets. Also PV systems are getting more common in private households, since they reduce the amount of grid sourced electricity.

District heating and cooling networks are foreseen as the most promising applications for bioenergy RES hybrids. Bioenergy offers a fast pathway to increase the RES share and cut emissions in the heating sector, of which district heat represents 46.3%. Co-combustion of coal and pellets, solid biomass combustion both in CHP and heat boilers, and biogas are possible ways to increase the role of bioenergy. Heat sources complementing bioenergy consumption are important in order to guarantee the bioenergy availability for all end-uses. Waste heat recovery to DH network offers rather stable heat load, but it also reduces needs for new investments in generation capacity while replacing fossil fuels. Other likely technologies for DH production are geothermal and solar thermal energy. The first 40 MW pilot geothermal plant is under construction. The first pilot integrating solar thermal, wood chips and electric heater is in operation, and will provide further information on the feasibility of the concept in Finnish conditions.

Since solar thermal technology requires a parallel heat source due to high annual variability of irradiance in Finland, solar thermal technology matches well to hybrid solutions. In the DH network areas, large-scale solar thermal installations are foreseen to have more economic benefits compared to distributed installations. If following the capacity development in Denmark, the capacity could increase from zero to approx. 800,000 m^2 in Finland in short term. Solar thermal is able to complement or, with a storage system, even cover the low heat demands during the summer periods, which could avoid running biomass boiler on part load with reduced efficiency or oil boiler. The maintenance period for boiler would be extended and in extreme case, the lifetime of the boiler could be enhanced. However, the challenges for market uptake are investment cost especially in the case of large solar share (storage system), high temperature levels applied in the DH networks (65–115 ˚C depending on the weather [165]), capacity factor required for existing capacity and high land-use requirement.

The high energy consumption in industry (45% of the final energy consumption in 2015) and environmental aspects are good drivers for renewable technologies in industrial scale. Bioenergy, heat pumps and solar thermal and electricity are foreseen as important elements to increase the energy self-sufficiency and reduce energy related costs. Waste heat recovery plays an important role from the efficiency point of view. In food manufacturing industry, the waste management can be improved by using sludge and other waste for biogas production and further for energy production.

Bioenergy is a natural and widely utilized energy source in agriculture, representing 45% of the direct energy use. Bioenergy is used for heat and power production and can be flexibly complemented by other energy sources. Farms offer good potential for example for solar thermal and electricity production due to large rooftop areas available. The main driver for renewable energy adoption is increased level of energy self-sufficiency and reduced need for grid sourced power. There are already some reference farms in Finland, which are close to or even fully self-sufficient. Possibility for additional incomes increases the attractiveness of hybrid system implementation. Biogas is not only produced and used to replace oil and increase the self-sufficiency, but also to increase the incomes. The techno-economic potential of manure based biogas is 3.24–6.48 PJ/year (0.9–1.8 TWh/year), which corresponds on average to annual direct energy consumption of 13% of farms in the country. The challenge of excess heat during the summer period can be overcome by wood or wood chip drying, which at the same time enhances the efficient use of bioenergy and brings up new business opportunities. The renewable and hybrid system potential at farms is relatively low, approx. 10 TWh, but significant in terms of profitability of agriculture.

Transport sector is a significant energy consumer in Finland with the 17% share of the final energy consumption. Options to increase RES share to the 40% target by 2030 include liquid biofuels, biogas, hydrogen and electric vehicles. In order to undergo fast implementation of renewables, advanced drop-in biofuels are foreseen to be a likely pathway, since they do not require the renewal of vehicle stock. The report by VTT & VATT on possibilities to reduce road traffic related CO_2 emission 40% by 2030 (see [23]) shows that investments in domestic drop-in fuels and biogas production would be the most cost-competitive ways to cut road traffic related emissions from the point of view of GDP, as shown in **Figure 47**. Hybrid technologies in other sectors are important to release bioenergy resources to transport sector.

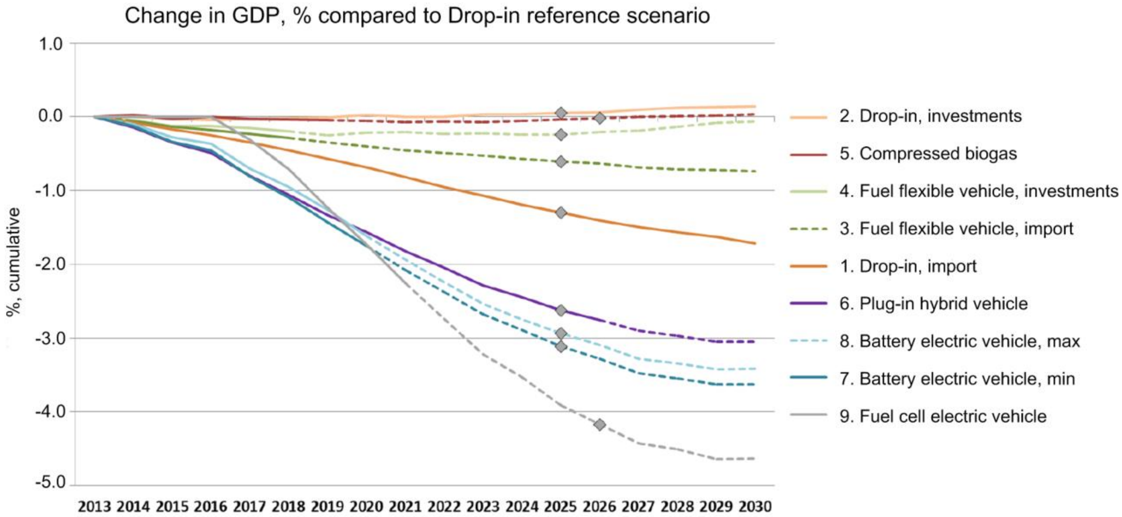

Figure 47. Effect of different scenarios on gross domestic product while aiming to 40% GHG reduction from the transport sector in Finland (dashed line = scenario unlikely as such, ♦ = 30% CO2 reduction achieved); retrieved from [23].

Currently, most of the hybrids can be found in the heating sector, where a lot of resources, which can be easily integrated, are available. In the power sector, hybrid systems (excl. virtual power plants) do not make that much sense due to stable Nordic power grid and plenty of resources available for the decarbonisation of the sector. Solutions directly integrating PV and wind production with bioenergy are foreseen to be rare, but bioenergy can have a significant role *in balancing the power system* with increasing amount of intermittent generation. In the heating sector, bioenergy is the fast way to cut the fossil fuel consumption. Bioenergy will not only serve as *base load producer*, but also as *a balancing source*. In order to guarantee bioenergy also for other end-uses, hybrid technologies become important.

Main outcomes of the review on bioenergy RES hybrids in Finland are:

- Main drivers for investments are increased self-sufficiency, reduced energy related costs and environmental aspects; in some cases, also additional incomes.
- The main challenge for wider market uptake is to find profitable business cases in large-scale, while no major technical challenges are identified.
- Most of the hybrids can be found in the heating sector, particularly in detached houses (not DH connected), due to simple and robust integration and natural flexibility offered by the integrated system.
- In domestic heating systems, bioenergy and heat pump are typically considered as alternative options for base load production. Recently, movement to also larger scale hybrid heating units has been identified, e.g. in industry and DH networks. In larger scale, integration of cost-intensive bioenergy and heat pump technologies makes more sense.
- Bioenergy is a fast way to increase the RES share in district heating and cooling networks, while other RE sources release bioenergy also for other end-uses. Solar thermal is not yet an established technology in DH production, but could contribute to production during summer periods. Waste heat recovery reduces investment needs in new generation capacity.
- Bioenergy as a natural energy source at farms creates good preconditions for hybrid systems in farm-scale. Besides increasing the self-sufficiency in all energy sectors, hybrid system might allow additional incomes for the farm (biogas, liquid biofuels, biomass drying, nutrients).
- In the power sector, the role and potential of hybrid systems (excl. virtual power plants) is limited due to rather established and strong Nordic power grid.
- In the transport sector, options to cut emissions are more limited than in other energy sectors. The use of hybrid systems in other sectors increase the availability of bioenergy at a cost-competitive price for use in transport.

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Appendix A: Domestic hybrid concepts

Table A1. Example hybrid concepts identified in domestic use in Finland or exported abroad.

Hybrid solution	**Supplier /Owner**	**Application**	**Product**	**Status / Current supply ***	**Year in use**	**Location**
solar thermal + wood + oil	Alternative Solutions Finland Oy	Detached house	Heating	Commercial <10	-	-
solar thermal + PV	Alternative Solutions Finland Oy	Detached house	Heating, electricity	Commercial <10	-	-
solar thermal + PV + water circulation fireplace and sauna stove + heat storage	Ekolämmöx Oy	Detached house	Heating, electricity	Commercial <10	-	Klaukkala, Finland
solar thermal + water circulation fireplace and sauna stove + heat storage + oil heating	Ekolämmöx Oy	Detached house	Heating	Commercial <10	2012, 2013, 2015	Espoo and Klaukkala, Finland
solar thermal (4.5 kW) + wood (40 kW) + heat storage (1800 l) + electric boiler (18 kW) + air/water heat pump + air heat pump + stove	Ekolämmöx Oy	Detached house	Heating	Commercial <10	2014	Vihti, Finland
ground source heat + stove + heat storage	Ekolämmöx Oy	Detached house	Heating	Commercial <10	2012	Lohja, Finland
solar thermal + water circulation system (e.g. stove) + electric heater + air/water heat pump + heat storage (+ oil)	Ekolämmöx Oy	Detached house	Heating	Concept	-	-
DH + solar thermal (4 m^2, 2 kW, 2–3 MWh/yr) + wood stove + ground-source cooling	Jyväskylä Energy, Ruukki	Detached house	Heating, cooling	Pilot	2015	Jyväskylä, Finland
solar thermal + heat pump + hot water boiler + heat storage + waste heat recovery	Polarsol	Detached house	Heating	Commercial >10	-	Joensuu, Multia and Oulu, Finland; Chelyabinsk, Russia; Morshin and Goshia, Ukrainian; Stuttgart, Germany; Bolzano, Italy
wood + solar thermal + heat storage	Kaukora	Detached house	Heating	Concept	-	-
wood chips/pellets + solar thermal + heat storage	SolarBiox	Detached house	Heating	Concept	-	-
solar thermal + heat pump + heat storage	Lakeuden Ekolämpö Oy	Detached house	Heating	Concept	-	-
wood + solar thermal + heat pump + heat storage	Nibe	Detached house	Heating	Concept	-	-
PV (to run heat pump) + ground source heat	Solarvoima, Nibe	Detached house	Heating	Commercial n/a	-	Espoo, Finland

Hybrid solution	Supplier /Owner	Applica-tion	Product	Status / Current supply *	Year in use	Location
solar thermal + PV + waste heat recovery (fireplace & waste water)	Hybridi-osaajat Oy	Detached house	Heating	Commercial (RESCA project) <10	2012–2014	Oulu, Finland
ground source heat + solar thermal + stoves + waste heat recovery + PV	Private	Detached house	Heating, cooling, electricity	Talo2020 project	2015	-
DH + ventilation heat recovery	Several	Apartment house	Heating	>100	-	Finland
PV + wind	Eurosolar	Domestic	Electricity	Concept	-	-

* Quantity of supply: <10 i.e. small, >10 i.e. modest, >100 i.e. high.

Appendix B: Utility-scale hybrid concepts and district heating and cooling networks

Table B1. Example hybrid concepts identified in utility-scale and representative district heating and cooling networks in Finland.

Hybrid solution	Supplier /Owner	Application	Product	Status / Current supply *	Year in use	Location
solar thermal (240 m^2, 120 kWnom, 215 kWp, 120 MWh/yr) + PV (7 kW, 50 m^2) + DH + heat storage (3 x 3,000 l)	Savosolar	Nursing home	Heating, electricity	Commercial <10	2013	Lahti, Finland
solar thermal + DH	Savosolar	Office building (η=56%), DH plant	Heating	Commercial <10	2012, 2013, 2015	Helsinki, Lappeenranta and Myrskylä, Finland; Løgumkloster, Denmark
solar thermal + DH network + DH accumulator + ground-source heating/cooling + cooling storage + PV + waste heat recovery	Lemminkänen, Merinova Oy, Granlund Oy	City block: Wasa Station (shopping centre, hotel, offices, apartments etc.)	Heating, cooling, electricity	Commercial <10 (Tekes project)	Construction starting 2017 if funding received	Vaasa, Finland
solar thermal (150 kW, calc. 120 MWh/yr) + ground source heat (275 kW, 956 MWh in 2014) + bio-oil (max 1500 kW: 500 kW & 1 MW) + heat storage (2 x 4,000 l)	HELEN (Savosolar)	School (at least 80% produced with renewables)	Heating	Commercial <10	2014	Sakarinmäki, Helsinki, Finland
solar thermal + biomass + ground source heat	HELEN	Residential area	Heating	Planned (extension to previous one)	-	Östersundom, Helsinki, Finland
Two-way connected DH + solar thermal + ground-source heat + waste heat + energy storage + cars in joint-use	City of Turku	Residential area	Heating, cooling, electricity, transportation	Commercial <10	Construction starting 2017	Skanssi, Turku, Finland
waste heat recovery (heat from buildings and waste water treatment) + DH	HELEN	DH and DC networks	Heating, cooling	Commercial <10	-	Helsinki, Finland
pellet boiler (500 kW) + electric heater (70 kW) + solar thermal (8 kW, 12 m^2, 3-4 MWh/yr) for DH (total 1,000 MWh/yr)	Savon Voima	DH network	Heating	Commercial <10	2015	Nipanen, Tahkovuori, Finland
solar thermal + ground source heat + natural gas	One1 (Savosolar)	Residential area	Heating	Pilot (housing fair area) <10	2012	Lappeenranta, Finland

Hybrid solution	Supplier /Owner	Application	Product	Status / Current supply *	Year in use	Location
solar thermal (55 kW) + ground source heat (800 meters heat collection piping)	One1 (Savosolar)	Residential area (60 households)	Heating	Commercial <10	2013	Myrskylä, Finland
biomass + ground source heat	One1	Residential area	Heating	Commercial <10	-	Artjärvi, Finland
Geothermal + DH	St1 (Fortum buying the heat)	DH network	Heating	Pilot	2017	Espoo, Finland
Geothermal + DH	St1 (Turku energy buying the heat)	DH network	Heating	Commercial <10	2018	Turku, Finland
PV (257 kWp, 211 MWh/yr, 886 panels) + heat recovery from waste water + ventilation heat recovery + biogas (from sludge)	HSY (plant owner)	Waste water treatment plant	Heating, electricity	Commercial <10	2016	Helsinki, Finland
DH + PV (15 kW) to drive the DH network pumps	GreenEnergy Finland, Elenia Lämpö Oy	DH network		Pilot <10		Hämeenlinna, Finland
bio-CHP + PV + solar thermal + heat pumps + stove + waste heat recovery	RESCA and Future buildings and renewable energy projects	Residential area	Heating, cooling, electricity	Pilot <10	2012-2014; 2014–2016	Oulu, Finland
wind (2 MW, 20 GWh/yr) + PV (745 kW, 680 MWh/yr, 2,784 PV panels)	NWE Sales Oy and Hyundai Heavy Industries, Suomen Voima Oy (owner)	Power plant	Electricity	<10	2016	Mäkelänkangas, Hamina, Finland
PV + wind (off-grid)	Finnwind	University	Electricity	Pilot <10	-	Espoo, Finland
PV (220 kW, ~160 MWh/yr) + wind	LUT	University	Electricity to replace power from the grid and 20 kW to smart grid	Pilot <10	2014	Lappeenranta, Finland

* Quantity of supply: <10 i.e. small, >10 i.e. modest, >100 i.e. high.

Appendix C: Farm-scale hybrid concepts

Table C1. Example hybrid concepts identified in farm-scale in Finland or Finnish concepts exported abroad.

Hybrid solution	Supplier /Owner	Applica-tion	Product	Status / Current supply *	Year in use	Location
PV + biomass CHP (sawdust), 1 MW off-grid solution	Nocart	Power plant	Electricity	Commercial <10	2016	Nigeria
solar based wood drying	Private	Farm	Heat	Pilot, <10	-	Saarijärvi, Finland
biodiesel (500,000 l/yr) + wind power (5 kW) + PV (10 kW) + ground-source heat	Private	Farm	Heating, electricity, transportation	Commercial <10	-	Iisalmi, Finland
biomass gasification and CHP (140 kW; heat 100 kW, power 40 kW) + PV (50 kW)	Private	Farm	Heating, electricity	Commercial >10	2012	Nurmes, Finland
biomass gasification and CHP (110 kW; heat 80 kW, power 30 kW) + PV (15 kW, 10 MWh/yr)	Private	Farm	Heating, cooling, electricity	Commercial >10	2015	Sukeva, Finland
biomass (19.5 MWh/yr) + PV (48 m^2, 6.75 kW, 5.5 MWh/yr) + air-source heat pump + oil (15 MWh/yr)	Private	Farm	Heating, electricity	Commercial >10	-	Pieksämäki, Finland
biomass + wind power (600 kW, 350–400 MWh/yr) + ground-source heat pump	Private	Farm	Heating, electricity	Commercial >10	-	Tuuri, Finland

* Quantity of supply: <10 i.e. small, >10 i.e. modest, >100 i.e. high.

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Title	**Bioenergy RES hybrids in Finland**
Author(s)	Elina Hakkarainen
Abstract	Bioenergy has a central position in Finland to achieve its targets to produce over 50% of the final energy consumption by renewable energy sources (RES) in a sustainable manner and halve the use of imported oil for domestic purposes by 2030. Bioenergy is foreseen as a fast way to achieve the targets and increase the level of energy self-sufficiency. Currently, bioenergy represents over 80% of the renewable energy production in Finland and over 15% of total power production. In the transport sector, the target is to increase the RES share to 40% by 2030. High share of bioenergy is forest residues, and bioenergy based energy production is in strong relation to forest industry. Finland's ambitious renewable energy targets raise questions about the availability of sustainable bioenergy for all end-uses with cost-competitive price. By integrating other RE sources together with bioenergy pressure from the bioenergy availability can be released and it can be used in the most profitable end-uses. As a storable and dispatchable source of energy, bioenergy simultaneously allows larger amount of variable renewable generation to be integrated to the system by creating flexibility. Hybrid system can offer cost savings in energy production, especially during the winter peak consumption periods, which are typical in the Finnish climate conditions. In the best case, hybrid system can lead to improved system efficiency and component lifetime with respect to utilization of a single energy source. In Finland, hybrid technologies based on both fossil and renewable sources are already widely applied in heating solutions in households. Since fully renewable large-scale solutions are not that common yet, the status of bioenergy RES hybrids is mainly reviewed through case examples in this report. A high potential for bioenergy RES hybrids is foreseen in the heating sector. By replacing bioenergy consumption there, more resources are available for example in the transport sector, where exist less options to cut emissions compared to heat and power sectors.
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Nimeke	**Uusiutuvat bioenergiahybridit Suomessa**
Tekijä(t)	Elina Hakkarainen
Tiivistelmä	Bioenergia on keskeisessä roolissa, kun Suomi pyrkii tavoitteisiinsa saavuttaa uusiutuvien energialähteiden yli 50 % osuus energiasektorilla kestävästi ja puolittaa tuontiöljyn käyttö kotimaan tarpeisiin vuoteen 2030 mennessä. Bioenergia nähdään nopeana tienä saavuttaa tavoitteet ja parantaa maan energiaomavaraisuutta. Tällä hetkellä bioenergia kattaa yli 80 % kaikesta uusiutuvasta tuotannosta Suomessa ja yli 15 % sähköntuotannosta. Liikennesektorilla tavoitteena on saavuttaa 40 % uusiutuvien osuus vuoteen 2030 mennessä. Metsäteollisuuden jätteet muodostavat suuren osan bioenergiasta, ja bioenergiaan pohjautuva energian tuotanto onkin vahvasti sidoksissa metsäteollisuuteen. Suomen kunnianhimoiset uusiutuvan energian tavoitteet herättävät kysymyksiä siitä, riittääkö kestävästi saatavilla oleva biomassa kaikkiin käyttökohteisiin kustannustehokkaasti. Integroimalla muita uusiutuvia energialähteitä bioenergian kanssa voidaan vähentää painetta bioenergian riittävyydestä ja sitä voidaan kuluttaa kannattavimmissa kohteissa. Varastoitavana energialähteenä bioenergia luo joustavuutta energiajärjestelmään ja mahdollistaa näin sen, että järjestelmään voidaan integroida suurempi määrä vaihtelevaa uusiutuvan energian tuotantoa. Hybridi voi tarjota taloudellisia säästöjä energian tuotannossa, erityisesti Suomelle tyypillisten talvikauden huippukulutusjaksojen aikana. Parhaassa tapauksessa hybridi johtaa parempaan kokonaishyötysuhteeseen ja pidempään komponenttien elinikään kuin yksittäiset energialähteet. Suomessa sekä fossiilisiin että uusiutuviin energialähteisiin perustuvat hybridisysteemit ovat jo tavanomaisia kotitalouksien lämmitysratkaisuina. Uusiutuviin energialähteisiin täysin perustuvat suuren kokoluokan ratkaisut eivät ole vielä yhtä yleisiä, ja uusiutuvien bioenergiahybridien nykytila onkin esitelty tässä raportissa lähinnä esimerkkeihin perustuen. Lämmityssektorilla on arvioitu olevan suuri potentiaali uusiutuville bioenergiahybrideille. Kun lämmityssektorilla korvataan bioenergian käyttöä, enemmän varantoja on käytettävissä esimerkiksi liikennesektorilla, jossa energiankäytön päästöjen leikkaamiseen on tarjolla vähemmän vaihtoehtoja kuin lämmitys- ja sähkösektoreilla.
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