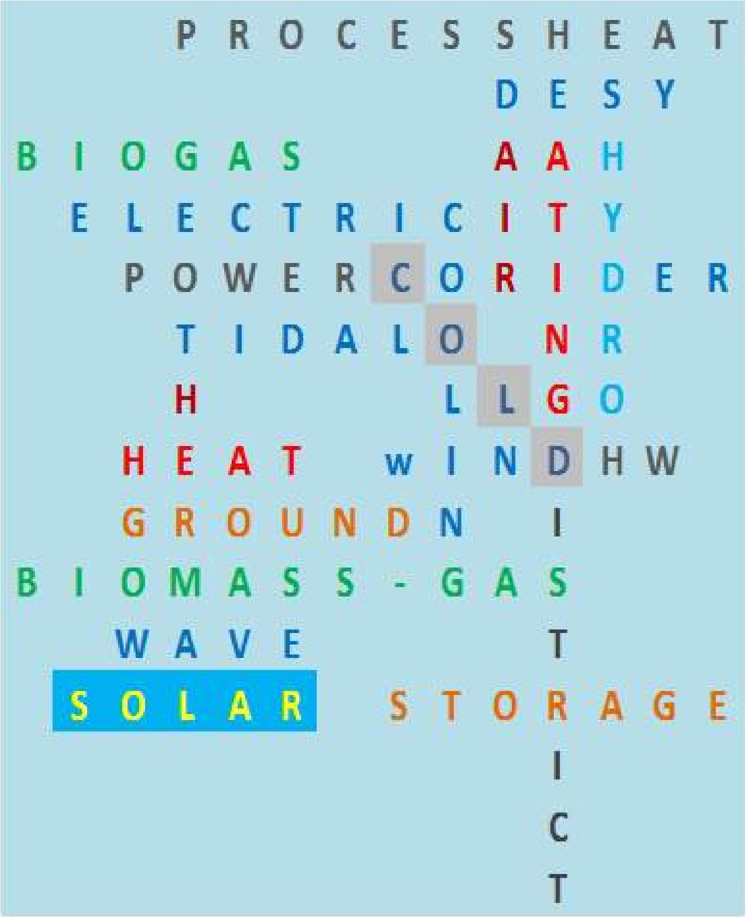

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Distributed Energy Systems – DESY

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Distributed Energy Systems – DESY

Kari Sipilä, Miika Rämä, Esa Pursiheimo, Laura Sokka, Atte Löf & Rami Niemi; VTT Technical Research Centre of Finland Ltd

Jukka Konttinen, Milena Rodriguez, Salvatore Ruggiero, Jussi Maunuksela, Mikko Hietaranta, Henri Karjalainen & Jorma Valta; University of Jyväskylä

Timo Kalema, Joni Hilpinen, Jarkko Nyrhinen, Jari Rintamäki & Maxime Viot; Tampere University of Technology

Mika Horttanainen, Sanni Väisänen & Jouni Havukainen; Lappeenranta University of Technology

Erkki Hiltunen, Raija Koivisto & Birgitta Martinkauppi; University of Vaasa

Pasi Rikkonen, Vilja Varho, Saija Rasi, Taija Sinkko & Laura Koistinen; Natural Resources Institute Finland (Luke)

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Teknologian tutkimuskeskus VTT Oy
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

Teknologiska forskningscentralen VTT Ab
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland Ltd
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Abstract

Decentralized energy production and markets for renewable energy technologies are continually expanding. The market growth is ensured, for example, by international and EU policies for renewable energy generation, the EU directives for increasing competition within the electricity industry and the rising prices of fossil fuels. Local energy production increases energy efficiency because of lower transport or transfer losses. Local energy production also increases local business and energy production from local waste reduces waste management costs, thus enabling other local business and local employment. Local energy production also increases energy, electricity and fuel security by reducing import dependency.

Combining together different technologies can form a strong hybrid solution adapted to local needs. Here the technologies interconnect and work in symbiosis supporting each other so that, in some cases, waste from one process is raw material or fuel for another. By combining the technological solutions for local needs, high primary energy efficiency can be achieved, thereby ensuring that local energy production potential is fully realized.

Possibilities and new solutions based on energy saving and the use of local energy sources were studied in a single-family house. The annual energy consumption of space heating and ventilation in the climate of Southern Finland is approximately 50 kWh/m^2 calculated per floor area. With an extremely well insulated envelope and effective heat recovery from exhaust air, it is possible to achieve the passive house level of 15 kWh/m^2. However, this is an expensive way because usually improvements in HVAC systems are more cost-effective than constantly improving the thermal insulation of the envelope from the Finnish reference values of the year 2012. The net zero energy level is difficult to reach because of heating of hot water, if you do not also build solar heating system for heating or warm waste water recovery system.

A ground heat pump system offers a possibility to reduce the electricity consumption of heating, including also the heating of hot water, of a new single-family house to the level of 30–40 kWh/m^2. With an exterior air heat pump and solar water heating, the corresponding energy consumption is 35–60 kWh/m^2.

The net zero-energy building resulted in lower environmental impacts than the other cases (district heating and electricity) in all other environmental impact categories except for eutrophication impacts. The high eutrophication impacts are caused by the high phosphorus emissions resulting from the solar panel manufacturing. In the other impacts studied, those caused by the net-zero energy house were only approximately. 50% or less of those caused by the other two cases. The difference between Cases 2 and 3 was very small, although impacts were caused by different processes in the two cases.

The cost efficiency of the measures studied, investment cost/annual energy saving, is 0.4–4.8 €/kWh. Generally the investments in heating and heat recovery devices are the most advantageous ones. Effective and cheap seasonal heat storage is required for good utilisation of solar heating. It is shown by simulations that district heating systems fed by solar heating does not need short-time heat storage. The heat network itself has enough capacity for heat storing.

The Desy-model was developed in the project. The model can simulate buildings physics and HVAC system. Area heating network, distributed heat production in the buildings and concentrated heat production connected to network (solar, wind, boiler plants and CHP plants with many fuels and energy storages) are included in the model. It seems that distributed energy production is economical, if you can use all the energy yourself and the pay-back time of investment is less than 6–10 years.

Keywords distributed, decentralised, energy, system, renewable, local, energy source, energy storage

Tiivistelmä

Hajautettu energiantuotanto ja uusiutuvan energian markkinat kasvavat nopeasti. Tähän ovat vaikuttaneet mm. kansainväliset ja EU:n toimenpiteet uusiutuvan energian käytön edistämisessä, EU-direktiivit, energiateollisuuden kiristyvä kilpailu ja fossiilisten polttoaineiden kohoavat hinnat. Hajautettu paikallinen energiantuotanto parantaa kokonaishyötysuhdetta, koska pitkät polttoaineen kuljetusmatkat jäävät pois ja energiasiirtomatkat lyhenevät. Paikallinen tuotanto lisää liiketoimintamahdollisuuksia ja luo työpaikkoja, ja jätteestä tehty energia vähentää jätteen kuljetuskustannuksia. Paikallinen hajautettu energiantuotanto parantaa energiaturvallisuutta ja vähentää tuontienergian tarvetta. Yhdistämällä useampi energiantuotantotapa hybridituotannoksi muodostetaan paikallisiin tarpeisiin vahva energiantuotanto. Energiantuotantoa voidaan myös paikallisesti ketjuttaa siten, että toisen prosessin jäte-energia voi olla toisen prosessin energialähde. Näin voidaan saavuttaa primäärienergian tehokas hyötykäyttö.

Energian tehokasta käyttöä paikallisista energialähteistä tutkittiin omakotitalossa. Nollaenergiatalon kulutusvaatimusta (15 kWh/v) vuositasolla on vaikea saavuttaa ainoastaan eristetasoa lisäämällä, vaan tarvitaan tehokasta ilmastointijärjestelmää ja lämmön talteenottoa poistoilmasta ja lämpimästä käyttövedestä sekä aurinkoenergiaa lisälämmön ja sähkön lähteenä. Maa- tai poistoilmalämpöpumppu pienentää myös primäärienergian tarvetta, ja lämpöpumpun sähkön tarvetta voidaan pienentää aurinkosähköllä sekä COP-lukua parantaa aurinkolämmöllä. Energiainvestointien kustannustehokkuus osoittautui parhaimmaksi 0,4–4,8 €/kWh lämmityksessä ja lämmön talteenotossa. Aurinkolämmön tehokas hyödyntäminen edellyttää riittävän hyvän ja edullisen kausivaraston kehittämistä. Aurinkolämmöllä tuetun aluelämmitysjärjestelmän simuloinneilla havaittiin, että lyhytaikaista erillistä lämpövarastoa ei välttämättä tarvita, vaan paikallinen lämpöverkko pystyy hoitamaan sen tehtävän.

Nettonollaenergiatalon ympäristöpäästöt todettiin 50 % pienemmäksi kaukolämpöön ja sähkölämmitykseen verrattuna. Ainoastaan rehevöitymisvaikutus oli nettonollaenergiatalolla suurempi aurinkopaneelien valmistuksen suuremman fosforipitoisuuden takia.

Energian hybridituotannon laskentaan kehitettiin DESY-simulointimalli, jolla voidaan vertailla eri energiajärjestelmiä niin rakennustasolla kuin aluejärjestelmätasolla sekä rakennusten fysikaalisia ominaisuuksia. Aluetasolla voidaan simuloida myös kaksisuuntaista energiakauppaa tuottajien ja kuluttajien välillä. Energialähteinä voidaan käyttää aurinkoa, tuulta, kattiloita ja CHP-tuotantoa eri polttoaineilla sekä energiavarastoja. DESY-simulointimalli on kaikkien tutkijaosapuolten käytössä.

Hajautettu tuotanto on vielä nykyisin edullisinta, jos tuotettu energia voidaan käyttää itse omassa kohteessa ja investoinnin takaisinmaksuaika on korkeintaan 6–10 vuotta.

Avainsanat distributed, energy, system, renewable, local, energy source, energy storage

Preface

The DESY project is guided by Cleen Oy. The project focuses on distributed energy production using energy resources near the production. A short introduction to the research is in Chapter 1. The research is divided into three parts: Chapter 2; Hybrid energy production and energy storing, Chapter 3; Business concepts in small hybrid renewable energy production and Chapter 4; Sustainability optimization of the local energy system. Demonstrations in connection to the research project are described in Chapter 5. Conclusions, recommendations and discussion of the major results are written in Chapter 6.

The steering committees of the project consist of 12 company partners, Tekes, Cleen Oy and 6 research partners. The steering committee is listed below:

Tekes	Pia Salokoski
ABB Oy	Jukka Tolvanen, *chairman*
Fortum Oyj	Marja Englund
Valmet Oy	Tero Joronen
Helsingin energia	Jaakko Tiittanen
Wärtsilä Oy	Juha-Pekka Sundell
Envor Group Oy	Mika Laine
Vantaan energia	Pertti Sahi
Ekogen Oy	Lasse Koskelainen
St1 Oy	Mika PA Anttonen
Savosolar Oy	Kaj Pischow
Gasek Oy	Pekka Ahvenniemi
HT-Enerco Oy	Hannu Teiskonen
Cleen Oy	Jatta Jussila-Suokas
JYO	Jukka Konttinen
TUT	Timo Kalema
LUT	Mika Horttanainen
VYO	Erkki Hiltunen
LUKE	Pasi Rikkonen
VTT	Kari Sipilä, *secretary*

Total amount of 29 people were connected to the project during 2.5 years. In the project was written 5 scientific articles, 10 papers for conferences, 7 internal deliverables, 6 MSc Diplomas, 1 Dr Thesis and 12 technical reports totally 41 technical publications.

Contents

Appendices

List of symbols

CHP	Combined Heat and Power
COP	coefficient of performance
DBES	Dynamic Building Energy Simulation
DC	District cooling
Dendrogram	Clustered tree construction
DG	Distributed generation
DH	District heating
DSO	Electricity or heat distribution system operator
GHG	Greenhouse gas
PV	Photo voltage
RE(S)	Renewable energy (source)
ZnB	near-zero energy building

1. Introduction

1.1 Background to distributed energy systems

All EU countries have agreed in the energy and climate package to increase energy efficiency by 20% by 2020, utilisation of renewable energy sources to 20% of total consumption and reduce the CO_2 emission load by 20% from the 1990 level. By 2050 the emission reduction target is even more challenging: 60–80% of the 1990 level. All EU Member States, including Finland have introduced feed-in-tariffs and other subsidies for renewable energy generation. Finally, the key objectives of the European Union's Strategic Energy Technology Plan (SET-plan, November 2007) are to lower the cost of clean energy and to put EU industry at the forefront of low carbon technology.

Decentralized energy production and markets of renewable energy technologies are continually expanding. The market growth is ensured, for example, by international and EU policies for renewable energy generation, the EU directives for increasing competition within the electricity industry and the rising prices of fossil fuels. Local energy production increases energy efficiency because of lower transport or transfer losses. Local energy production also increases local business and energy production from local waste and reduces waste management costs, thus promoting other local business and local employment. Local energy production also increases energy, electricity and fuel security by reducing import dependency.

Combining together different technologies can form a strong hybrid solution adapted to local needs. Here the technologies interconnect and work in symbiosis, supporting each other so that in some cases waste from one process becomes raw material or fuel for another. Many technologies operate on the side-flows or waste from other processes and provide side benefits such as for example reducing nutrient runoff or capturing carbon. By combining the correct technological solutions for local needs, high primary energy efficiency can be achieved, thereby ensuring that local energy production potential is fully realized.

Although there are many technologies in place that enable local production of energy and efficient use of energy or energy production from local sources, there are still great challenges for a larger market penetration of distributed energy production systems:

- The overall effect of implementing local energy production is often seen from too narrow a cost perspective, and positive side-benefits are disregarded.
- Comprehensive assessments and comparisons of the environmental and social impacts of different energy solutions are seldom made from a life-cycle perspective.
- Possibilities of smart interaction of different technologies and business models as a hybrid solution for local energy needs are not yet fully understood.
- Varying legislation, local authority requirements and local community planning practices are creating barriers for system standardisation which blocks mass production and scale of economy in many cases
- No common calculation methods are generally used in the analysis of new and renewable energy systems. This is an obstacle to companies when trying to export their products. Calculation methods based on European and international standards would be one solution to this problem.

To exploit market opportunities new technical and business innovations are needed. As energy generation becomes an increasingly local and regional business, new actors are involved creating increased business opportunities and diversification.

Renewable energy technologies, such as wind, solar - and biomass - based energy generation are seldom sufficient on their own to meet the energy needs of society, but the full benefit of those distributed and small scale local energy generation technologies can be obtained when they are used to complement each other. Energy storage in different ways is an essential component towards the effective utilisation of renewable energy sources.

In the DESY Research

- Sustainable means environmental, social, and economic feasibility of the solution
- Local means short distance from the energy source to the energy consumer
- Demonstration means to verify efficiency and sustainability of the solutions in real operation
- Optimal means in addition to the cost-optimum also a multi-criteria optimum from the points of view of minimum CO_2-emissions and primary energy consumption renewability and recyclability, as well as a social acceptance

Elements of efficient utilisation of renewable energy are optimal coupling of components, good technical efficiency, small heat losses and good cost-efficiency. In order to achieve these goals knowledge and methods on the correct dimensioning of renewable energy systems are needed. The European standardisation organisation CEN presents dimensioning methods for renewable energy systems in its energy package. This is one way to obtain more reliable and transparent dimensioning methods for renewable energy systems.

There are many reasons why the use of renewable energy should be increased and why energy efficiency should be improved. So far, the energy efficiency of buildings has been improved with traditional methods such as by improving the level of thermal insulation and the tightness of the building's envelope and by improving the efficiency of heat recovery from exhaust air. The only renewable energy systems used on a large scale so far are ground heat pumps and exterior air heat pumps. Ground heat pumps cannot be used everywhere due to the difficulties of placing the ground collector. The efficiency of exterior air heat pumps is low and they may even have to be shut down in the coldest weather. Therefore also other systems and technologies of renewable energy production and energy storing effectively are needed.

1.2 DESY vision

The overall objective and the vision of the Distributed Energy Systems (DESY) Programme are to enhance and develop locally-based, renewable resource utilizing and multifunctional sustainable energy systems. DESY systems support small-scale energy solutions, with representative technologies and serve as complementary and are applied in parallel with the more conventional, large-scale and centralized fossil energy systems approach. DESY adds the diversification of the societal energy portfolio. DESY contributes to economically, ecologically and socially sustainable development of local economies.

The data and analysis of the demonstration plans will be used for long-term research purposes. The long-term research goal is to produce methodologies and models for technology development and decision making so that the optimal sustainable distributed energy solutions can be found for different regions, countries and applications in the future.

Objectives of the DESY research are to:

- Develop and demonstrate new hybrid solutions for distributed energy (≥10 demos)
- Define solutions on how to adopt hybrid solutions to local energy systems; energy self-sufficiency
- Define business logics, models and norms of hybrid solutions
- Assess the sustainability of hybrid solutions also in a broader societal context

1.3 DESY structure

The DESY Programme consists of DESY R*esearch (DRE)* and DESY D*emonstration (DDE)* cases.

DESY R*esearch* part was carried out as a separated research project, where research institutes and universities co-operated with DESY companies. DESY research was structured in research themes (Fig. 1.1), which are essential and mostly common to all distributed energy systems, regardless of the specific type of the applications (for example solar, wind, fuels, ground, wastes, energy storages, etc.). DESY R*esearch* was studied and tools and models developed for technical, economic and sustainability assessment, alternative technical solutions, products and concepts of DESY systems that were later to be demonstrated at full scale.

DESY *Demonstrations* were investment projects (Fig. 1.2), which aimed to demonstrate new techniques and/or new hybrid concepts as well as to verify the new technologies in operation. The solutions to be demonstrated were planned, built and taken into operation during the programme. The research groups working in the programme focused on developing and evaluating the demonstration plants. The operation, measurement, testing and analysing of demos were carried out in close co-operation between the participating companies and research institutes.

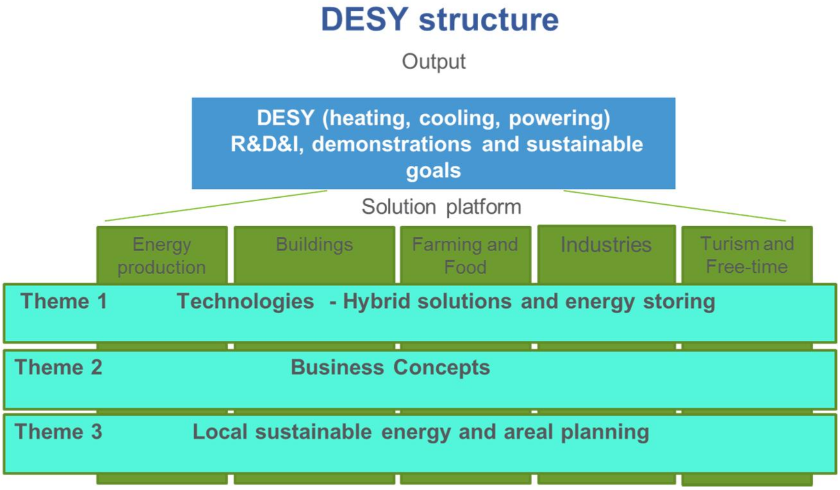


Figure 1.1. DESY structure consists of 3 Themes covering case studies in 5 sectors.

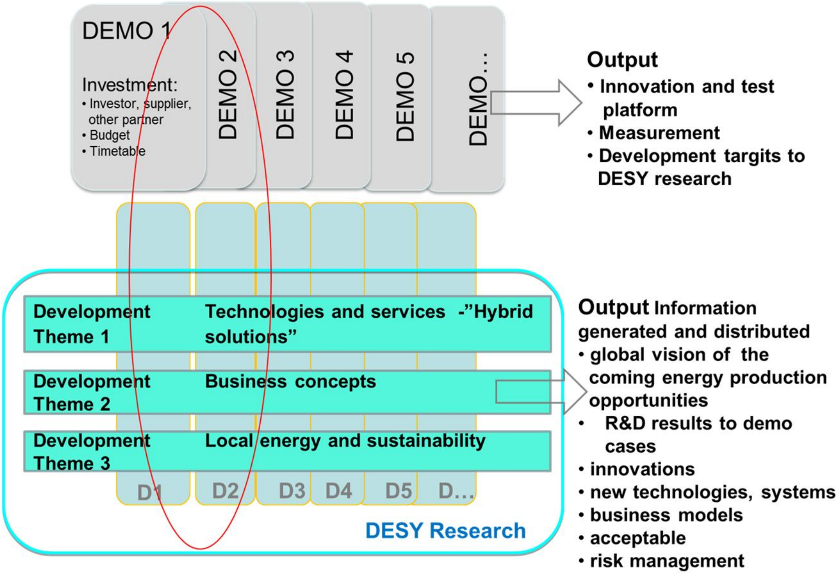


Figure 1.2. DESY demonstration in connection to DESY research.

2. Hybrid energy solutions and energy storage

2.1 General

Hybrid energy solutions for buildings and building areas handle efficient energy use of buildings e.g. by utilizing good thermal insulation and tightness of the envelope and efficient heat recovery from exhaust air. In summertime solar shading and night ventilation solutions are important. The main elements of hybrid energy solutions are various heat pumps, solar energy, energy storage and local district heating. In order to combine from these optimal solutions cost or multi-criteria optimization can be used.

2.2 Buildings and local energy systems

2.2.1 Buildings' energy modelling and energy consumption

In modelling buildings' energy systems, it is important to take into account the dynamic behaviour which takes into account the thermal storage in the buildings' structures. In our work we have used the MATLAB-model DBES (Dynamic Building Energy Simulation; Viot et al., 2013a) in which the time step of calculating is one hour. DBES is validated using two EN-standards and it is based on the TASE-program developed at VTT and TUT (Aittomäki & Kalema, 1976 and Haapala & al, 1989; Kalema, 1992). DBES is a multi-roomed model, which uses the transfer factors (Mitalas & Arsenault, 1972) for calculating the transient values of walls' heat fluxes. The transfer factors make the program very rapid. The whole DBES-model is described in the report of Viot et al. (2013, a).

Energy saving methods of buildings and their heating systems are studied for a one-storey 150 m^2 single-family house, which is modelled as a two zone building (Figure 2.1). The two rooms represent the living areas on the south facade and the bedrooms on the north facade. Table 2.1 gives the main characteristics of the house. The detailed input data of calculations and their results are reported by Viot (Viot et al., 2013b).

Table 2.1 a. Description of the two-zone single family house.

Basic information			Amount	Unit
Climate	Location		Helsinki; 60,1 N; 24,9 E	
	Weather data		FMI1), Helsinki-Vantaa test year 2012	
	Surroundings		Open ground, no external shading	
Internal gains	Building usage		Detached house	
	Average internal gains from lighting + appliances + occupants		5.0	W/m^2
	Use profiles	Kitchen + living room	Morning - evening	
		bedrooms	Evening - night	
Building systems	Efficiency of heat production	District heating	95.5	%
		Electric heating	100	%
		Heat pump	Given by COP	
	Heat distribution efficiency	Space heating (radiators)	90	%
		Space heating (air)	95	%
		Domestic hot water	90	%
Building set points and schedules	Temperature set points	Heating	21	°C
		Cooling when used	27	°C
	Schedules	Occupancy	Mostly during morning and evening	
		Lighting	Mostly during morning and evening	
		Equipment	Mostly during morning and evening	
		Ventilation	Always	
		Heating	Always	
		Cooling, shading and night-ventilation	In special studies	

1) FMI Finnish meteorological institute

Table 2.1 b.

Location	Helsinki
Azimuth of southern façade	0
Net heated floor area	150 m^2
Total window area	22.3 m^2 (15% of floor area)
Window area on south facade	10.5 m^2
Ventilation air change rate	0.5 h^{-1}
Internal heat loads on the average	5 W/m^2
Floor	Ground coupled
Thermal insulation, heat recovery from exhaust air and tightness of the envelope according to the energy requirements of Finnish building regulations 2012 /?/	

The thermal mass (heat capacity) affects the cooling energy need and interior temperatures in the summer time. There were three alternatives for the thermal mass:

- Light, heat capacity 0.22 MJ/Km^2 /EN 13790/
- Light with an internal heat capacity 0.29 MJ/Km^2
- Heavy 0.60 MJ/Km^2

The calculations have been made mainly for the light house except those handling the effect of the thermal heat capacity.

The Finnish building regulations for the thermal insulation and the energy performance have been changed and made stricter over the years. This concerns the U-values of the elements of the exterior envelope, the tightness of the envelope and the efficiency of the heat recovery from exhaust air (Table 2.2). In addition from the year 2012 a maximum allowed total primary energy demand (E-number) has been stated for the new buildings (Energy performance of buildings, Regulations..., 2012). The last column in Table 2.2 “ZnB” refers to a ‘near-zero energy building’ for which the values are taken from the Villa Isover situated at the Finnish house fair 2013 area in Hyvinkää (Viot et al., 2013b).

The heating systems were analyzed for buildings having two levels of thermal insulation and heat recovery from exhaust air (Table 2.3). Both of houses have the same layout as in Figure 2.1. House 1 is made according to the Finnish building regulations from 2012 and house 2 is more energy efficient. The space heating energy, including also the energy for heating of supply air, is 57 kWh/m^2 for the house 1 and 18 kWh/m^2 for the house 2.

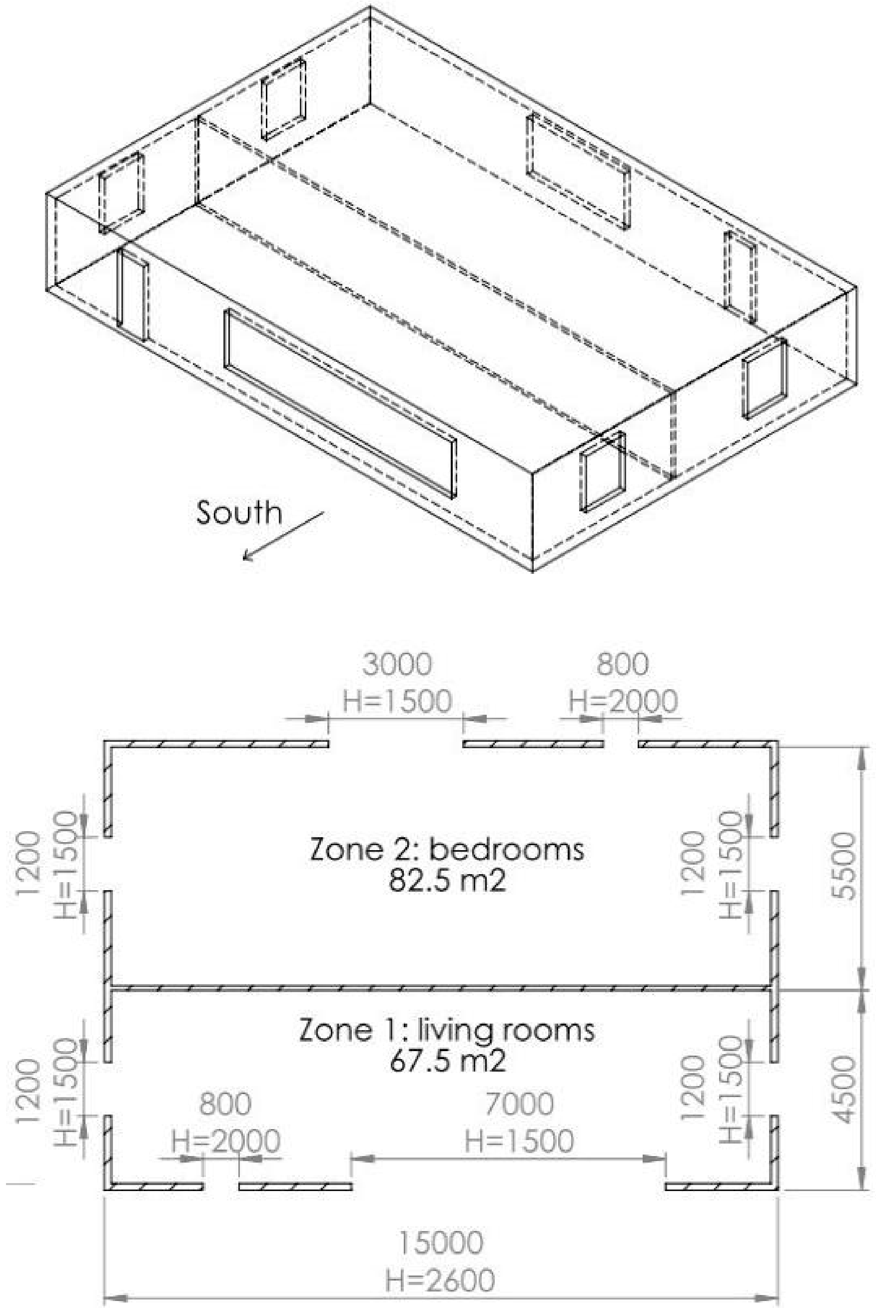


Figure 2.1. Simplified two-zone single-family house of calculations.

Table 2.2. Thermal performance demands of the buildings' envelope and ventilation according to Finnish building regulations of 1985, 2003 and 2012. For the 'near-zero energy building' ZnB the values are from the Villa Isover in Hyvinkää.

	Building regulation and year			
	C3 1985	**C3 2003**	**D3 2012**	**ZnB**
		U-value	**[W/m^{2}K]**	
Walls	0.28	0.25	0.17	0.10
Roof	0.22	0.16	0.09	0.06
Slab on ground	0.36	0.25	0.16	0.08
Suspended floor	0.22	0.20	0.17	0.09
Windows	2.10	1.40	1.00	0.80
Doors	0.70	1.40	1.00	0.75
		Ventilation		
Infiltration rate [1)	6 1/h (n_{50})	4 1/h (n_{50})	2 m^3/m^{2}h (q_{50})	0,5 m^3/m^{2}h (q_{50})
Efficiency of heat recovery	0%	30%	45%	75%
Air temperature				
Set point of heating	21 ^{o}C	**Set point of cooling** [2)		27 ^{o}C

1) n_{50} air change rate due to infiltration at 50 Pa pressure difference

q_{50} air flow rate/envelope area at 50 Pa pressure difference

2) RakMk D3 2012 (Energy performance of buildings, Regulations, 2012)

Table 2.3. Thermal insulation and heat recovery of the houses used in analysis.

House 1		
U-values		
External walls	0.17	W/m^{2}K
Roof	0.09	W/m^{2}K
Floor	0.16	W/m^{2}K
Windows	1.0	W/m^{2}K
Vent. heat recovery	45	%
Total space heating need	57	kWh/m^{2}a

House 2		
U-values		
External walls	0.10	W/m^{2}K
Roof	0.06	W/m^{2}K
Floor	0.08	W/m^{2}K
Windows	0.8	W/m^{2}K
Vent. heat recovery	75	%
Total space heating need	18	kWh/m^{2}a

The annual energy for space heating and mechanical ventilation has noticeably decreased from 24 MWh/a to 8 MWh/a (from 160 to 53 kWh/m^2 calculated per floor-area) due to the tightening of building regulations from the level of year 1985 to the level of year 2012. This concerns the improvement in thermal insulation, heat recovery from exhaust air and tightness of the envelope (Figure 2.2). At the same time, the need for mechanical cooling or effective solar shading and night ventilation in order to keep the interior temperature below 27 °C in summer has increased. When using the solutions of the Hyvinkää nearly zero energy building, the energy for space heating and mechanical ventilation is just 2.3 MWh/a (15 kWh/m^2), which is the demand of a passive house. In this case the reduced heat losses are mostly covered by internal and solar heat gains (Figure 2.3).

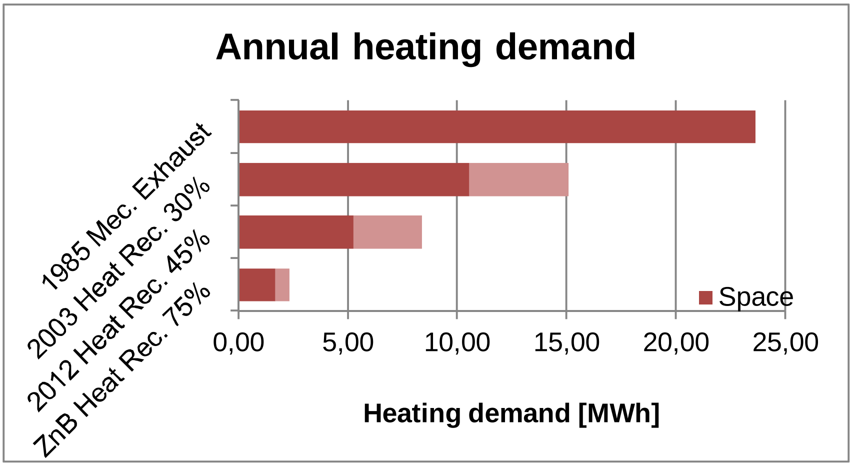


Figure 2.2. Total heating demand, including spaces and ventilation of supply air, for the two-zone single-family house according to the Finnish building regulations of years 1985–2012 and for a ZnB-building at Hyvinkää (Viot et al., 2013b).

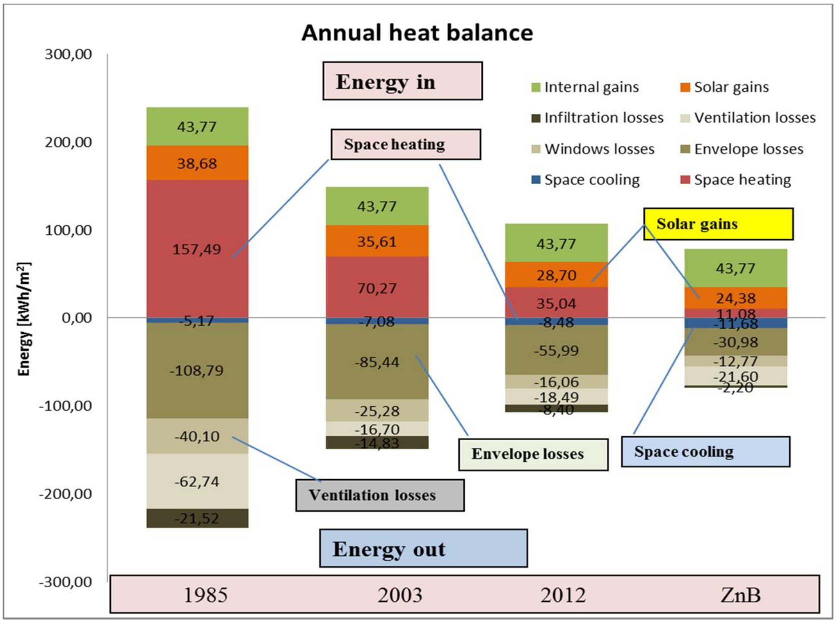


Figure 2.3. Annual heat balance of the two-zone single-family house according Finnish building regulations 1985–2012 and the ZnB-building.

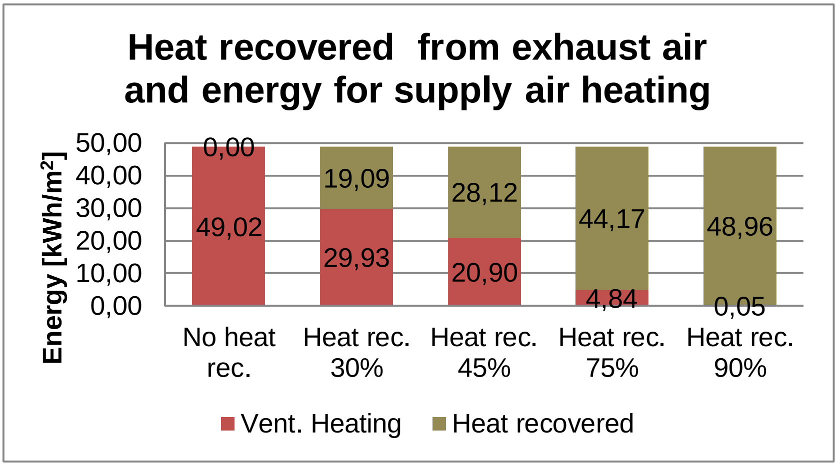


Figure 2.4. Effect of the performance of the heat recovery system on the demand for supply air heating and heat recovered from exhaust air for the two-zone single-family house. The protection against freezing is not taken into account.

The main factor in reducing the energy consumption has been the improvement of the heat recovery from exhaust air (Figure 2.4). The solar shadings and night cooling effectively reduce the air temperatures in summertime and the need for mechanical cooling (Figures 2.5 and 2.6). The thermal mass effects to some extent on the cooling demand.

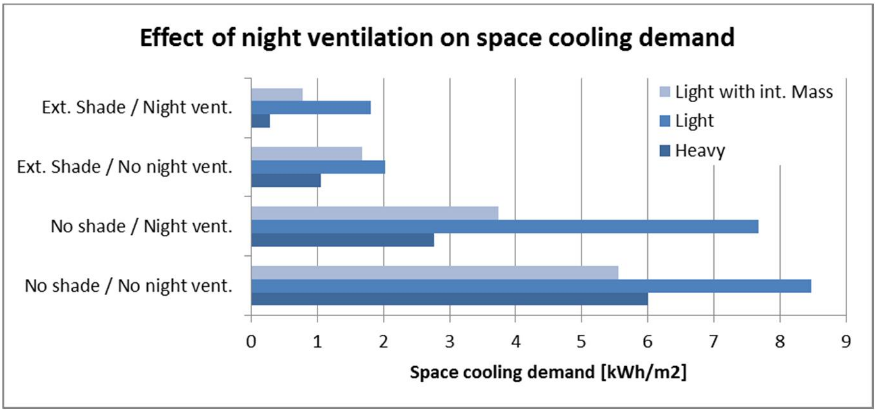


Figure 2.5. The effect of external shadings, night ventilation and thermal mass on the space cooling demand (Viot et al., 2013b).

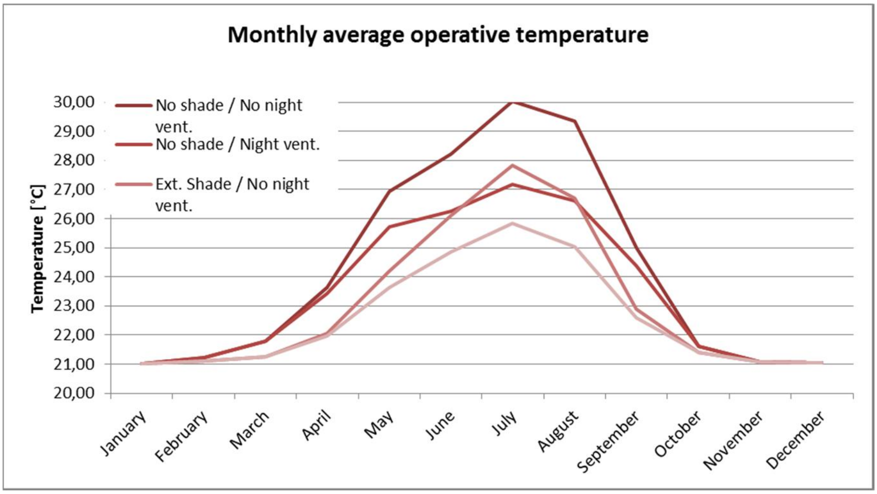


Figure 2.6. Effects of shadings and night ventilation on the monthly average operative temperature of the living room. Light structures (Viot et al., 2013b).

2.2.2 Buildings energy systems

Three basic energy sources, district heating, ground heat pump and exterior air heat pump, supplemented in some cases with a 6 m^2 solar water collector and 300 or 700 dm^3 hot water storage, were used in the analysis (Figures 2.7 and 2.8). In air heat pump heating part of the energy is in addition produced with electric heating (Table 2.4). Two small houses (Figure 2.1, Table 2.3) were used in calculations. In the former the thermal insulation is according to the building regulations of the year 2012, and in the latter improved from that. The modelling is detailed by Viot et al. and Hilpinen (Viot et al., 2013a and Hilpinen, 2015).

The coefficient of performance (COP) of heat pumps depends on their quality and the temperatures of the heat source and the heat sink (Table 2.5). In the modelling of the performance of heat pumps, the data of heat pumps' producers have been utilized. The borehole heat sink is modelled according to the model by Eskilson (Eskilson, 1987).

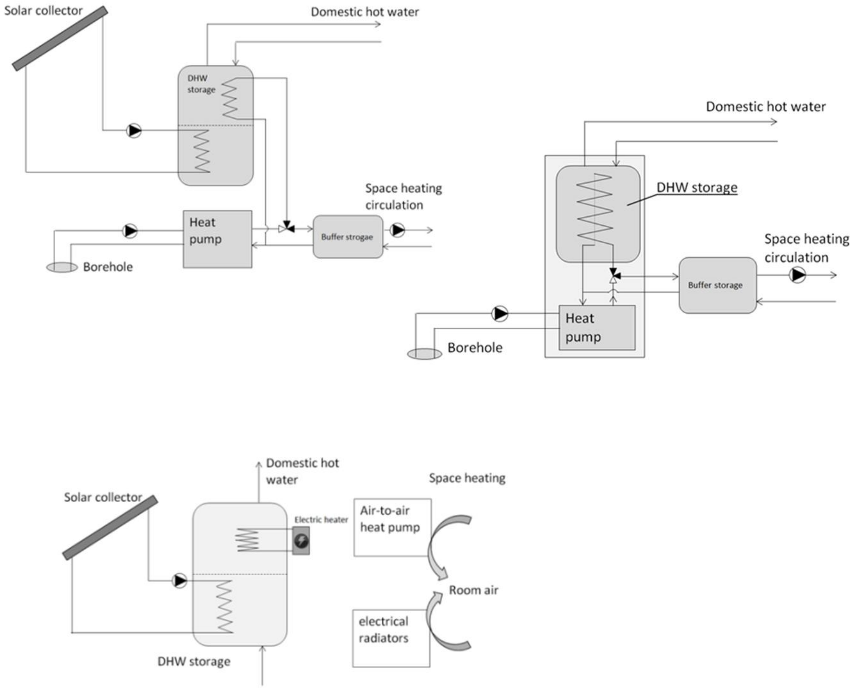


Figure 2.7. Heat pump systems.

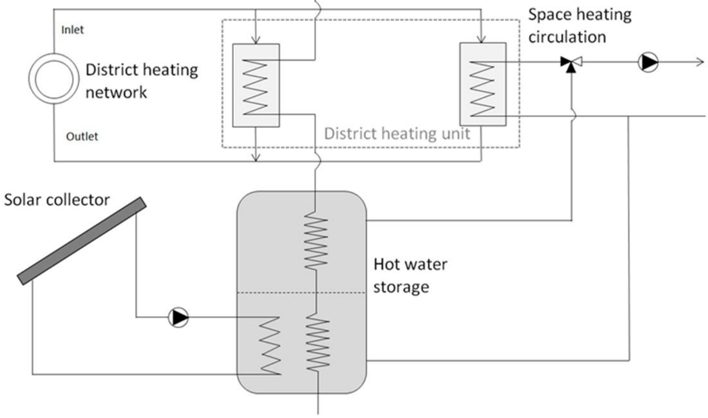


Figure 2.8. District and solar heating.

Table 2.4. Heating systems studied for house 1 made according to the building regulations 2012.

Heating system's name	**System details**
District heating	District heating system
District + solar heating	District heating system with flat plate solar collector (6 m^2) and 300 dm^3 hot water storage
Air-to-air heat pump + solar heating	Air-to-air heat pump (3.65 kW) with flat plate solar collector (6 m^2) and 300 dm^3 hot water storage
Ground heat pump	Ground heat pump (6 kW) with an integrated 180 dm^3 hot water storage
Ground heat pump+ solar heating	Ground heat pump (6 kW) with flat plate solar collector (6 m^2) and 700 dm^3 hybrid storage

A high quality flat plate solar collector was used in calculations (Figure 2.9). Its efficiency can be presented (Duffie & Beckman, 2006) as a function of the ratio temperature difference between the incoming fluid and the exterior air and the incident solar radiation. Figure 2.9 presents as a comparison also the efficiency of two evacuated tube solar collectors and a poorer quality flat plate collector.

Two sets of solar collectors were used in calculations. There was both a flat plate collector and an evacuated tube collector from which there was both a high quality one and normal quality one (Figure 2.9).

Table 2.5. The values of coefficients of performance (COP) for the two heat pump types in relation to the temperatures of the heat source and the heat sink.

Coefficient of performance						
Ground heat pump			Exterior air heat pump			
	Temperature of heat source					
Temperature of heat sink	0 °C	5 °C	-20 °C	-10 °C	0 °C	10 °C
35 °C	4.6	5.1				
55 °C	2.9	3.2				
20 °C			1.8	2.4	3.1	4.0

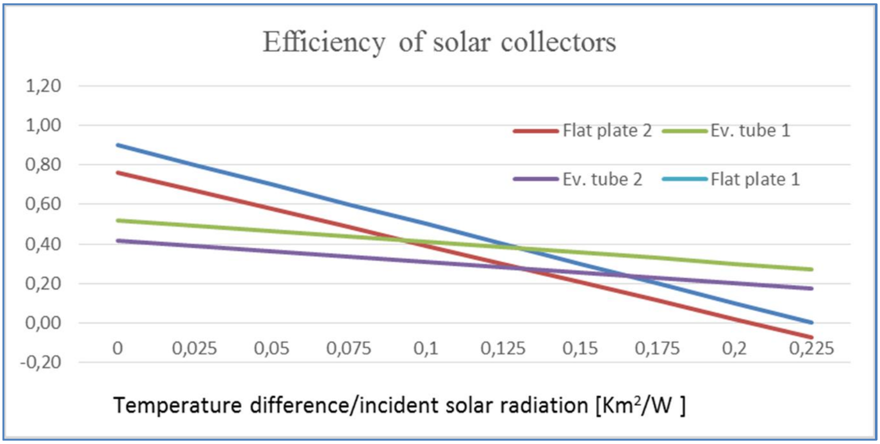


Figure 2.9. Efficiency of solar collectors. 1 high quality, 2 normal quality.

Depending on the heat losses of heating systems, the annual energy demand for the single-family house built according the regulations of year 2012 are 103–108 kWh/m^2. This includes the space, supply air and hot water heating (Table 2.6). For the house having an improved insulation and heat recovery, the corresponding values are approximately 62 kWh/m^2 (Table 2.7). The annual efficiency of the solar collector is 40–50% due to the fact that high a quality solar collector is used.

Table 2.6. Energy consumption of various systems in house 1 (energy performance according to the level of year's 2012 regulations).

House 1: **Heating system**	**Heat produced [kWh/m^2]**				Efficiency of collector[1] [%]
	District heating	Heat pump	Electric heating	Solar collector	
District heating	108.3	0.0	0.0	0.0	
District + solar heating	87.0	0.0	0.0	20.8	50
Air-to-air heat pump + solar heating	0.0	40.9	40.8	20.8	47
Ground heat pump	0.0	99.7	4.3	0.0	
Ground heat pump + solar heating	0.0	86.4	0.4	18.7	42

[1] High quality plate collector of Figure 9

Table 2.7. Energy consumption of various systems in house 2 (energy performance improved from the level of year's 2012 regulations).

House 2: **Heating System**	**Heat produced [kWh/m^2]**				Efficiency of collector[1] [%]
	District heating	Heat pump	Electric heating	Solar collector	
District heating	61.9	0.0	0.0	0.0	
District + solar heating	41.9	0.0	0.0	19.7	47
Air-to-air heat pump + solar heating	0.0	19.4	19.9	20.8	47
Ground heat pump	0.0	58.6	0.9	0.0	
Ground heat pump + solar heating	0.0	43.9	0.0	17.4	38

[1] High quality plate collector of figure 9

The electricity consumption of houses is separated into three categories. The first is the electricity consumption of the compressor of the heat pump excluding the borehole circulation pump of the ground heat pump. The second one is auxiliary electricity, which includes the electricity consumption of circulation pumps (space heating, borehole and solar collector), ventilation fans and control systems.

Household electricity includes the consumption of lighting and appliances. Electric heating from Tables 2.6 and 2.7 is not included in Table 2.8.

The total energy consumption of the systems studied is approximately 50–140 kWh/m^2 including the district heating, when used, the electricity for heating, the auxiliary equipment and the household electricity. The consumption depends on the use of solar heating and the energy demand of space heating (house 1/house 2). The lowest purchased energy consumption (50 kWh/m^2) is in the ground heat pump system in house 2 supplemented with the solar collector. This is total electricity consumption. On the other hand, the highest energy consumption is in house 1 with district heating without solar heating (140 kWh/m^2). From this, the share of district heating is 108 kWh/m^2 and that of auxiliary energy and household energy 32 kWh/m^2.

The following conclusions can be drawn from Tables 6–8, when the consumption of auxiliary energy (9–13 kWh/m^2) is not taken into account:

- The energy saving obtained with the 6 m^2 of solar collectors is 20 kWh/m^2 in district heating and 6 kWh/m^2 in ground heat pump system. Thus, the efficiency of the ground heat pump noticeably reduces the efficiency of solar heating.
- The benefit of reducing the heat losses (changing house 1 to house 2, Table 2.3) is with district heating 45 kWh/m^2, with an exterior air heat pump 27 kWh/m^2 and with a ground heat pump 12 kWh/m^2. Also, here multiple energy saving methods (heat pump, thermal insulation) can be clearly seen to reduce the effect of each other.
- The reduction of energy consumption when changing district heating to ground heat pump heating is in house 1, 79 kWh/m^2 and in house 2 slightly over half from that, 44 kWh/m^2.

The consumption of district heating is 42–108 kWh/m^2 depending on the house and the use of solar heating. The electricity consumption for heating (compressor + electric heating in air heat pump system) is 12–52 kWh/m^2 depending on the system (air heat pump/ground heat pump, solar heating and house 1 or 2. With complex systems, the energy consumption can be reduced very low (Table 2.9).

The energy efficiency numbers (E-number) are 80–140 kWh/m^2 and the corresponding energy performance ratings are B–C according to Finnish building regulations. The primary energy coefficients are for electricity 1.7 and for district heat 0.7.

Table 2.8. Electricity consumption of heating systems.

House 1 **Heating system**	**Electricity**		
	Compressor **kWh/m^2**	**Auxiliary** **kWh/m^2**	**Household** **kWh/m^2**
District heating	0.00	10.5	22.8
District + solar heating	0.00	11.6	22.8
Air-to-air heat pump + solar heating	11.0	9.0	22.8
Ground heat pump	28.8	11.9	22.8
Ground heat pump + solar heating	23.5	12.9	22.8

House 2 **Heating system**	**Electricity**		
	Compressor **kWh/m^2**	**Auxiliary** **kWh/m^2**	**Household** **kWh/m^2**
District heating	0.00	10.5	22.8
District + solar heating	0.00	11.7	22.8
Air-to-air heat pump + solar heating	5.2	9.0	22.8
Ground heat pump	18.3	11.9	22.8
Ground heat pump + solar heating	12.3	12.8	22.8

Table 2.9. E-numbers and energy performance rating.

House 1 **Heating system**	**E-number** **kWh/m^2**	**Energy perfor-mance** **rating**	**Bought electricity kWh/m^2**	**Bought heat kWh/m^2**
District heating	**132**	**C**	33.3	108.3
District + solar heating	**119**	**B**	34.4	87.0
Air-to-air heat pump + solar heating	**142**	**C**	83.6	0.0
Ground heat pump	**115**	**B**	67.7	0.0
Ground heat pump + solar heating	**101**	**B**	59.5	0.0

House 2 Heating system	E-number kWh/m²	Energy perfor-mance rating	Bought electricity kWh/m²	Bought heat kWh/m²
District heating	**100** *(-24%)* [1)]	**B**	33.3	61.9
District + solar heating	**88** *(-26%)*	**B**	34.4	41.9
Air-to-air heat pump + solar heating	**97** *(-31%)*	**B**	56.9	0.0
Ground heat pump	**92** *(-20%)*	**B**	54.0	0.0
Ground heat pump + solar heating	**81** *(-20%)*	**B**	47.9	0.0

[1)] Reduction of E-number compared with the house 1

2.2.3 Multicriteria optimization

It is possible to reduce the energy consumption to a very low level reducing heat losses and improving the performance heating and ventilating devices. For a certain energy consumption level, there are solutions which have the lowest total costs (investments + energy costs). These solutions are pareto-optimal solutions and can be found using multi-criteria optimization.

For optimization cost data is needed. Prices given here do not include taxes, but a 24% VAT is included when calculating the results. The life cycle cost of the building includes the energy costs for a 25-year period with an interest rate of 4%. Energy prices are assumed to be constant for the whole calculation period. The costs are additional costs compared with the basic case, which is defined by the building regulations of the year 2012.

Genetic algorithm (GA) of MATLAB was used to find pareto-optimal costs and E-numbers for the single-family house of Figure 2.1. Population size was 100 and the number of generations was 80 for all cases. The costs include investment costs for relevant building parts and systems as well as the energy costs for a 25-year time period. Design variables are U-values of exterior walls, roof, floor and windows, air tightness of building (infiltration), efficiency of ventilation heat recovery, the area of flat plate solar collector (high quality one) and the heating system. The cost data of calculations is given in Table 2.10 and the range of design variables in Table 2.11.

Table 2.10. Costs used in optimization. Prices don’t include 24% VAT except for energy prices.

Structures		
External walls (U= 0.17 | 0.13 | 0.08 W/Km^2)	146.8 | 153.7 | 234.7	€/wall-m^2
Roof (U= 0.09 | 0.07 | 0.05 W/Km^2)	77.2 | 84.5 | 91.8	€/roof-m^2
Floor slab (U= 0.16 | 0.13 | 0.10 W/Km^2)	42.0 | 49.0 | 61.6	€/floor-m^2
Windows (U continuous)	$134.9 \cdot U^{-1,168}$	€/window-m^2
Tightness ($q_{50} = 4 \mid 2 \mid 0.6$ m^3/m^{2}h)	450 | 900 | 2100	€
HVAC-system		
Ventilation		
Efficiency of heat recovery (65% | 80%)	2100 | 2500	€
Ground heat pump		
6 kW unit	5200	€
6 kW unit with integrated 180 dm3 DHW storage	5700	€
Installation (+ if external storage)	2000 (+ 800)	€
Borehole	28	€/m
Air to air heat pump		
3.65 kW unit	950	€
Installation	600	€
District heating		
Connection cost	2180	€
District heating unit	3150	€
Installation	400	€
Solar collector system		
2m^2 solar collector (Savo Solar SF100)	475	€
Other equipment	790	€
Installation	800	€
Energy (includes all taxes)		
Electricity	154	€/MWh
District heat	68	€/MWh

DBES was used to calculate the E-number for all the solutions tested. Two objective functions, the total costs and the E-number, make this a multi-criteria optimization problem and therefore there is not one optimal solution but a group of solutions that are not dominated by others (pareto solutions).

The lowest E-numbers (also smallest purchased energy consumptions) are obtained with the ground heat pump system supplemented with solar heating and the lowest costs with the exterior air heat pump system supplemented with solar heating. District heating has never lowest E-number or lowest costs for the 150 m^2 studied (Figure 2.10). The pareto-optimal E-numbers vary from 80 to 120 kWh/m^2 and the costs from 600 to 800 €/m^2. Table 2.12 presents details of some of the pareto-optimal solutions for the systems studied.

Table 2.11. Design variables.

Design variables	U-value[1]				Infiltration q_{50}	Efficiency of heat recovery	Area of solar collector
	Wall W/Km^2	Roof W/Km^2	Floor W/Km^2	Window W/Km^2	m^3/m^2h	%	m^2
Lower bound	0.08	0.05	0.10	0.50	0.60	65	0
Upper bound	0.17	0.09	0.16	1.00	4.00	80	12

[1] *Discrete variables with 0.01 W/m^2K steps.*

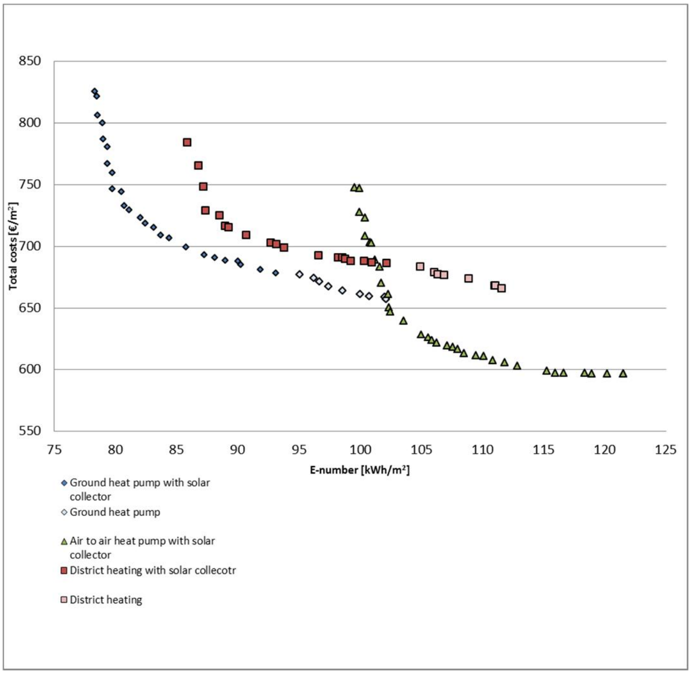
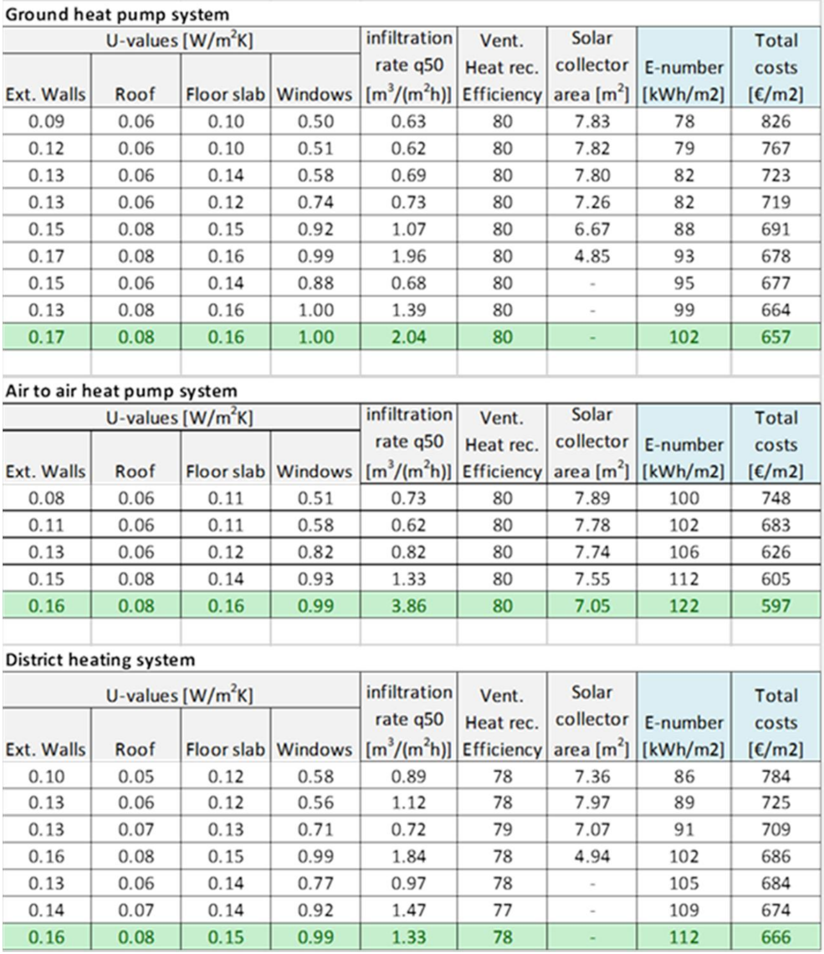


Figure 2.10. Pareto-optimal solutions for total costs and E-number.

The solution for achieving the rating A and the E-number 80 kWh/m^2 with a ground heat pump, solar heating and an energy efficient building is approximately 30% more expensive than the pareto-optimal solution with an exterior air heat pump, solar heating and a house with moderate energy efficiency (Figure 2.10).

Table 2.12. Pareto-optimal solution for different heating systems.Cost-optimal solutions marked in green (Hilpinen, 2015).



Ground heat pump system

U-values [W/m^{2}K]				infiltration rate q50 [m^3/(m^{2}h)]	Vent. Heat rec. Efficiency	Solar collector area [m^2]	E-number [kWh/m2]	Total costs [€/m2]
Ext. Walls	Roof	Floor slab	Windows					
0.09	0.06	0.10	0.50	0.63	80	7.83	78	826
0.12	0.06	0.10	0.51	0.62	80	7.82	79	767
0.13	0.06	0.14	0.58	0.69	80	7.80	82	723
0.13	0.06	0.12	0.74	0.73	80	7.26	82	719
0.15	0.08	0.15	0.92	1.07	80	6.67	88	691
0.17	0.08	0.16	0.99	1.96	80	4.85	93	678
0.15	0.06	0.14	0.88	0.68	80	-	95	677
0.13	0.08	0.16	1.00	1.39	80	-	99	664
0.17	0.08	0.16	1.00	2.04	80	-	102	657

Air to air heat pump system

U-values [W/m^{2}K]				infiltration rate q50 [m^3/(m^{2}h)]	Vent. Heat rec. Efficiency	Solar collector area [m^2]	E-number [kWh/m2]	Total costs [€/m2]
Ext. Walls	Roof	Floor slab	Windows					
0.08	0.06	0.11	0.51	0.73	80	7.89	100	748
0.11	0.06	0.11	0.58	0.62	80	7.78	102	683
0.13	0.06	0.12	0.82	0.82	80	7.74	106	626
0.15	0.08	0.14	0.93	1.33	80	7.55	112	605
0.16	0.08	0.16	0.99	3.86	80	7.05	122	597

District heating system

U-values [W/m^{2}K]				infiltration rate q50 [m^3/(m^{2}h)]	Vent. Heat rec. Efficiency	Solar collector area [m^2]	E-number [kWh/m2]	Total costs [€/m2]
Ext. Walls	Roof	Floor slab	Windows					
0.10	0.05	0.12	0.58	0.89	78	7.36	86	784
0.13	0.06	0.12	0.56	1.12	78	7.97	89	725
0.13	0.07	0.13	0.71	0.72	79	7.07	91	709
0.16	0.08	0.15	0.99	1.84	78	4.94	102	686
0.13	0.06	0.14	0.77	0.97	78	-	105	684
0.14	0.07	0.14	0.92	1.47	77	-	109	674
0.16	0.08	0.15	0.99	1.33	78	-	112	666

2.2.4 Cost-efficiency of energy saving measures

Energy should be saved cost-effectively. Optimisation is a method of finding cost-effective energy saving methods. The optimal thermal insulation level the building's envelope can be optimised when the unit costs of insulation are known. The thermal insulation of exterior walls is clearly more expensive than that of roofs and floors. There are two reasons for this. First, the thermal insulation of exterior walls increases the areas of the floor and the roof which is an additional cost due to additional insulation. Second, in the exterior walls there are necessarily new frame structures for certain insulation thickness. The unit costs of thermal insulation calculated per insulation volume are approximately from 100–500 €/m^3 (Table 2.13) (Calculation of cost optimal, 2012, Kalema, 2001–2002, Kalema et al., 2014). The unit cost of windows calculated per the area of the opening is 150–350 €/m^2 depending on the U-value (Figure 2.11). The costs of the heating and ventilating devices and the tightening of the envelope are presented in Table 2.14.

Table 2.13. Unit costs of thermal insulation/insulation volume.

Unit costs of thermal insulation		
Exterior wall	500	€/m^3
Floor	150	€/m^3
Roof	100	€/m^3

Table 2.14. Costs of systems and tightening of the envelope.

Equipment / Measure	Cost [€]
Electric heating	3000
Ground heat pump including the ground collector	20000
Exterior air heat pump + solar heating with a 6 m^2 collector	8000
Heat recovery device, efficiency 45/80%	2600/3100
Tightening of the envelope [q_{50}] from 4 to 0.5 m^3/(m^{2}h)	2600

The values for the interest and the length of the analysis period are 4% and 40 years. The price of electricity is constant 15 s/kWh. The energy consumption is calculated using the monthly method of the standard EN 13790 (Energy performance of buildings, 2008) and EN 13370 (Thermal performance, 2007). The building is the one of Figure 2.1. The optimisation is done with the non-linear optimisation method of the Solver of MsExcel (Kalema, 2001–2002).

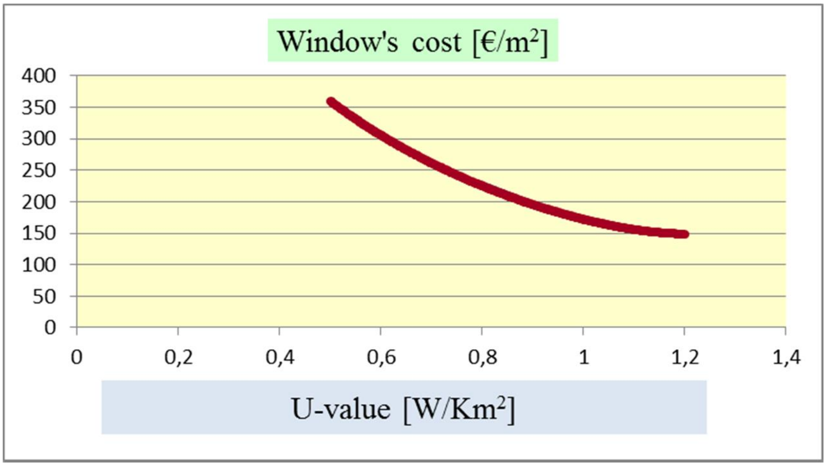


Figure 2.11. Unit costs of windows as a function of the U-value.

The total costs of the building with a ground heat pump system with an optimized envelope are approximately 25% lower than those with the electric heating. The total costs of the building with an optimized envelope and the ground heat pump are approximately 15% lower than those of the building having the envelope fulfilling the demands of Finnish building regulations (reference U-values). The reason is naturally that the fixed reference values cannot be optimal for all cases (Figure 2.12). The building fulfilling the passive house requirement (annual space heating need 15 kWh/m^2) is clearly a more expensive alternative than the house with the ground heat pump.

For electric heating, the optimal U-values of the floor and the roof are near the reference values of the year 2012, but for the exterior walls they are higher than the reference values (Figure 2.13). With an insulation cost of 500 €/m^3, the optimal U-value of exterior walls seems to be 40% higher than the reference value 0.17 W/Km^2 for electric heating. For heat pump heating, the optimal U-values of insulated structures are approximately doubled with the reference values (Figure 2.13).

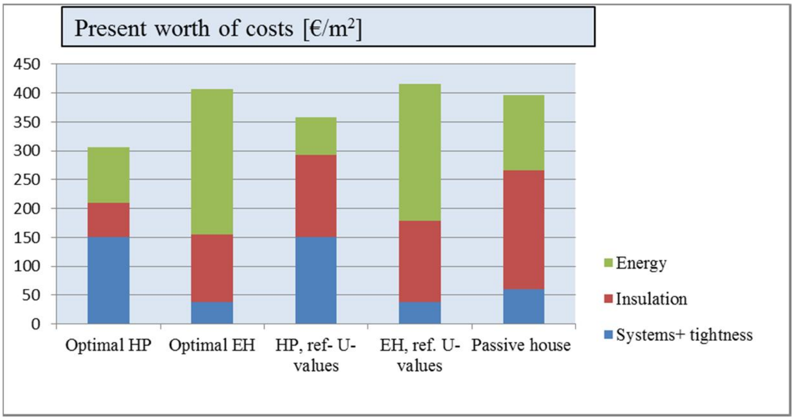


Figure 2.12. Total costs for two heating systems with an optimal envelope and the envelope with the reference values of Finnish building regulations. Last case is a building fulfilling the passive house demand with electric heating.

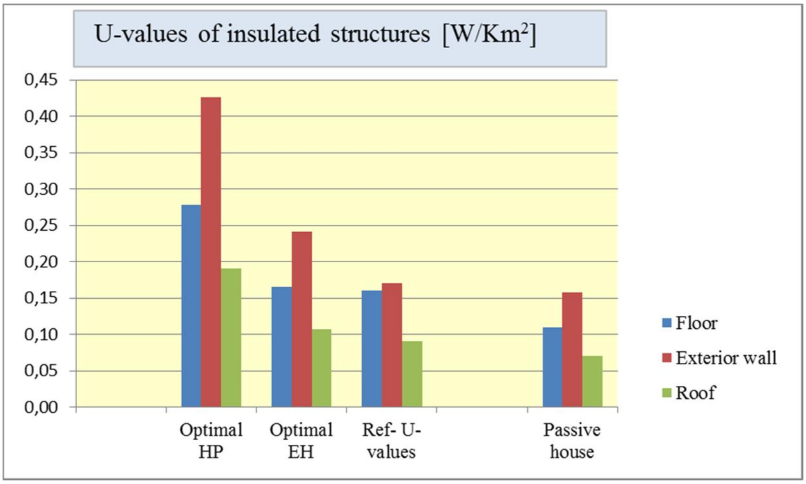


Figure 2.13. Optimal, reference and passive house level U-values of insulated structures for two heating systems (ground heat pump HP and electric heating EH).

The reference U-value of building regulations 1.0 W/Km^2 for windows is near the optimal one with the cost function of Figure 2.11. In electric heating the optimal U-value is approximately 0.8 W/Km^2 and in heat pump heating approximately 1.1 W/Km^2. In a passive house, the windows' U-value must be very low (0.5 W/Km^2) in order to achieve the space heating demand 15 kWh/m^2, and thus their price is high (Figure 2.14).

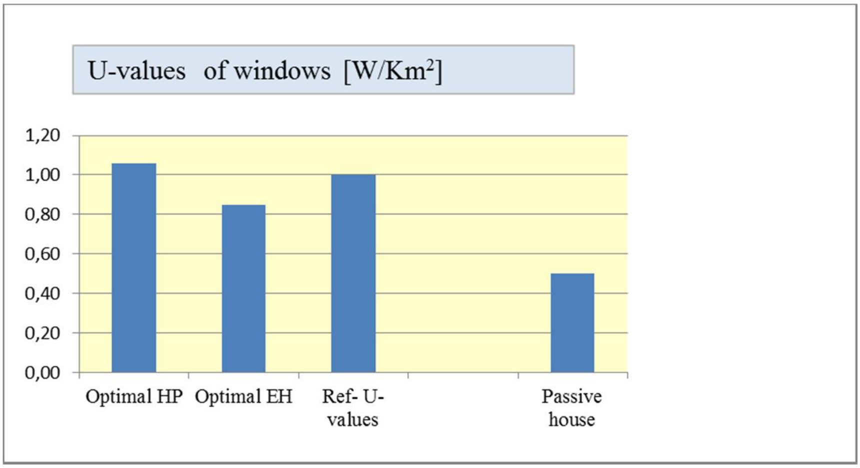


Figure 2.14. Optimal, reference and passive house level U-values of windows for two heating systems (ground heat pump HP and electric heating EH).

The basic values for the interest and the calculation period are 4% and 40 years. When a shorter calculation period and a higher rate of interest are used (20 years and 5%), the optimal average U-value of the envelope increases by 20% from 0.20 W/Km^2 to 0.24 W/Km^2 when electric heating is used. If a longer calculation period and a lower rate of interest are used (50 years and 2%), the corresponding decrease of the average U-value is 15% from 0.20 W/Km^2 to 0.17 W/Km^2.

In heat pump heating, the 50 years calculation period and the low 2% interest lead to a 15% lower optimal average U-value than the basic case. Depending on the calculation period and the interest, the total costs with the heat pump heating and an optimal envelope are 15–45% lower than with electric heating.

The cost efficiency of the measures studied, investment cost/annual energy saving, is 0.4–4.8 €/kWh. Generally the investments in heating and heat recovery devices are the most advantageous ones. The improvement of the exterior walls' and roofs' U-values from the reference values are the most expensive alternatives. In exterior walls, the unit cost of insulation is high and in roofs the marginal benefit of increasing the insulation thickness from approximately 350 mm (U-value 0.09 W/Km^2) is small. The best cost efficiency is obtained when the investment cost is low and the energy saving high, which is the case with heat recovery systems and exterior air heat pumps.

Table 2.15. Cost efficiency of various energy saving methods. Basic heating is electric heating.

Change	Cost efficiency €/kWh
Change from electric heating to ground heat pump[1)]	2.0
Change from electric heating to air heat pump + 6 m^2 solar collector [2)]	1.3
Improvement of floor's U-value 20%	2.5
Improvement of exterior walls' U-value 20%	4.8
Improvement of roof's U-value 20%	3.5
Improvement of windows' U-value 20%	2.5
Improvement of tightness of envelope from 4 to 0.5 $m^3/(m^2 h)$	1.8
Improvement of efficiency of heat recovery from 0 to 80% (electric heating)	0.4
Improvement of efficiency of heat recovery from 0 to 80% (heat pump heating)	1.7

[1)] COP 3.6

[2)] Energy consumption calculated with DBES-model, COP 3.7

2.3 Modelling solar thermal collectors

Steps have been taken to develop an operational simulation model for a flat-plate solar thermal collector (Figure 2.15). This model is part of a wider modelling effort for distributed energy production that incorporates a wide variety of distributed energy generation technologies as well as modules for simulating energy consumption in housing. The purpose of this model is to facilitate investigation of system performance and the effect of solar thermal collectors for district heating or distributed energy production in general.

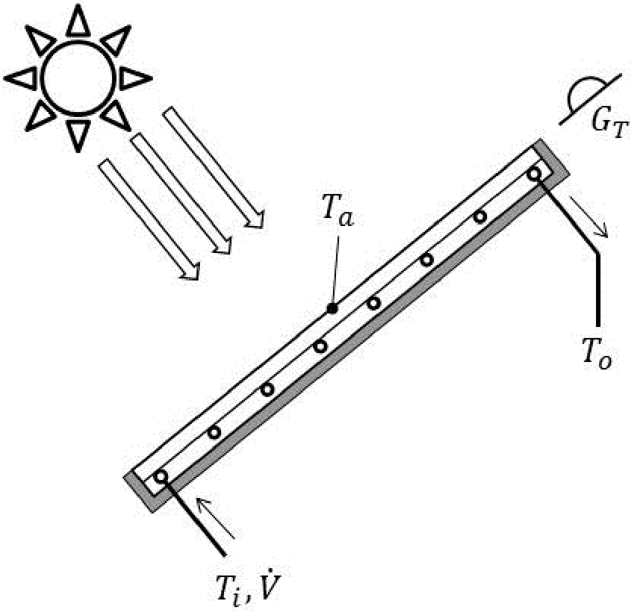


Figure 2.15. Schematic of a basic flat-plate solar collector.

Solar collector testing

In the procedure for collector evaluation, the key point is the determination of the parameters of a model capable of satisfactorily describing the energy behaviour of the collector. In this study, it is assumed that the behaviour of the collector can be described by a 3-parameter steady-state model:

$$\eta = \eta_0 - a_1 T_m^* - a_2 G_T (T_m^*)^2. \tag{2.1}$$

The basic scope of solar collector testing is the determination of the collector efficiency η by conducting measurements under specific conditions defined by international standards such as

- EN ISO 9806. Solar energy – Solar thermal collectors – Test methods
- EN 12975. Thermal solar systems and components – Solar collectors
- ASHRAE 93. Methods of Testing to Determine the Thermal Performance of Solar Collectors
- ASHRAE 96. Methods to Testing to Determine the Thermal Performance of Unglazed, Flat Plate, Liquid Solar Collectors.

Considering these standards, it has been noted by European Solar Thermal Industry Federation (ESTIF) that “EN standards are often referenced in financial incentive programmes and building regulations.”

The thermal performance test characteristics (η_0,a_1,a_2) of a solar thermal collector certified according to European standard series EN 12975 can be obtained e.g. from the Solar Keymark Database in http://www.solarkeymark.dk/. The reduced temperature difference T_m^* is calculated with respect to the (arithmetic) mean collector fluid temperature T_m as follows:

$$T_m^* = (T_m - T_a)/G_T \ , \tag{2.2}$$

where T_a and G_T are the ambient temperature and the total solar irradiance at the collector aperture area A, respectively.

2.3.1 Simulation model for certified flat-plate collectors

The purpose of our simulation model is to estimate the fluid outlet temperature and furthermore the useful gain of the collector when we know

- the thermal performance characteristics (η_0,a_1,a_2)
- the fluid inlet temperature (T_i)
- temperature dependence of the fluid specific heat at constant pressure and density (c_p, ρ)
- climatic quantities obtained either from actual on-site measurements or from climatic models (T_a, G_T).

In the steady-state, the useful gain of the collector is given by

$$\dot{Q}_u = \dot{m} c_p (T_o - T_i), \tag{2.3}$$

where the fluid temperatures T_o and T_i are determined at the collector outlet and inlet, respectively. A value of c_p corresponds to the mean collector fluid temperature, and the fluid mass flow $\dot{m}$ through the collector is calculated by multiplying volumetric flow-rate $\dot{V}$ with the fluid density at the fluid inlet temperature, ρ.

Substituting eq. (2.3) into the definition of instantaneous efficiency η_i provides an expression that is the basis for our simulation model:

$$\eta_i = \frac{\dot{Q}_u}{AG_T} = \frac{\dot{m} c_p}{AG_T}(T_o - T_i). \tag{2.4}$$

We can rewrite eq. (2.4) in terms of the reduced temperature difference:

$$\eta_i = \frac{2\dot{m} c_p}{A}(T_m^* - T_m^0),$$

where

$$T_m^0 \equiv \frac{T_i - T_a}{G_T}.$$

While the outlet fluid temperature is not known, the specific heat can be evaluated at the inlet fluid temperature. The outlet fluid temperature is now solved by first setting eq. (2.1) equal to the rewritten equation for the instantaneous equation and then rearranging to obtain a quadratic equation whose positive solution for the reduced temperature difference gives an estimate for T_o. Since the initial estimate was calculated using the value of specific heat evaluated at the inlet fluid temperature, we can refine the result by using the calculated T_o to obtain a value of c_p that corresponds to the mean collector fluid temperature and then repeating the calculations. If necessary, these calculations can be repeated until the difference between successive estimates is small enough.

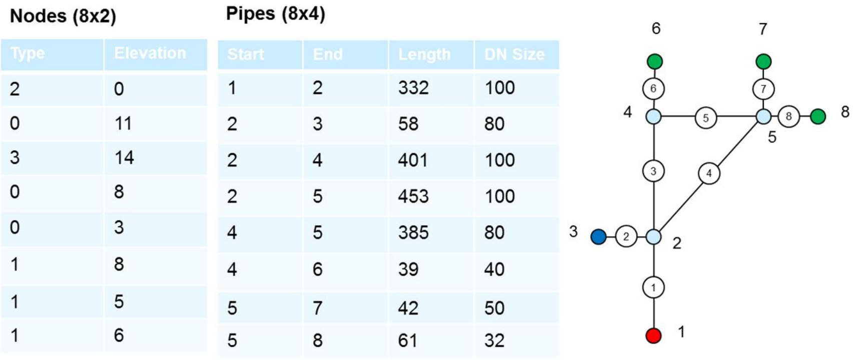
2.3.2 Model validation and results

The model has been validated using historical input data collected from a real-world collector system located in Central Finland. To measure the linear dependence between the measured and modelled daily instantaneous outlet temperatures we have calculated the Pearson product-moment correlation coefficient. Initial results show that there is positive correlation with a mean coefficient of 0.85±0.02 for clear-sky days between the measured and the modelled temperatures. The results indicate that the model works best while a system operating under steady-state conditions is being simulated.

2.4 Local heating network model

The local heat distribution network simulation modelling utilised in the project is based on network simulation model developed by VTT (Ikäheimo et al. 2005). It has been significantly modified to accommodate linking with dedicated models for production and consumption. The model runs in MATLAB environment and is a typical node-and-branch type of network model with dynamic temperature simulation.

The model requires information on the structure of the network; task of each node and start and end nodes for each pipe. The roles of the nodes can be consumer, connector or producer. Every node is also given elevation data. For the pipes and in addition to start and end nodes, lengths, sizes (DN), insulation standard (1, 2, 3 or 4) and type (Mpuk, 2Mpuk) the matrixes for both flow and temperature profile calculation are also defined. An example of this definition is shown in Figure 2.16.



Nodes (8x2)

Type	Elevation
2	0
0	11
3	14
0	8
0	3
1	8
1	5
1	6

Pipes (8x4)

Start	End	Length	DN Size
1	2	332	100
2	3	58	80
2	4	401	100
2	5	453	100
4	5	385	80
4	6	39	40
5	7	42	50
5	8	61	32

Figure 2.16. An example of structural network definition.

In normal operation of the original network simulation model, time series on demand are used to provide the necessary data for calculating the flow through each consumer. However, in the current case this is done by the dedicated consumer or building models. The network model provides the feed temperature and optionally the pressure difference during a single time step for the consumer model, which in turn calculates the flow and return temperature based on heating system setup in general, heat load and secondary side temperatures.

The mass flow at the producer node is a sum of the flows through every consumer. The model calculates the return temperature for each time step at the producer node, after which the required production of heat can be calculated in turn. The feed temperature is given as input.

2.4.1 Area simulation model

The area simulation model developed within the project is the outcome of an effort to combine several individual component models into a single tool with which a local small scale energy system could be simulated and analysed. The main focus was on heating, and the component models included solutions for heat supply, heat distribution network, consumer with storage and solar collector capabilities. Table 2.16 below lists and briefly describe the component models included.

Table 2.16. Component models included in the area simulation model.

Component	**Description**
Heat supply	Heat supply component includes a small scale CHP unit and a connection block linking the area with the main district heating system. Calculates e.g. production, efficiency and the flue gas composition for the unit as well as the heat flow into the area, the main system and, during periods of high solar heat input, surplus heat input into the main system.
Local heating network	Distribution network model calculates the flows, pressures, temperatures and heat losses for a defined network structure consisting of nodes and pipes. Nodes can be defined as consumers, producers or connecting nodes and the pipes are given length, type and size.
Consumer	Consumer model can be divided further into three closely linked parts. These are building, solar collector and heat storage. The building is given location, floor area, orientation and series of structural and technical parameters. Floor or radiator heating system can be defined as a method of distributing the heat. Volume and area is defined for the optional storage and solar collectors.

The area simulation model prepares the input data for each model, runs the models for a given time period, records the results of individual models and manages the communication between the models for during the simulation. The models were implemented as series of MATLAB functions and the area simulation model as a main script calling the component models as needed.

The input data includes model specific parameters, time series on e.g. heat demand and weather-related data such as outdoor temperature and solar irradiation. These data sets are processed and defined for respective component models. The input data requirements are described in more detail in specific chapters for each component model.

Figure **2**.17 describes the basic structure of the model including initial configuration (top), communication between the models (two-way arrows between the models, input and output data exchange listed) and the results (bottom).

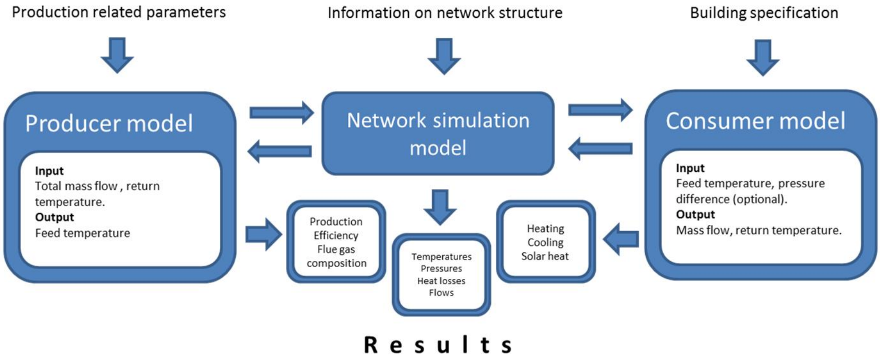


Figure 2.17. Basic structure for the area simulation model.

Simulated case example

In order to demonstrate the operation of the area simulation model, a typical Finnish low-heat demand area consisting of a group of detached houses and a district heating network for distributing the heating has been selected to act as a case example. Additionally, all the detached houses were equipped with solar collectors and an accumulator. Any surplus heat production was introduced into the district heating network. The area was connected to a larger district heating system, but a small CHP unit supplied the heat for the area during most of the year. The unit was shut down in the summer months, during which the main district heating system provided the necessary heating. The general setup with the system boundaries and a realistic representation of the network is illustrated in Figure 2.**18** below.

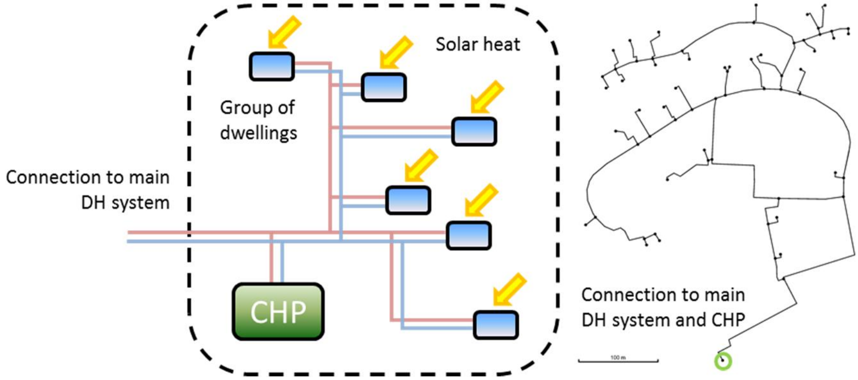


Figure 2.18. Illustration of the selected demonstration case example.

The simulated area included 30 dwellings with a floor area of 200 m^2 each. The collector area and heat storage volume for the dwellings were set to 300 l and 6 m^2, respectively. In addition to radiator heating, the dwellings were also equipped with heating and cooling by ventilation.

The heat distribution network in the area was approximately 2500 m long, with the pipe sizes based on the heat demand of the defined consumers. The supply temperature level for the area was kept constant at 85 °C, while the temperature of the main district heating network varied according to the outdoor temperature from 85 °C when the outdoor temperature was 8 °C or higher, and 115 °C when the temperature was -26 °C or lower.

The CHP unit modelled here was a small-scale combined heat and power (CHP) production unit developed by Ekogen Oy in collaboration with Lappeenranta University of Technology. An externally fired micro gas turbine (EFMGT) based production unit generated 100 kW of electricity and 300 to 600 kW of heat.

Results

The area studied consisting of detached houses was a low heat demand area and thus the efficiency of heat distribution network was expected to be low. However, introduction of solar collector-based heating in similar areas in the outlying regions of a district heating system can still be beneficial to the system as a whole due to savings in fuel in case where summer time heat load is supplied by boiler units. For this reason, it can be useful to position distributed or centralised solar heat in these outlying regions and let CHP- or boiler-based heat production supply heat for the more efficient parts of the system. The results given below show that the small detached house area studied could handle even more solar collector-based heat production.

Figure 2.19 below shows the heat demand of the area and solar heat surplus introduced into the network during the summer months. The peak demand within the area is 277 kW, and the maximum solar surplus 69 kW.

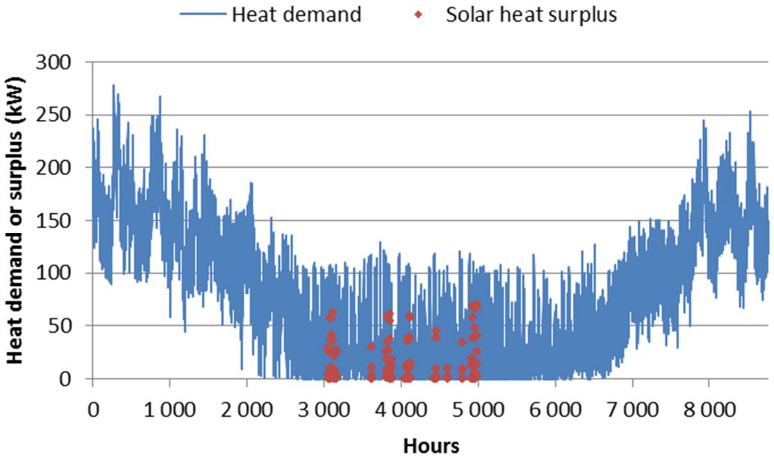


Figure 2.19. Heat demand and solar heat surplus for the area.

The Figure 2.20 shows the heat demand in units of energy (MWh) divided between heating and domestic hot water (DHW). Share of DHW of the MWh/m total consumption was approximately 20%. Heat losses of the distribution system are also added here. Yearly heat consumption with solar heat excluded is 568 MWh which, divided by network length, gives a heat density of 0.23 MWh/m.

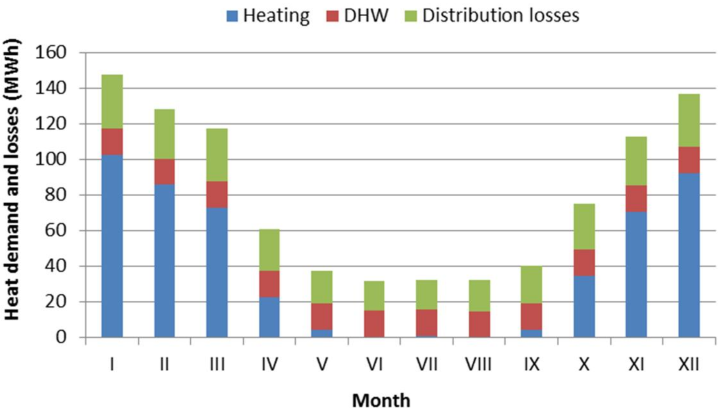


Figure 2.20. Heat losses and heat demand divided between heating and DHW.

Figure 2.21 below shows the distribution of heat sources. The local CHP unit supplies 792 MWh, main district heating system 63 MWh and solar collectors 103 MWh for the area.

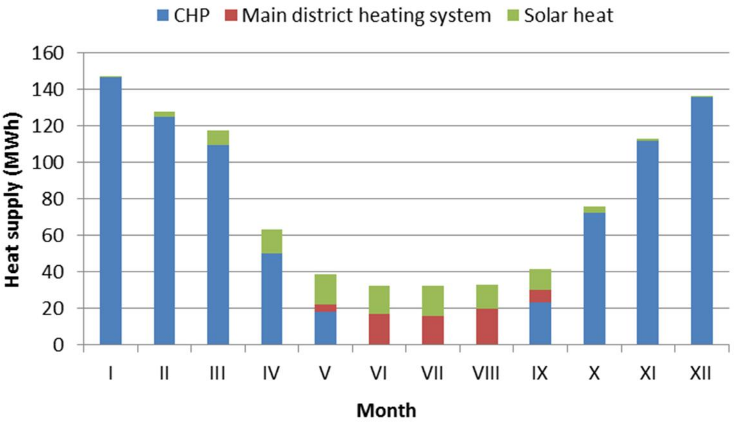


Figure 2.21. Distribution of heat sources utilised.

Figure 2.22 below presents the relative heat losses, i.e. losses per produced heat. On a yearly level, the heat losses are 285 MWh (33%), which is quite a high number. During the summer months, due to the solar collectors, the losses are over 100%, meaning that the heat losses are higher than the heat input by CHP or main district heating network. A total of 2.7 MWh is returned to the local heating network, and only 0.6 MWh is transferred to the main district heating system. Over 99% of solar heat is thus consumed within the area.

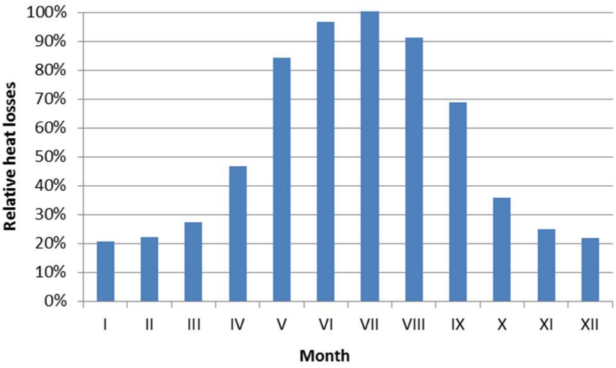


Figure 2.22. Monthly relative heat losses.

Especially during the summer months, a significant share of the consumption is supplied by the solar collectors. The monthly share of solar heat of total consumption within the area is shown in Figure 2.23 below. Solar heat corresponds to a 15% share of all heat consumption.

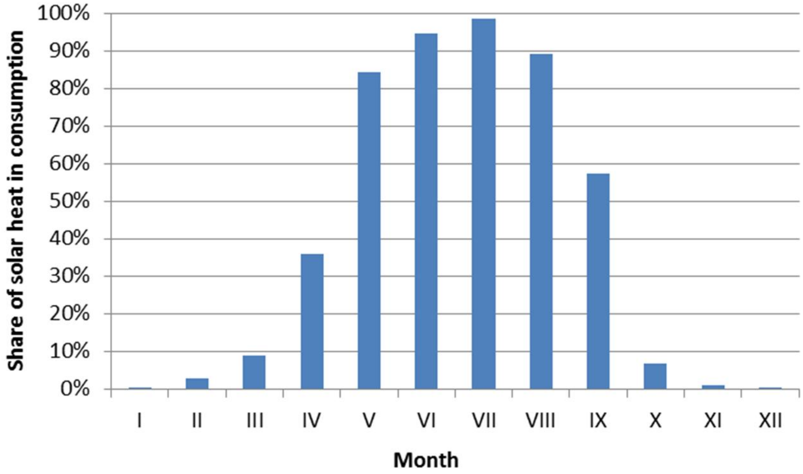


Figure 2.23. Share of solar heat in total consumption within the area.

Heat losses in the system are high, especially outside the heating season. This translates into very low distribution efficiency, and can make the system with solar collectors more energy efficient than a traditional setup due to savings in fuel.

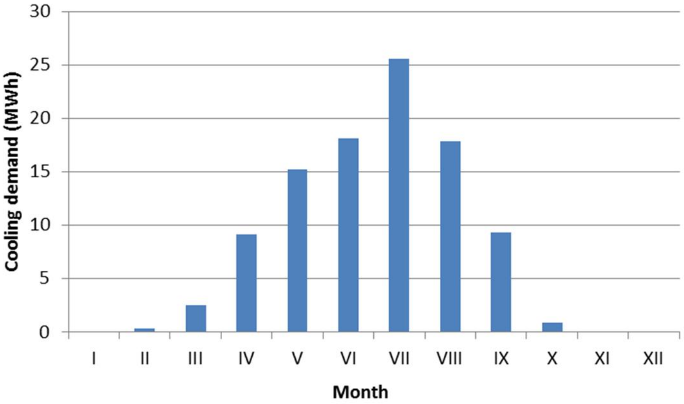


Figure 2.24. Cooling demand within the area.

Whether this is reasonable from an economic point of view depends on how heat is produced for the main district heating system and on the business model.

In addition to heating, the dwellings within the area are also equipped with cooling systems. In energy, the cooling demand is 15% of the heating demand, 99MWh. The monthly cooling demand is shown in Figure 2.24.

The area simulation model provides a tool for studying hybrid energy systems with consumers that can also produce heat for the surrounding system. It can also be considered a proven platform for connecting other MATLAB-based component models in the future.

2.5 Implemented Matlab-programs for geothermal energy and wind energies

Matlab software was selected for implementing energy evaluation models for borehole well and wind mills. The models are basic and thus suitable for general evaluation of energy amounts. The models are implemented as inline-functions as well as with graphical user interface.

2.5.1 Geothermal energy model for boreholes

The implemented geothermal energy model is suitable for evaluating the energy *Q* from a borehole well. The implemented formula is the following:

$$Q = 2\pi\lambda H\frac{To-Tb}{\ln\frac{H}{D}}, \qquad (2.5)$$

where

H = depth of the well
λ = thermal conductivity [W/m*K]
T_o = temperature of the wall of the borehole [K]
T_b = temperature of the intact soil [K]
D = diameter of the well [m]

The formula allows the simulation of both energy collection and storage. This is indicated by the sign of *Q*.

Geothermal energy model – inline implementation

The user calls the function Thermal Energy Borehole and gives 0-5 parameters. If zero parameters are given, then default values are used: 100 – Borehole depth, 0.5 – conductivity, 0.5 – Borehole diameter, 420 – temperature in K – borehole wall and 400 – temperature in K – soil.

Examples:

A. No parameters are given

```
ThermalEnergyBorehole

Q =  1.1859e+03
```

B. Two parameters, borehole diameter 0.3 and temperature of soil 380 are given

```
ThermalEnergyBorehole([],0.3,[],380,[])
Default value 100 is set to parameter H
Default value 420 is set to parameter To
Default value 5.000000e-01 is set to parameter lamda

Q =  2.1632e+03
```

C. All values are given

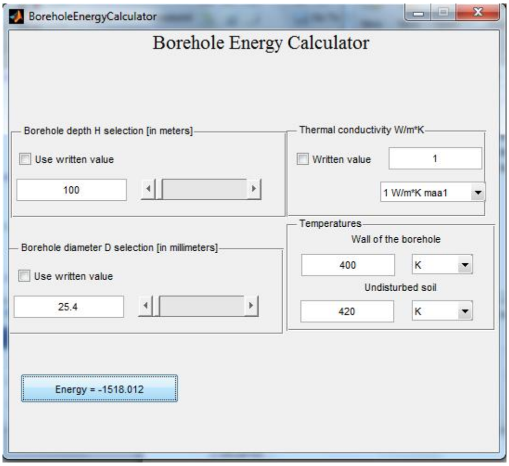
```
ThermalEnergyBorehole(200,0.3,360,380,0.4)

Q =  -1.5461e+03
```

Geothermal energy model – graphical user implementation

The user calls the function

```
>> BoreholeEnergyCalculator
```

and the graphical user interface opens (see Fig. 2.25). There the user can give own values or use default values. When the user pushes the Energy-button, the calculated values is shown there.



BoreholeEnergyCalculator

Borehole Energy Calculator

Borehole depth H selection [in meters]
☐ Use written value
100

Thermal conductivity W/m*K
☐ Written value 1
1 W/m*K maa1

Temperatures
Wall of the borehole
400 K
Undisturbed soil
420 K

Borehole diameter D selection [in millimeters]
☐ Use written value
25.4

Energy = -1518.012

Figure 2.25. Borehole Energy Calculator.

2.5.2 Wind energy model

The aerodynamic power P_a available in wind can be approximate using the following model:

$$P_a = \frac{1}{2} C_p A \cdot R_{air} v^3, \tag{2.6}$$

where

C_p = power factor (0.59)
A = swept area
R_{air} = density of air
v = wind speed

This model is simple but very useful and can be used as a rapid modeling.

Wind energy model – inline implementation

The user calls the function “Wind Energy” with 0-4 parameters. If zero parameters are given, then the default values are: 0.3 – power coefficient, pi*70*70 – Area of circle, radius 70 m (radius=length of a blade, 1.1839 – density of air kg/(m^3) and 3 – speed of wind, m/s.

Examples:

A. No parameters are given

```
>> WindEnergy

ans =  7.3810e+04
```

B. One parameter, wind speed is given

```
>> WindEnergy ([],[],[],5)

Default value 3.000000e-01 is set to parameter Cp
Default value 1.539380e+04 is set to parameter A
Default value 1.183900e+00 is set to parameter Rair

ans =  3.4171e+05
```

B. All parameters are given

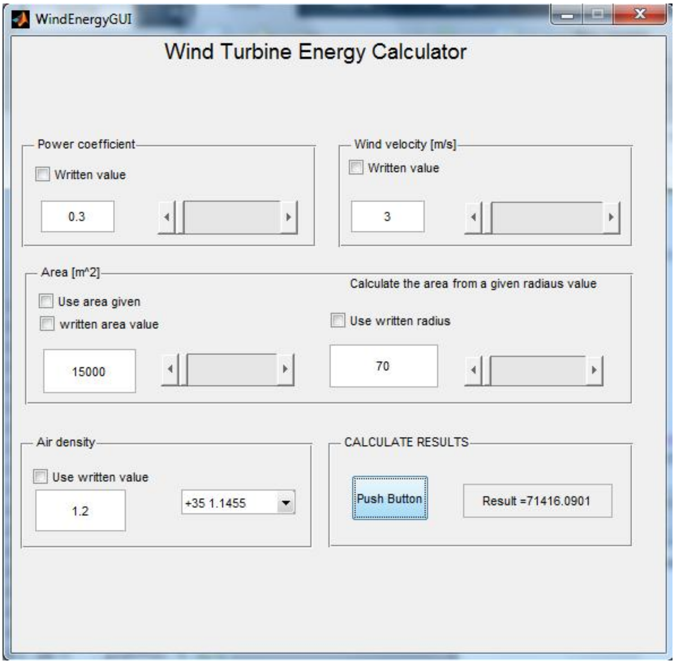
```
>> WindEnergy(0.4,pi*70*70,1.2,5)

ans =  4.6181e+05
```

Wind energy model – graphical user interface

The user calls the function Wind Energy GUI and the graphical user interface opens (Fig. 2.26). There the user can give own values or use default values.

When the user pushes Push Button, the calculated aerodynamic power is shown there.

```
>> WindEnergyGUI
```



Power coefficient
☐ Written value
0.3

Wind velocity [m/s]
☐ Written value
3

Area [m^2]
☐ Use area given
☐ written area value
15000

Calculate the area from a given radiaus value
☐ Use written radius
70

Air density
☐ Use written value
1.2
+35 1.1455

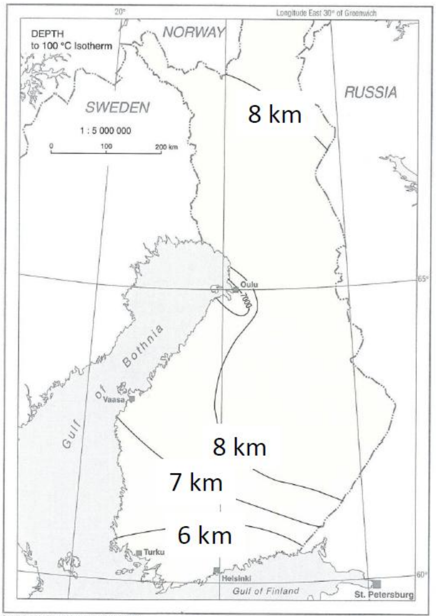
CALCULATE RESULTS
Push Button
Result =71416.0901

Figure 2.26. Wind Turbine Energy Calculator.

2.6 Engineered/enhanced geothermal system (EGS)

Geothermal energy has many apparent benefits, making it an excellent candidate to be an energy source of the future. Most importantly, it does not rely on burning fuel, and hence it is practically emission-free. Whereas wind power, for example, has a visible effect on the environment, geothermal energy lacks even this downside.

The real issue for deployment of geothermal energy on a large scale is the lack of adequate resource. The main obstacle limiting the use of geothermal energy is the lack of enough heat, but almost equally critical is to have fluid in the formation and permeability of the formation for fluid to penetrate. Engineered/enhanced geothermal system (EGS) describes a set of geothermal systems with less than optimum characteristics.



Commission of the European Communities EUR 17811, 2002

Figure 2.27. Depth of 100 °C isotherm in Finland. Kukkonen (2002), in Atlas of Geothermal Resources in Europe.
http://www.geoelec.eu/wp-content/uploads/2012/04/GEOELEC-BSA-GT-Electricity-Vilnius.pdf

The difference between an engineered and enhanced geothermal system is somewhat inconsistent in the literature. The usual way to differentiate the two is to call “enhancement” the lack of just one key parameter (heat, fluid and permeability) and “engineered” as the situation in which multiple key parameters are inadequate.

The limiting parameter of geothermal energy use in Finland is heat. Figure 2.27 shows the temperature isotherm of 100 °C in Finland. Finland is far from the edges of tectonic plates and therefore our continental crust (top layer of mantle) in Finland is old and cold. In order to produce electricity one would want to have at least 150°C temperatures. Electrical efficiency of such turbines is around 10%. Reaching 150°C would mean more than 50% deeper holes compared to the 100°C isotherm.

A good alternative is to try to produce heat instead of electricity. Heat is exchanged with a district heating network easily if the heat is over 100°C. In Finnish tariffs this appears economical.

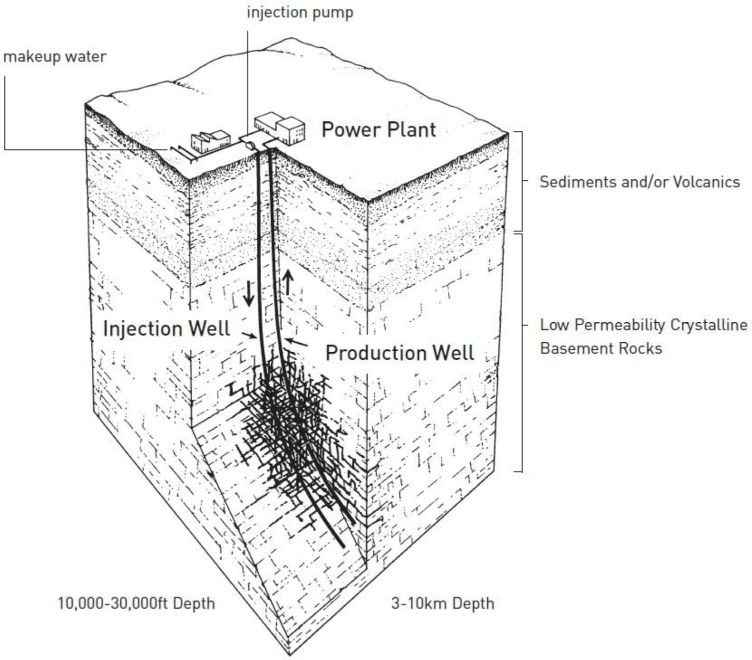


Figure 2.28. Schematic of a two-well Enhanced Geothermal System. DoE, (The Future of Geothermal Energy 2006).

In Figure 2.28 the structure of EGS is presented. Two wells are connected by an area of higher permeability. This enhancement is generated by pumping water in pressure into the formation. Chemical mechanical erosion helps alleviate the flow. In addition, thermal expansion (contraction) enhances the flow rate.

The cost of drilling holes grows fast as a function of depth. Oil and gas average cost follows the exponential curve quite well, at least to 6000 m level (Figure 2.29, note logarithmic axis). The cost of drilling appropriate holes appears to be the main obstacle in the way of EGS energy to becoming viable.

Uncertainties for using EGS geothermal energy in Finland for heat production lie in drilling costs and connecting the wells, i.e. creating permeable heat exchanger. Temperature at specific depths is more easily estimated.

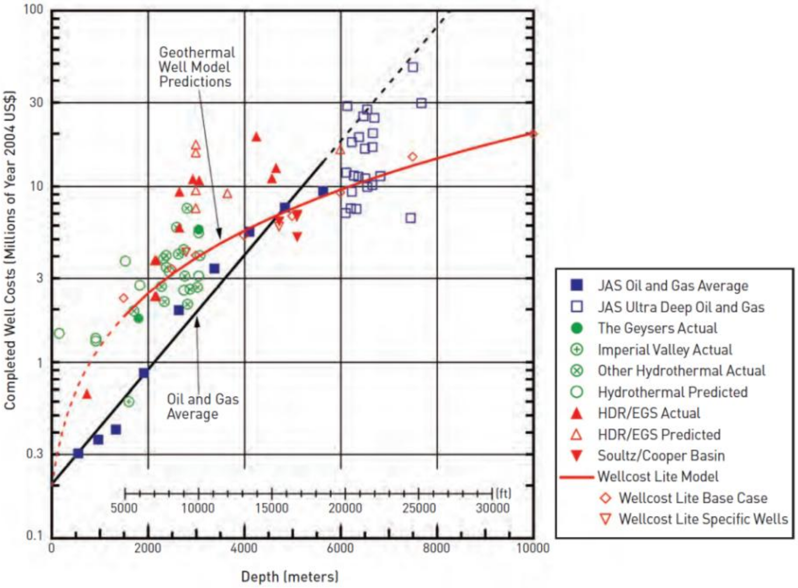


Figure 2.29. Drilling costs as a function of depth. DoE, (The Future of Geothermal Energy 2006).

2.7 Standards and determinations related to hybrid energy systems

2.7.1 Power Generation systems connected to the low-voltage distribution network (VDE-AR-N 4105:2011-08)

General connection criteria

Power generation systems must be connected to the LV distribution network without interfering reactions and without affecting the supply of other customers. Power generation systems are mainly connected with symmetrical three-phase connection, but it is also possible to make single-phase connections. In such cases, the maximum power may not exceed 4.6 kVA per line conductor. Every generation system that exceeds the above-mentioned limit must be connected to the network by using three-phase connection.

Power quality requirements

Power generation systems connected to same connection point may not cause over 3% voltage change compared with the voltage without power generation system (*VDE-AR-N 4105)*:

$$\Delta u_a \leq 3\%$$

If necessary, it may be permitted in justified cases to deviate from this value. In addition, connection and disconnection of power generation systems may not cause over 3% voltage change at the connection point (*VDE-AR-N 4105)*:

$$\Delta u_{max} \leq 3\%$$

The power generation system fulfils the requirements for flicker strength, if it complies with the limits that are set in the standards EN 61000-3-3 and 61000-3-11. In addition, in *the standard VDE-AR-N 4105 it is added, that the* power generation systems in the connection point may not exceed the flicker value (*VDE-AR-N 4105)*:

$$P_{lt} = 0.5$$

This value is also valid for power generation systems with rated current over 75 A. Power generation system fulfils the requirements for harmonics, if it complies with the limits that are set in the standards EN 61000-3-2 and EN 61000-3-12. *In addition, in* the standard VDE-AR-N 4105 it is added, that if the limit values of above-mentioned standards are not complied with, then the maximum permissible harmonic current is calculated by using related harmonic current table from the standard and following equation *(*VDE-AR-N 4105):

$$I_{v,allowed} = i_{v,allowed} \cdot S_{kv} \qquad (2.7)$$

Where $I_{v,allowed}$ is the harmonic current of a power generation system, $i_{v,allowed}$ is the related harmonic current which is presented in a table in the standard and S_{kv} is the network short-circuit power at connection point (minus the power generation system's share in short-circuit power). This equation is also valid for power generation systems with rated current over 75 A.

Connection conditions and synchronisation

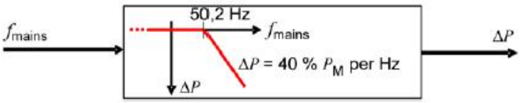


Figure 2.30. Active power reduction when frequency exceeds 50,2 Hz. f_{mains} is frequency, P_m is generation system power, when it has exceeded 50,2 Hz and ΔP active power change.

If the frequency drops below 47.5 Hz or rises over 51.5 Hz, power generation system must immediately disconnect from the network. Power generation systems must also be able to adjust their reactive power when they produce at least 20% of their rated active power. The reactive power adjustment is done with the following displacement factors (*VDE-AR-N 4105)*:

- Power generation systems $\sum S_{\mathrm{Emax}} \leq 3.68$ kVA :
  Within cosφ=0.95$_{\text{under-excited}}$ to cosφ=0.95$_{\text{over-excited}}$ in accordance with DIN EN 50438.
- Power generation systems 3.68 kVA < $\sum S_{\mathrm{Emax}} \leq 13.8$ kVA :
  Characteristic curve provided by the network operator within cosφ=0.95$_{\text{under-excited}}$ to cosφ=0.95$_{\text{over-excited}}$
- Power generation systems $\sum S_{\mathrm{Emax}} > 13.8$ kVA :
  Characteristic curve provided by the network operator within cosφ=0.90$_{\text{under-excited}}$ to cosφ=0.90$_{\text{over-excited}}$

Figure 2.31 represents the standard characteristic curve for cosφ (P). (*VDE-AR-N* 4105)

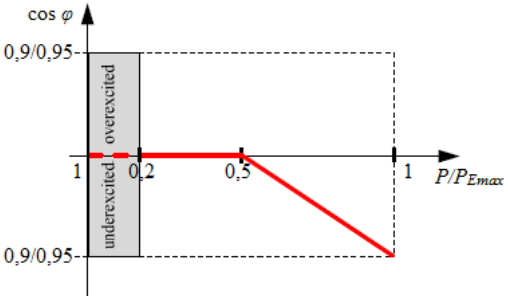


Figure 2.31. Standard characteristic curve for cosφ (P).

Protection requirements

NS protection is used to disconnect power generation systems from the network in the event of inadmissible voltage or frequency values. NS protection can be either an integrated or separated protection device. The following conditions apply for the power generation system's protection (*VDE-AR-N 4105)*:

- $\sum S_{\mathrm{Emax}} > 30$ kVA :

- Central NS protection is required at the central meter panel. Combined heat and power units are the exception, and integrated NS protection is permitted for systems over 30kVA, if there is a disconnection device available at the customer connection point.

- $\sum S_{\mathrm{Emax}} \leq 30$ kVA :

- Integrated NS protection is permitted and no central NS protection is required.

NS protection system controls the interface switch and it activates automatically if at least one protective function responds. The interface switch is used to connect the customer's power system to the network or the power system to the customer's own network.

Table 2.17. Technical requirements for power systems connected to LV distribution network (Energiateollisuus 2009, Energiateollisuus 2013, SFS-EN 50438, VDE-AR-N 4105).

<table>
<tr><th colspan="4">Connection criteria</th></tr>
<tr><td></td><td colspan="2">SFS-EN 50438 / ET</td><td>VDE-AR-N 4105</td></tr>
<tr><td>Maximum power of a single-phase connected power generation system</td><td colspan="2">≤ 3.7 kVA per line conductor</td><td>≤ 4.6 kVA per line conductor</td></tr>
<tr><td>Permissible voltage change</td><td colspan="2">Connection or disconnection of a power generation system may not cause over 4% voltage change at the connection point.</td><td>Connection or disconnection of a power generation system may not cause over 3% voltage change at the connection point.</td></tr>
<tr><th colspan="4">Power quality requirements</th></tr>
<tr><td>Rapid voltage changes</td><td colspan="2">≤ 3.3%</td><td>≤ 3%</td></tr>
<tr><td>Flicker</td><td colspan="2">EN 61000-3-3</td><td>EN 61000-3-3 ($I_n \leq 16$ A) ja
EN 61000-3-11 (16 A < $I_n \leq 75$ A)</td></tr>
<tr><td>Harmonics</td><td colspan="2">EN 61000-3-2</td><td>EN 61000-3-2 ($I_n \leq 16$ A) ja
EN 61000-3-12 (16 A < $I_n \leq 75$ A)*</td></tr>
<tr><td colspan="4">* VDE-AR-N 4105: If the limit values of above mentioned standards are not complied with, then the maximum permissible harmonic currents are calculated by using related harmonic current table from the standard and equation 1.</td></tr>
<tr><th colspan="4">Power generation protection</th></tr>
<tr><td rowspan="2"></td><td rowspan="2">Disconnection time</td><td colspan="2">Setting values</td></tr>
<tr><td>SFS-EN 50438 / ET</td><td>VDE-AR-N 4105</td></tr>
<tr><td>Over voltage</td><td>≤ 0.2 s</td><td>U_n + 10%</td><td>U_n + 10%</td></tr>
<tr><td>Under voltage</td><td>≤ 0.2 s</td><td>U_n – 15%</td><td>U_n – 20%</td></tr>
<tr><td>Over frequency</td><td>≤ 0.2 s</td><td>51 Hz</td><td>51.5 Hz</td></tr>
<tr><td>Under frequency</td><td>≤ 0.2 s</td><td>48 Hz</td><td>47.5 Hz</td></tr>
<tr><td>Loss of Mains (LoM)</td><td></td><td>≤ 5 s</td><td>≤ 5 s</td></tr>
<tr><th colspan="4">Connection conditions and synchronisation</th></tr>
<tr><td></td><td colspan="2">SFS-EN 50438 / ET</td><td>VDE-AR-N 4105</td></tr>
<tr><td>Reconnection</td><td colspan="2">20 s</td><td>long interruption: 60 s **
short interruption: 5 s **</td></tr>
<tr><td>Active power reduction at over frequency</td><td colspan="2">no</td><td>50.2 Hz – 51.5 Hz
($\Delta P = 40\%\ P_m$ / Hz)</td></tr>
</table>

Displacement factor	$\cos\varphi=0.95_{ind}-\cos\varphi=0.95_{cap}$	$\cos\varphi=0.95_{ind}-\cos\varphi=0.95_{cap}$ $(\sum S_{Emax} \leq 3.68$ kVA)
		$\cos\varphi=0.95_{ind}-\cos\varphi=0.95_{cap}$ (3.68 kVA $< \sum S_{Emax} \leq$ 13.8 kVA)
		$\cos\varphi=0.90_{ind}-\cos\varphi=0.90_{cap}$ $(\sum S_{Emax} >$ 13.8 kVA)
** In a short time interruption the threshold levels are exceeded or undershot for a maximum period of 3 seconds. Long interruption is over 3 seconds.		

The above-mentioned criteria and requirements are collected to the Table 2.17 and this also shows the comparison between standards used in Finland and Germany for connection criteria of power generation systems connected to the LV distribution network. Connection criteria in Germany are collected from the standard VDE-AR-N 4105 and connection criteria in Finland are collected from the standard SFS-EN 50438 and recommendations from Energiateollisuus.

2.7.2 Solar heat energy standards

SFS-EN 12975-1 + A1

Solar heat systems and components. Solar collectors. Part 1: General requirements application area, norms, terms, definitions, symbols and units

- Long-life and reliability
  - materials and construction
  - requisite tests
  - acceptable criteria (liquid leakages, cover and collector material damages, loss of vacuum, dampness collection, tolerance of high temperature (both outdoor and indoor thermal tolerance), mechanical load tolerance, freezing tolerance
- Security
- identification data
  - drawings, type notes, manual

SFS-EN 12975-2

Solar heat systems and components. solar collectors. Part 2: test methods

Look at the previous standard **12975-1 + A1**

SFS-EN 12976-1

Solar heat systems and components. Factory made systems. Part 1: General require

- Mostly the same requirements as previous **12975-1 ja -2** standards
- Prevents contamination into drinking water
- Safety equipment, safety valves, discharge of over pressure
- Characteristic of heat production
- Description of annual production and daily production with testing and simulation
- Requirements of connection to separate heat production
- feedback flow prevention
- Electrical safety

SFS-EN 12976-2

Solar heat systems and components. Factory made systems. Part 2: Test methods

Look at the previous standard **12976-1**

SFS-EN 12977-1

Solar heat systems and components. Tailor-made systems. Part 1: General requirements for household and heating water.

Mostly the same requirements as in **12975-1 ja -2 standards. In addition:**

- Snow and wind loads

SFS-EN 12977-2

Solar heat systems and components. Tailor-made systems. Part 2: Test methods for household and heating water made.

Look at the previous standard **12977-1**

SFS-EN 12977-3

Solar heat systems and components. Tailor-made systems. Part 3: Performance characteristic definition for heat storages in solar heat systems.

Heat storage (50 l - 3000 l)

- heat losses
- effectiveness of heat exchangers
- Measurement of temperature; meter location

SFS-EN 12977-4

Solar heat systems and components. Tailor-made systems. Part 4: Testing method for co-operation storing and capacity definition of heat storages

Look at the previous standard **12977-4**

SFS-EN ISO 9488:en

Solar energy. Terminology

3. Alternative futures and business concepts in small-scale renewable energy production

3.1 Background

Decentralised energy production and markets for renewable energy (RE) technologies are expanding. This is due to the greener policy goals within the European Union and globally resulting from sustainability concerns. All EU countries have agreed in the energy and climate package to increase energy efficiency by 20%, utilisation of renewable energy sources, up to 20% of total consumption and to reduce CO_2 emissions by 20% from the 1990 level by the year 2020 (EU Commission 2008 and 2014). Even more ambitiously, a national target to reduce GHG emissions by 80% below 1990 levels by 2050 was set in a Finnish Government's foresight report (Prime Minister's... 2009).

Policies play a major role, as growth is supported by, e.g. EU policies for renewable energy and subsidy systems introduced in all EU member states. The allocation of support systems varies. For example, in Finland the feed-in-tariffs are allocated to large-scaled plants, whereas in Germany small-scaled energy production is more extensively supported (Fulton & Capalino 2012, KPMG 2012, Koistinen et al. 2014). The German Energiewende is one example of a strong turnaround in long range energy policy (BMU 2012a). As a result, consumer electricity prices have risen, but at the same time, the capacities of different renewable energy sources have increased considerably (Trendresearch 2011). This has meant new business opportunities and a need for new networks and concepts to emerge at local level (Wasserman et al. 2012).

While the traditional energy production is based on a centralized large-scale infrastructure, the emerging customer-side business concepts are based on a large number of small projects (Koistinen et al. 2014). These small-scale projects, in which energy production occurs in the consumption section of the energy value chain, instead of energy utilities, are conducted through, for example, communal investment networks, co-operatives and farm clusters. According to Richter (2012), these customer-side business models are in an early stage of development. Small-scale energy production in households, farms or small enterprises has received relatively little attention to date in the energy transition. Distributed systems can, however, help in achieving the official targets, as well as offering economic opportunities for small-scale energy producers and the producers, retailers, and installers of energy devices. Although Finland has an important share of renewables in its energy mix, renewable energy production is mainly centralized.

There is also a change in perceptions of energy that have created a market pull, which is supported by feed-in-tariffs that enable consumers to generate their own energy and to sell the excess to the grid. Local energy production also increases energy, electricity and fuel security by reducing dependency on imported fuel or electricity or on grid failures. Local energy production increases energy efficiency because of lower transport or transfer losses. It also increases local business, employment, and energy production from local waste reduces waste management costs.

3.2 General research objectives in Theme 2

The overall objective of the Distributed Energy Systems (DESY) project is to enhance and develop locally-based, renewable resource utilizing and multifunctional sustainable energy systems. DESY systems strive towards a balance between cooperation and competition. Multiple fuel suppliers and diverse users/customers imply that local systems are a diverse collaborating network including many different firms, processes, organisations and actors within the local economy. To exploit these market opportunities, new technical and business innovations are needed. As energy generation becomes increasingly a local and regional business, new actors are involved.

Furthermore, in the DESY project one important aspect was to bring together energy users, energy producers, technology providers, engineering and consultant companies and researchers, whose ambition is to tackle the present and foreseen challenges and thus lay the ground for a real market penetration of distributed energy systems.

3.2.1 Research questions in Theme 2

In this theme we have analysed alternative future paths, practical business opportunities as well as new business concepts among the many renewable energy value chains in today's technological platforms.

Research questions in Theme 2:

1. Benchmark analysis: German model in promoting renewable energy
    - o What is the German model in promoting RE? What kinds of successes and drawbacks are there in DESY concepts and their promotion in Germany? What kind of business models are there in Germany?
    - o This part was studied based on the literature.

2. Business concepts analysis in the DESY system
    - What are the emerging business models for distributed energy generation in Finland? What kinds of concepts are currently developed and what alternatives are there until 2025? Where will the business opportunities appear in the next ten years?
3. Future scenarios in DESY
    - What is the vision of distributed energy generation in Finland?
    - What are the alternative future scenarios in the RE development until 2025? What are the preferred and probable future developments in (1) RE technology solutions, (2) RE market functionality, (3) RE business concepts, and (4) energy policy and support to RE. What are the preferred and probable future views considered by DESY value chain experts?
    - What drivers and factors will be important in order for the DESY system to grow?

The research theme builds scenarios as a basis for evaluations of actual and hypothetical future development of DESY systems, taking into account changing situational factors such as fuel and energy costs/prices, market functionality and opportunities, policies and legislation, societal changes, technological development, and sustainability and environmental challenges.

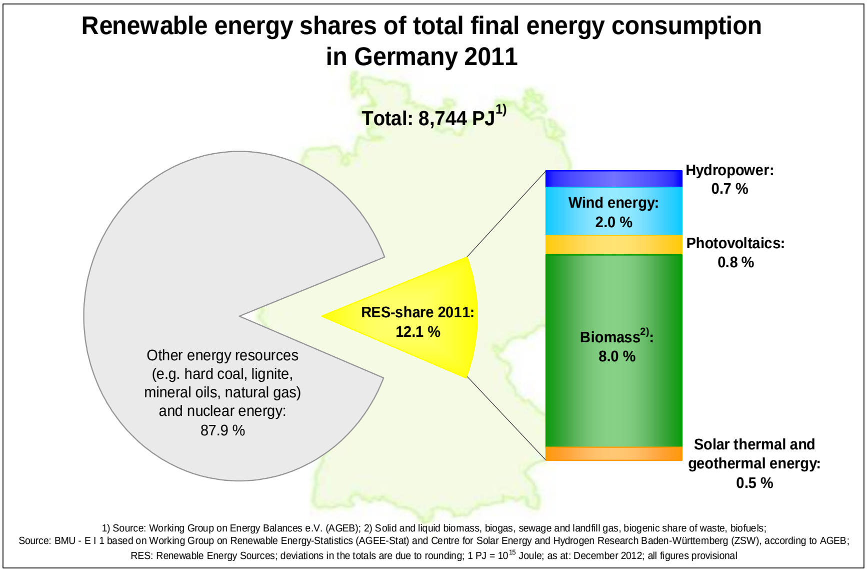
3.3 The German model in promoting renewable energy

Renewable and distributed energy concepts and promotion in Germany were studied based on the literature, and the results of this work were published by Koistinen et al. (2014). In the report there is more detailed analysis of the adopted business concepts during the *Energiewende* era in Germany. The results are summarized here.

3.3.1 Renewable energy concepts in Germany

Decisions made in Germany in renewable energy politics in the 1990's have increased the use or renewable energy remarkably. By 2012 the green-house gas (GHG) emissions were decreased by 25.5% from the 1990 level. Increasing use of renewable energy has had a big role in GHG emission reduction. Even though renewable energy production has increased, Germany is still depend on fossil fuels and nuclear power as the share of renewable energy of total energy consumption is around 12%. The current view is, nevertheless, that Germany's expectations on increasing the share of renewable energy will be achieved if the operational environment continues to develop to a favourable direction (Figure 3.1). Crucial factors for achieving the goals are the integration of renewable energy to markets and the over-all systems, increasing the capacity of electricity networks and electricity storage, the flexibility of power plants and the optimization and control of electricity loads. The main risk of increasing the share of renewable energy is that Germany will increase the dependency on coal as reserve capacity. It has already been shown that short term investments are made more to coal power plants than gas plants.

Conditions for increasing renewable energy production have been similar in Germany to those in other western countries. There are a large number of small energy producers in Germany, but the electricity markets are still quite clustered. The four largest energy companies own about 73% of the electricity production capacity and 80% of fossil and nuclear power. In contrast 40% of the renewable energy production capacity is owned by private persons, usually through cooperatives. The strong economic and legislative support to small scale energy production has encouraged citizens; the number of private owners follows also from citizens' interest in collaboration and the success stories around them.


Renewable energy shares of total final energy consumption in Germany 2011

1) Source: Working Group on Energy Balances e.V. (AGEB); 2) Solid and liquid biomass, biogas, sewage and landfill gas, biogenic share of waste, biofuels;
Source: BMU - E I 1 based on Working Group on Renewable Energy-Statistics (AGEE-Stat) and Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), according to AGEB;
RES: Renewable Energy Sources; deviations in the totals are due to rounding; 1 PJ = 10^{15} Joule; as at: December 2012; all figures provisional

Figure 3.1. Renewable energy shares of total final energy consumption in Germany in 2011 (BMU 2012).

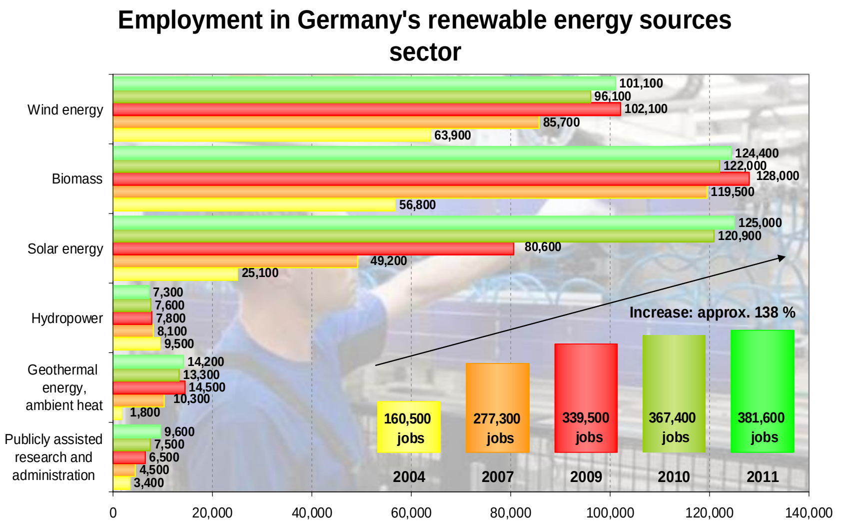
Unclear and unreliable political regulation environment, lack of public acceptance and slow expansion of electricity grids are seen as the main obstacles for changes in energy systems in Germany. Activities of public utilities and the energy co-operatives owned by citizens create a dynamic environment for the energy reform. Strong position of municipal actors creates opportunities to combine companies' economic goals to political points of view and adjusting to an area's special needs. Municipal energy companies are able to notice need of local communities with economic purpose.

The electricity grids in Germany are built for concentrated and fossil power production. The increasing amount of renewable and distributed energy production brings challenges to grid infrastructure. For the times when the renewable energy production is low, reserve power, sufficient storage capacity and control of the energy demand must exist. Grids should also be able to transfer electricity to both directions. Grid expansion has progressed slowly in Germany compared to the increase in renewable energy production. In the end of year 2012, a national plan for grid development was created but the support for grid expansions is still insufficient and currently the investments for grid expansions are not profitable.

To promote renewable energy in the markets, the support in Germany is allocated to a variety of processes (solar, wind, water, biogas and geothermal) more widely than, for example, in Finland. To have a stable investment environment, in Germany long term support programmes were launched, where the amount of support and decrease of support following capacity increases were defined. The main support in Germany is the feed-in-tariff, which is supported by a feed-in-premium.

The average price of electricity is higher in Germany than in the other European Union Member States. High energy prices have increased discussion and brought distrust towards renewable energy. The high level of support has promoted renewable energy production and development work in Germany, but also other countries have benefited from the technological development in, for example, solar power systems. The high energy prices are said to have weakened the international competitiveness of German industry even though they are compensated to industry by e.g. allocated price and tax reliefs.

In general, the attitudes in Germany towards renewable energy are quite positive. Private consumers have participated in the production of distributed energy, for both environmental and economic reasons. One of the main drivers for solar and wind power development has also been the innovativeness and courage of German companies in technology development. Germany competes for the leading position in solar and wind power with the USA and China. Many producers also collaborate with the research sector. The distributed and renewable energy has also a strong role as an employer (Figure 3.2).



Figures for 2010 and 2011 are provisional estimate; deviations in totals are due to rounding;
Source: O'Sullivan (DLR), Edler (DIW), Nieder (ZSW), Rüther (ZSW), Lehr (GWS), Peter (Prognos): "Bruttobeschäftigung durch erneuerbare Energien im Jahr 2011 – eine erste Abschätzung", as at: March 2012; interim report of research project „Kurz- und langfristige Auswirkungen des Ausbaus erneuerbarer Energien auf den deutschen Arbeitsmarkt"; image: BMU / Christoph Busse / transit

Figure 3.2. Employment in Germany's renewable energy sources sector (BMU 2012).

The aim in Germany, as in the European Union, is to compensate the high carbon dioxide emissions with renewable energy production. Emission reductions depend on what is being replaced. Nuclear power has lower carbon dioxide emissions than coal. Because of the low prices of emission allowances and Germany's goal to decrease nuclear production, the position of coal compared to other fossil fuels has improved. Relations in prices of raw materials have an effect on renewable energy investments unfavorable, but they also affect investments to gas power plants, which have lower emissions than other power plants with fossil fuels.

3.4 Anticipating the changes in RE value chain with a Delphi study

3.4.1 Background

Decentralised energy production and markets for renewable energy (RE) technologies are expanding. To date, households, farms or small enterprises have received relatively little attention. Distributed systems can, however, be part of the energy sector change, and offer economic opportunities for small-scale energy producers and for the producers, retailers and installers of energy devices. Policies play a major role in this process. RE growth is supported by both EU-level policies and national subsidy systems. The opportunities and challenges of this sector in Finland were assessed in this study. Here, the opportunities and obstacles of the distributed, small-scale energy sector in Finland are assessed in the current operational environment. The results have been reported by Varho et al. (2014) and Rikkonen and Varho (2014).

In this chapter, first the future views are presented according to the subjective importance rated by the expert panel. Then, the business concepts and opportunities are presented based on the first round evaluation. After that, a set of scenarios are presented based on a cluster analysis of experts' future views. Scenario construction bases itself on preferred and probable future views. The constructed scenarios represent alternative future paths of small-scale energy until 2025.

3.4.2 Material and methods

The material for this study consists of a two-rounded Delphi process that was conducted in Finland in August 2013 – February 2014. The Delphi method is widely used within futures research. Its users aim to explore alternative future images, possibilities, their probabilities of occurrence, and their desirability by tapping the expertise of respondents. The Delphi method consists of experts' judgements by means of successive iterations of a questionnaire, to show convergence of opinions or to identify dissent or non-convergence (Linstone & Turoff 1975, Sackman 1975, Kuusi 1999, Rowe & Wright 2001). There are three traditional principles that can be considered as irreducible elements of the technique, namely anonymity in answers, iteration and controlled feedback between organised enquiry rounds (Rowe & Wright 1999, 2001). Rowe and Wright (1999) also mention statistical aggregation of responses into a group response as a central characteristic, but in dissensus-based Delphi applications (e.g. Tapio 2003, Steinert 2009) such as the one used here, several group responses rather than a consensus seeking single response are sought for.

The Delphi panel

The Delphi panel experts were selected to represent the value chain of renewable, distributed energy production in Finland. The purpose was to cover the relevant viewpoints to be found within the field, and this was thought to be achieved best with a wide range of experts. Some panellists could be considered stakeholders rather than experts in a strict academic sense (see also Varho and Huutoniemi 2014).

The respondents were chosen with the help of an expertise matrix. Although some characterisation of respondents was done by the research team in order to find appropriate panellists, the respondents were also asked to estimate their own expertise. They named the renewable energy forms and the roles in the value chain they were most familiar with.

During the first round, 17 persons answered a questionnaire in face-to-face interviews where they were able to discuss their views in detail. A further 9 experts responded to a similar questionnaire online. The second-round questionnaire was organised as an online questionnaire. A feedback report was sent together with the questionnaire to the panellists, who had responded in the first round. 18 responses were received from the second round. The expertise of the panel that completed the second-round questionnaire is itemised in Table 3.1. In many cases, there was more than one respondent who completed the two dimensions of a cell. For example, there were several panellists whose expertise covered energy production and biogas. Although the cover is not perfect, each energy source and each field of expertise was given some coverage.

Table 3.1. Second round expertise matrix, based on experts' own estimate.

	Energy source / Fuel									Panellists in total
Field of action / Area of expertise	Solar power	Solar heat	Bio/ biogas	Bio/ ethanol	Bio/ micro-CHP	Wind power	Heat pumps (ground, water, air)	Hybrid systems	Other	
Fuel supplier					x					1
Equipment production and provision	x	x	x		x			x	x	6
Energy production	x	x	x	x	x	x	x	x	x	6
Energy transfer/distribution	x	x	x			x	x	x	x	3
Research & development	x	x	x	x	x	x	x	x	x	12
Consumer	x	x	x	x	x	x	x	x	x	6
Other			x							2
Panellists in total	9	10	7	2	3	4	6	10	4	

The bottom row of Table 3.1 indicates the number of panellists who named the energy source in question as their technological background. The right-hand column displays the number of panellists having indicated the field in question as their area of expertise. Solar power and heat as well as hybrid systems are somewhat more represented in the panel than other individual technologies. However, by combining together all bio-based technologies, bioenergy is strongly represented.

The questionnaires

The first round of the Delphi study data was gathered mainly through semi-structured interviews. A first round questionnaire was developed and pre-tested by the research group, and two additional experts in the distributed energy field. Based on the pre-testing, a few questions were eliminated to avoid a too laborious a questionnaire. The structure of the first round questionnaire allowed experts to express new questions or statements of their own. The aim was to assure that the principle of an iterative specification of answers could take place.

In the first round, altogether 50 driving forces were addressed concerning the renewable, distributed energy production in Finland. These were asked under four themes, namely: (1) RE technology solutions, (2) RE market functionality, (3) RE business concepts, and (4) energy policy and support to RE. The respondents gave their preferred and probable future view and an importance evaluation of each individual driving force using a five-step Likert scale. There was also a set of questions about business opportunities, and some open ended questions.

In the second round, a selection of the first round results were returned to the expert panel to acquire feed-back and re-evaluation of the results. These selected questions were chosen based on the rated importance, differences in preferred and probable future images, and deviation between the answers of the panellists. The panellists were shown their own response from the first round as well as the distribution of answers by the whole panel. The answers were asked for on the Likert-scale of –2 to 2 (–2 refers to a substantial decrease from present level, 0 refers to no changes to present level and 2 refers to substantial increase from the present level).

In addition, a new questionnaire part was prepared, based on the analysis of the first round questionnaire and interviews. The respondents gave their future view on the development of various business concepts and on the increase of different RE form capacities (i.e. installations of different energy forms). In these two sections an index was used. The present level (end of the year 2013) was defined as 1, and the panellist could give any number for the 2025 level.

In a final section, the panellists were asked to mark up to five most important obstacles in Finland to the growth of distributed RE capacity, for the growth of new business activity related to distributed RE, and for the export activity related to distributed RE. They were given a list of 16 obstacles to choose from.

Cluster analysis

In this study, the data was gathered so that the preferred and probable future development were asked for separately but analysed simultaneously. These formed the basis for scenario construction. The data analysis for scenario construction was performed with cluster analysis. The analysis was based purely on the second round answers (n=18, giving 36 visions of the future as each respondent provided both a probable and a preferable vision). All other questions apart from the obstacles were used in the clustering. The obstacles were excluded because they did not follow the same preferred/probable format as the other questions.

The statistical runs were done using IBM SPSS Statistics 21 software. Classification is often a useful way to analyse data. Cluster analysis is a collection of statistical methods, which identifies groups of samples behaving similarly or showing similar characteristics. The simplest mechanism is to partition the samples using measurements which capture similarity or distance between samples (Romesburg, 1984).

Within the method, hierarchical cluster analysis is the major statistical method for finding relatively homogeneous clusters of cases based on measured characteristics. It starts with each case as a separate cluster, i.e. there are as many clusters as cases, and then combines the clusters sequentially, reducing the number of clusters at each step until only one cluster is left. The clustering method uses the dissimilarities or distances between objects when forming the clusters. The SPSS programme calculates 'distances' between data points in terms of the specified variables (Burns & Burns 2009). A hierarchical tree diagram, called a dendrogram on SPSS, shows the linkage points.

Cluster analysis has often been used to construct scenarios from Delphi data (see Tapio 2002, Rikkonen 2005, Rikkonen & Tapio 2009, Varho & Tapio 2013)**.** Here cluster analysis was used because it allowed categorising similar future views of distributed energy system experts in clusters. To give equal weight to all variables, the values were standardised to a scale between 0...1 in each variable, as the scale had varied between the questions.

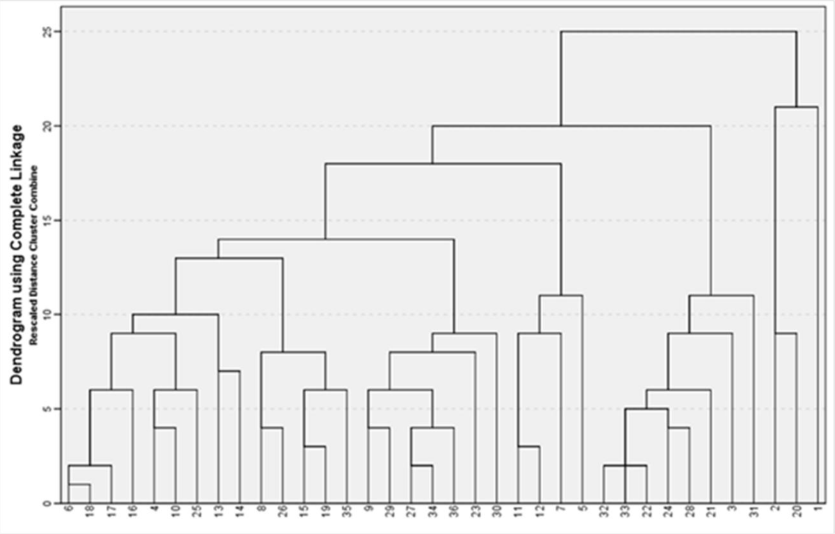


Figure 3.3. The dendrogram used in the scenario construction, depicting five clusters.

The dendrogram of clustered responses is given in Figure 3.3. We selected five clusters as the basis for the scenario construction. The aim was to find 4-7 clusters, because such a number has been considered suitable for scenario sets (see Varho & Tapio 2005). These five clusters represented sufficiently different viewpoints regarding the future development, so that an interpretation was possible to be found for the set. The average value (i.e. cluster mean) was calculated for each variable from the future images (both probable and preferable) that were included in each cluster. The scenario descriptions were constructed based largely on these values.

Key results

As said, in the first questionnaire section the panelists evaluated: 1) preferred, 2) probable future view and 3) importance of a topic out of the 50 topics asked. The five topics rated as most important are presented in Figure 3.4. The respondents emphasised the use of grid-connected small-scale solutions in households, farms and small enterprises, and the increase of such solutions was also considered rather probable. The panellists, however, expressed concerns about the clarity and ease of the construction permit process for implementation of small-scale RE production (including the length of the process). It was preferred, but this development was not seen as probable. It seems that there are still challenges in the market functionality, and the expert panel wished for small-scale producer's surplus electricity net metering to materialize. The number of hybrid energy systems in households, farms and small enterprises in small-scale production of heat and power was also seen to strongly increase (both preferred and probable).

The panelists also called for more mid-sized equipment or component manufacturers in the market. Another important topic was considered to be the growing public acceptance of distributed small-scale renewable energy production.

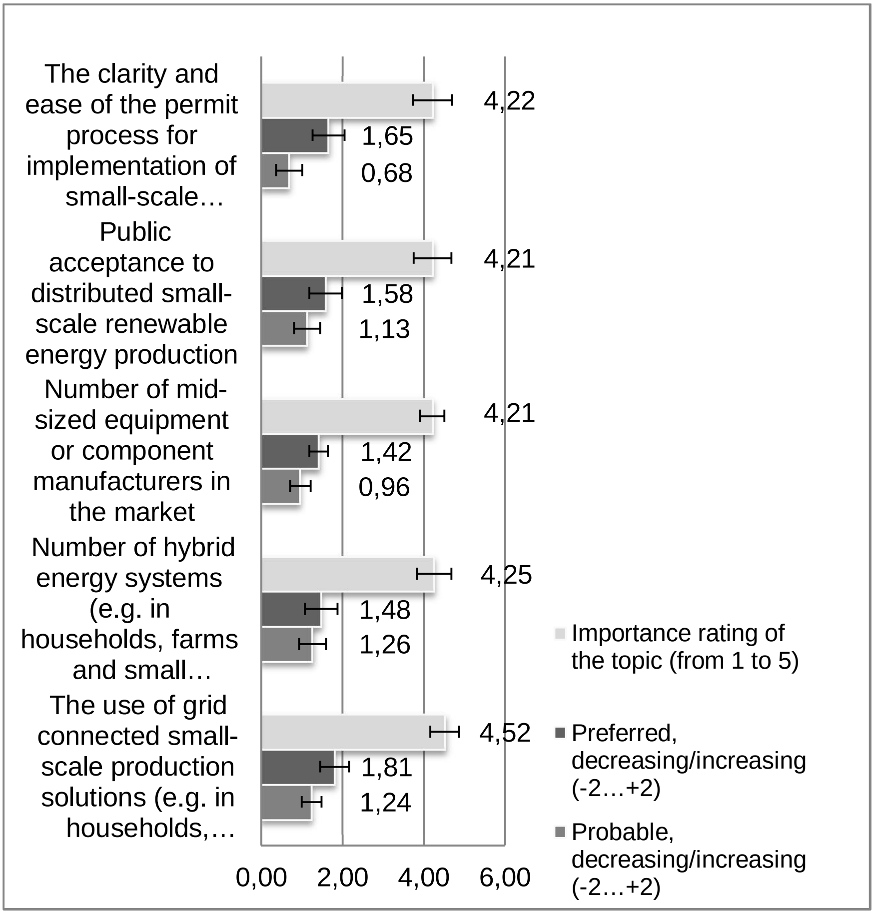


Figure 3.4. The importance, preferred and probable future views (Mean) of top-5 topics (note that the decrease/increase are given on a scale different from the importance).

The panel also gave their views on the emergence of new business concepts. According to the results (Table 3.2), the most preferred business concepts were the turnkey concepts, independent web-services that offer alternatives for selecting an energy system, ”production-site rent”–packages and virtual power plants in energy production. The probable future view is quite similar, but includes services for small-scaled energy producers where the technology supplier manages the cooperation and contracts with grid manager are probable.

Table 3.2. Envisioned development of business concepts, arranged by perceived importance.

Business concept	Preferred future view decrease /increase (-2…+2)		Probable future view decrease /increase (-2…+2)		The relative importance (1…5)	
	Mean	SD	Mean	SD	Mean	SD
Number of business networks that offer turnkey concepts for small-scale production	1.36	0.64	0.83	0.56	3.72	0.98
Independent web-services that offer alternatives for selecting an energy system solution to one's home.	1.27	0.92	0.85	0.67	3.69	1.09
Personal consultation services for choosing an energy system for one's home	1.23	0.76	0.77	0.59	3.56	1.12
Number of ”production-site rent” –packages, where a company installs and operates a renewable energy system on site it rents (e.g. roof or land)	1.38	0.75	0.76	0.60	3.56	1.26
Financing options offered by energy companies to distributed energy system investments	1.17	0.64	0.54	0.72	3.54	1.32

(e.g. to households, farms and small enterprises)						
Collective investments in RE small-scale systems procurement (i.a. crowd funding)	1.19	0.90	0.69	0.68	3.52	1.12
Virtual power plants in energy production (integrating growing number of distributed and renewable energy resources together as one virtual entity into the grid and into the markets)	1.28	0.79	0.58	0.64	3.52	1.16
Service for small-scaled energy producers in where the technology supplier manages the cooperation and contracts with grid manager	1.15	0.73	0.85	0.67	3.31	1.26
The number of cooperatives in local small-scaled RE production	1.08	0.80	0.54	0.71	3.28	1.14
The rented small-scaled energy system equipments from an energy company	0.88	0.77	0.65	0.69	3.00	1.36

In the second Delphi round, the panelists were asked about the growth of selected business concepts (Figure 3.5). Because comparable statistics were not available, the current state (year 2013) was given as index=1. In this evaluation, the small-scaled RE production sites (in farms, households etc.) whose production is marketed and sold by an energy company, were seen as the fastest growing concept. Turnkey concepts, joint investments and "production-site rent" -packages follow quite equally. It is somewhat surprising that the cooperatives in small-scale RE production were not seen as a probable way to organize ownership and production of RE, as cooperatives have played an important role in some other countries.

The panelists were also asked in the second Delphi round about the capacity growth of different RE sources in small-scale production (Figure 3.6). An index was used here, as well. The panel gave a strong support for solar based capacity growth supported by the hybrid systems. It seems a rather consistent result in the light of the business concepts' emergence. It is likely that the small-scale production is gathered and distributed by a larger energy company. It is notable that the air or ground-source heat pumps did not get strong growth rate from the panel, but this may follow from the fact that these technologies are already in fairly widespread use in energy production in Finland.

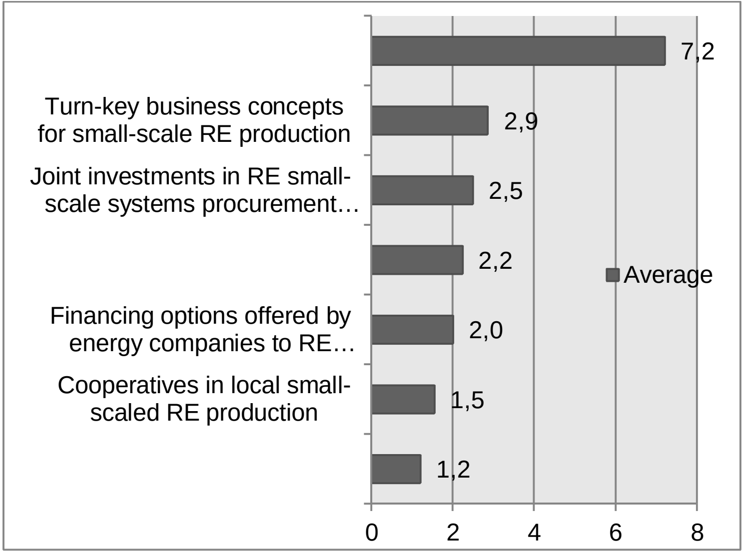


Figure 3.5. Business concepts emergence between 2013–2025 (current state 2013 is given as index=1).

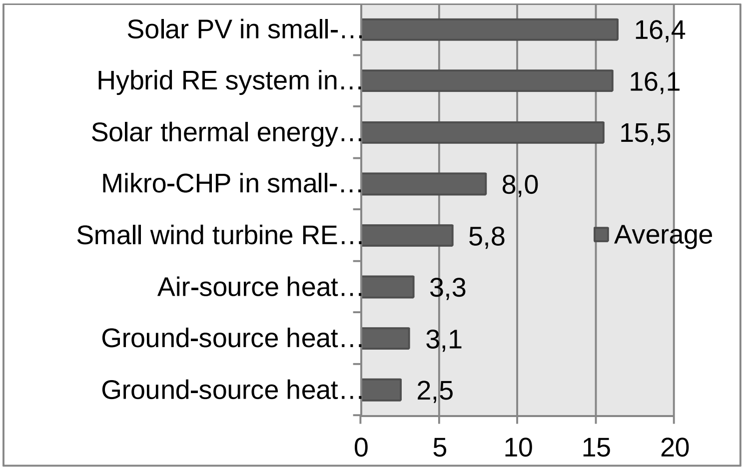


Figure 3.6. Capacity growth between 2013 - 2025 (current state 2013 is given as index=1).

The panelists were asked about the business opportunities within the RE value chain in solar power, solar heat and micro/small-CHP in the first-round questionnaire (Table 3.3). In solar power business the opportunities come from the supply of turnkey services, from installation phase and from planning and purchasing phase. The situation is quite similar for the solar heat but, in addition, the manufacturing phase was considered to contain more opportunities than in solar power. The micro/small-CHP business opportunities are equivalent to the solar power results.

Table 3.3. Envisioned development of business opportunities, arranged by decreasing perceived importance.

Business opportunities	**Solar power decrease /increase (-2…+2)**		**Solar heat decrease/increase (-2…+2)**		**Micro/small-CHP decrease/increase (-2…+2)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Manufacturing phase of the components and apparatus	0.88	0.97	1.25	0.61	1.13	0.85

Planning and purchasing phase (e.g. choosing suitable energy system, tailoring the purchasing process, developing the ease of procurement, contracts etc.)	1.33	0.64	1.26	0.69	1.33	0.73
Installation phase of the RE system	1.36	0.64	1.29	0.62	1.26	0.75
Using and maintenance phase (e.g. advisory services, consultancy, maintenance, aggregative services)	1.00	0.71	1.04	0.69	1.17	0.78
Renewal phase of the energy system (e.g. renewal, updating, replaceing investment, recycling)	0.75	0.79	0.74	0.69	0.77	0.75
Turnkey services (all the phases)	1.44	0.58	1.42	0.65	1.35	0.71
Grid connection services for small-scalew production	1.08	0.65	0.74	0.75	1.00	0.60

The panellists considered the underdevelopment of business concepts such as turnkey solutions the greatest obstacle to small-scale RE capacity growth (receiving 13 “votes”). Also the difficulty in finding trustworthy information on RE systems (9), the insufficient availability of professional sales and installation services (8), the difficulty or lacking profitability of selling small amounts of electricity (8), and the price of production systems (7) were among the top five barriers to capacity growth. The results are presented in Figure 3.7.

RE scenarios

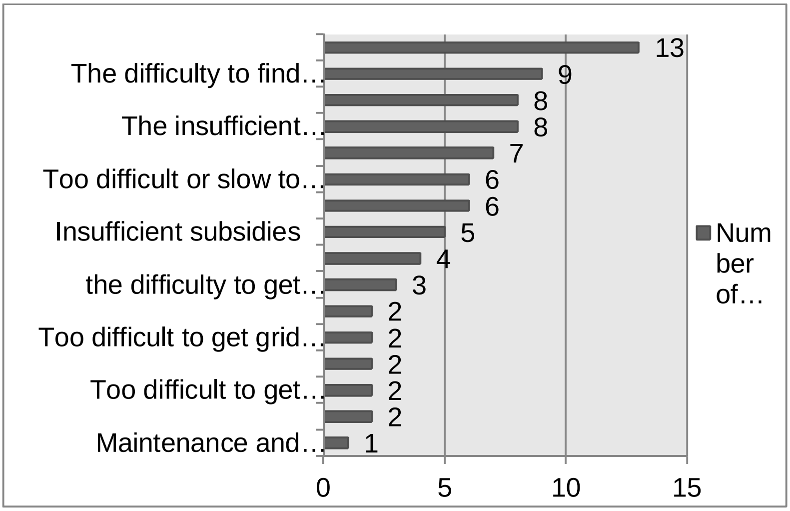
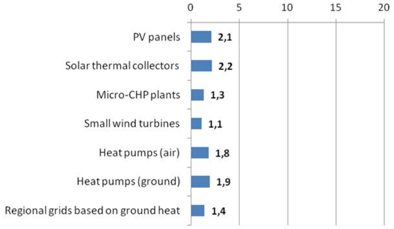
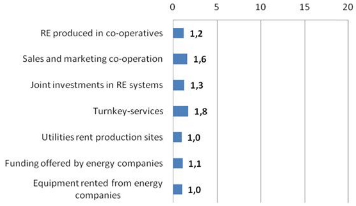
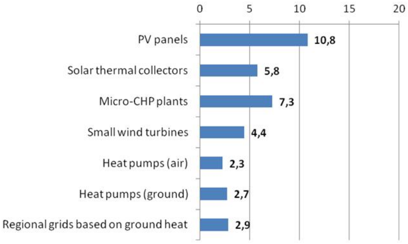
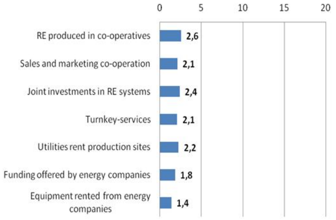
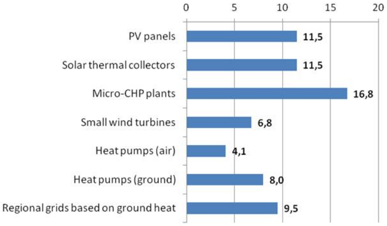
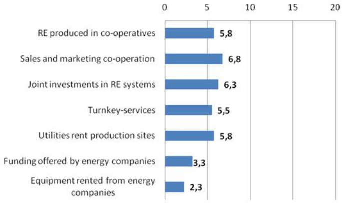


Figure 3.7. Obstacles to the growth in distributed RE. The Delphi panelists each had up to five “votes”.

Five scenarios were constructed from the second round answers, describing alternative futures for RE development in Finland in 2025. The order of scenarios described here is based on the overall renewable energy capacity growth, from smallest to largest. The RE capacities and the increase of various business concepts in each scenario are shown in Figure 3.8. Concerning RE capacities, also the growth of hybrid solutions was asked about in the questionnaire, and was included in the clustering. It was, however dropped from Figure 3.8 due to the ambiguity of the variable in the answers.

Stagnation

As the name implies, in the scenario *Stagnation* very little change takes place, in any field. For example, there is almost no potential for off-grid solutions. Support policies for the renewable energy remain rather similar to the present day, although the focus shifts slightly towards removing bureaucratic obstacles and to R&D funding. Investment subsidies to small-scale producers actually decline. The roles of consumers and small-scale producers are rather traditional, and there is no significant growth in the business concept prevalence. A positive change is the growing number of component and equipment manufacturers as well as of business networks providing ready-to-use installation packages for small-scale producers. The *Stagnation* scenario describes a future where some companies begin to grow, some very minor growth takes place in all renewable energy forms considered, but no real transformation takes place in either political, business, or consumer level.

	SMALL SCALE PRODUCTION CAPACITY IN 2025 INDEX: 1 = STATUS IN 2013.	BUSINESS CONCEPTS IN 2025 INDEX: 1 = STATUS IN 2013.
Stagnation		
Business-as-usual		
The "German way"		

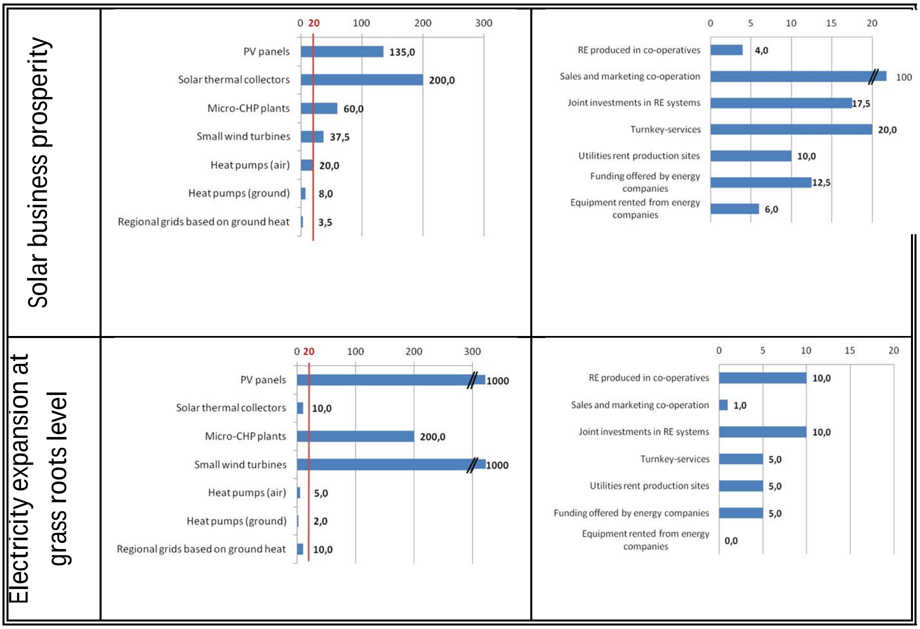


Figure 3.8. Scenario characteristics related to capacity growth and business concept increase. Note the different scales for production capacity in different scenarios.

Business-as-usual

The *Business-as-usual* scenario presents a stable but calm growth track for RE capacities, accentuating PV, and to some extent micro-CHP and solar thermal energy production. Power generation is relatively more pronounced than in the *Stagnation* scenario. Also, policy development is quite stable. Administrative steering has eased bureaucracy related to various permission processes and grid connections. R&D funding has increased and national low-interest financing programmes have emerged. Investment subsidies have increased more than the long-term subsidies. Different business concepts have arisen, but their popularity grows at a slow and even pace throughout the concepts.

The “German way”

The name of the *“German way”* scenario refers to the German *Energiewende* policy as well as to the significant growth of RE energy production and various types of business concepts. In this scenario, there are lots of off-grid solutions. Sales and marketing cooperation between small-scale producers and traditional energy companies, RE produced in small-scale co-operatives, and joint investments in procuring small-scale RE systems have become popular business concepts. There is a strong policy, particularly in terms of long-term support such as feed-in tariffs and national low-interest financing programmes. There is also significant R&D financing. Planning is not forgotten, either, as construction permits and connections to the grid are easy to obtain, and local plans direct towards renewable energy solutions. As a result, the regional networks for ground heat pumps gain popularity faster than in the other scenarios. All renewable energy form capacities grow significantly, with an emphasis on biomass through micro-CHP solutions.

Solar business prosperity

The *Solar business prosperity* scenario shows great growth in RE instalments, with the focus firmly on solar solutions. Unlike in any other scenario, here solar heat grows even faster than solar power. The growth has been achieved, in particular, by making the transition to renewable energy easy for the end customers. Buying renewable energy from a small-scale producer has become easy and commonplace. For example, traditional energy companies co-operate with small-scale producers by selling and marketing their energy to end consumers. Also, ready-to-use installation packages for small-scale producers have become widely available. Policy development is more modest, focusing on R&D financing and easement of construction and grid connection permits.

Electricity expansion at grass roots level

In the *Electricity expansion* scenario, solar power and small-scale wind power generation have “exploded”, and significant growth has also occurred in the installed micro-CHP capacity. Capacity growth has been slower for heat production capacity such as heat pumps and solar collectors. As opposed to the *Solar business prosperity*, the active involvement of citizens has played a significant role in the transformation. Co-operatives and joint investments in energy production equipment have become popular business concepts and forms of community involvement in distributed RE production. Long-term support mechanisms such as feed-in tariffs and national low-interest financing programmes have increased substantially. Permissions can be obtained easily for RE production systems.

Differences in subsidy levels for different RE forms have decreased significantly from their current state.

3.4.3 Conclusions and discussion

As a conclusion, the expert panel wished that the RE solutions, the markets for energy production, the business concepts and the policy support would develop in favour of small-scaled RE until 2025. The preferred future view demonstrated stronger growth than the probable future. However, both views (preferred and probable) included strong increase rather than a decrease or no change. In the preferred future view, the deviation in answers was also greater. The business opportunities were seen increasing mostly in the planning and purchasing phase, in installation phase and in turnkey concepts for small-scale production.

The Finnish strengths in responding to answer to the increase of RE growth are technology optimism, high educational level, enterprise-friendly culture, good condition of grids and the infrastructure overall and the well-organized energy system. There was faith among the panelists that the competitiveness of RE will increase due to the stricter climate policy and the rise in energy prices. In the current situation, as a large share of renewable energy comes from forest industry, the room for extra small-scale RE energy was considered feasible, especially in sparsely populated areas.

There are several direct measures and actions that can be taken when promoting renewable energy growth in Finland. The current policy support concentrates on large-scale energy production in few RE sources (wood fuel, wind power, bio gas), and the panel wished for a transition to support also small-scale production. Service-oriented business concepts together with adequate subsidies and administration were raised as potential means for creating growth in the distributed energy sector. This also calls for more networking and joint development between technology and service providers. There is also a need for independent information services that can provide valid information for choices e.g. for the most energy-efficient, suitable solution in the area. In addition, professionalism was called for. Currently the RE businesses were seen as too small and amateurish to be viable businesses capable to growth. The states and municipalities can set good examples in demonstrating RE energy solutions.

The five scenarios described here are rather different from one another, but they reflect certain basic assumptions that seem to exist in Finland. First, even the *Stagnation* scenario demonstrates *some* growth, and some scenarios are extremely optimistic. It seems that recent global growth in modern renewable energy are reflected in the RE capacity estimates. When the future views on different RE forms are compared, their starting levels must be kept in mind. Heat pumps have been fairly popular in Finland (Sulpu 2014), and their capacity is presumably much higher than that of solar panels or solar heat collectors. This is visible in the estimated rate of growth, as each energy form was given the index value 1 for the state at the end of 2013. *Solar business prosperity* demonstrates great faith in the future of solar applications in Finland, and all scenarios, apart from *Stagnation*, envision at least a ten-fold increase in only a decade for photovoltaics. The visions of strong growth are supported by recent development in other countries. For example, 21 000 MW of photovoltaic capacity was installed in the EU in 2011, which was almost half of all new power installations in the EU that year (EWEA 2012). Germany has been very active in this field, and the installed PV capacity grew from 75 MWp to 25 000 MWp in 2001–2011 (BMU 2012b).

Second, there is no scenario where significant growth in RE capacity would be combined with little governmental support. In *Solar business prosperity* the support is connected more to R&D and a decrease in regulation and bureaucracy, but governmental involvement is still necessary to some extent. *Stagnation* scenario shows that quite slow growth is seen as a distinct possibility, strongly connected with the lack of governmental support.

When the panel was asked about the greatest barriers to distributed RE capacity growth, the top three were not related to subsidies. Instead, insufficient services and business capacities were mentioned. It seems that growth might be generated by addressing the business sector. Of course, some of the most needed changes for the developing business sector were thought to be improved RE policies.

Emphasising the business environment rather than subsidies also reflects the aversion some interviewees had to subsidies. Interfering with free competition and market mechanisms, in order to support renewable energy, has occasionally been fiercely opposed in Finland (Varho 2006, 2007, Salo 2014). R&D funding and national low-interest funding could be more acceptable such as loans provided by the German KfW development bank (Koistinen et al. 2014, KfW 2014). Currently there is no Finnish funding program directed at RE on national level.

Third, an interesting topic that emerges from the scenario set is the role of citizens and consumers. When the panel was asked about obstacles for capacity growth, the most important ones reflected the underdeveloped business sector, such as lacking information and services.

In *Solar business prosperity,* the business sector has been renewed, and adequate services are available. Anyone investing in RE will find appropriate equipment and services, and permits and grid connections are easily arranged. In addition, small-scale production has been connected to ordinary consumers as traditional energy companies co-operate with small-scale producers, selling and marketing their energy. In *Electricity expansion*, on the other hand, the old businesses have to some extent been bypassed. The actors in the market are not so much producers and consumers as *prosumers*. Community-based solutions have become popular. Such development would benefit from local participation and from the distribution of the benefits of energy production locally, issues which have increasingly been mentioned as factors facilitating RE uptake (Rogers et al. 2008). Again, Germany is an interesting comparison, as private citizens owned 40% of RE capacity in 2010, often through co-operatives, and farmers another 11%. This has reflected both the lucrative RE policies and the German tradition of collective civic action (Buchan 2012).

For the future of distributed, small-scale renewable energy production in Finland, important questions thus arise: How will the RE business sector be able to form networks, co-operate and improve its business concepts? What will be the role of citizens – do they remain as passive consumers or take an active role? How will the government face the challenge of legislation that slows down the expansion of new business concepts, grid-connections and installations? Depending on the answers, the RE future in Finland can follow very different paths.

3.5 Emerging business models for distributed energy generation in Finland

3.5.1 Background

As in other EU countries also in Finland the energy provision system is undergoing a gradual change to a more profuse use of renewables. In the last decade much attention has been given to the development of large-scale wind power which together with forest biomass is one of the main renewable energy sources. Lately, the energy industry has recognized the promising potential of small-scale distributed generation (DG), not only in terms of new promising business opportunities, but also in terms of energy security. However, the factors that hinder the growth of this sector remain to be identified. This study aims at finding the main barriers and emerging business concepts for small-scale DG in Finland, and draws some conclusions for the policy maker.

3.5.2 Material and methods

The data for this study were collected through 12 semi-structured interviews with 14 experts from 11 Finnish organizations. The interviewees were all senior managers, advisers and researchers. They were selected based on their level of experience and knowledge of the Finnish distributed energy sector. The interview consisted of 4 main sections including the definition, 2) views, 3) obstacles to development, and 4) emerging business concept for DG in Finland. All the interviews were audio-recorded and transcribed verbatim by a professional transcriber. A thematic analysis method was employed for the analysis of the interviews' transcripts, which were coded using the qualitative analysis software ATLAS.ti 7.

3.5.3 Key results

The interviews revealed that one of the main barriers to the growth of small-scale DG in Finland is related to the development of the electricity grid which was not designed to withstand the impact of intermittent electricity supply from renewable sources. In this regard, the managers of the DSO[1] companies were particularly concerned about the rising costs that the network operators may face if the share of DG increases. Another two barriers to the integration of DG into the electricity grid were the lack of standardized procedures for grid connection and issues with smart meters. Administrative barriers such as the variability and complexity of building permit procedures and taxation law are also preventing the market development of small-scale energy generation. Another important element that is stopping the growth of small-scale DG is the fact that there are no governmental policies supporting it. According to the interviewees, a feed-in tariff scheme is not the best way to foster small-scale DG in Finland. On the contrary, one-time investment support and tax rebates were seen as the most appropriate solutions to promoting small-scale renewable energy generation due to the fact that they are more cost efficient and can instill confidence in the investors.

The interviews brought to light three emerging business concepts for small-scale renewable energy generation in Finland. They are consumption optimization, intermediator, and centralized solar PV model.

Consumption optimization model

In this model, the utility provides its customers with a turn-key solution that includes the generation equipment, grid connection, planning and installation. The main benefits to the customer include a significant increase in energy efficiency and cost savings. On the other hand, the utility can earn revenues from long-term energy services that aim to optimize the customer's energy consumption. This model has some downsides which include the still relatively high costs of generation equipment and installation, long payback time and low profitability of small domestic projects.

Intermediator model

This is the only model currently existing in Finland in which a user can sell its electricity surplus directly to another user. In this model it is the producer/customer who fixes the price, while the utility plays the role of an intermediator helping small energy producers to sell their electricity surpluses. The benefits for the users include the fact that this model can potentially solve the problem of lack of profitability connected to the current low pay-back rates. In addition, it can bring positive impacts on the economy of rural areas where farmers can be incentivized to engage in small-scale energy production.

Centralized solar PV model

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[1] DSO: Electricity distribution system operator

The main idea of this model is to give access to solar PV to those customers who do not have a suitable roof or do not want to get involved directly with energy generation. The company developing solar PV projects can earn new revenues from a novel market segment in which customers are more aware of sustainability issues and have a higher willingness to pay for green electricity. However, the main constraint on this model is that in Finland centralized energy installations, i.e. those generation projects that rely on the distribution network, are less competitive than building-integrated solutions, as the latter are not affected by electricity transfer fees and electricity tax.

3.5.4 Conclusions and discussion

Despite the growing interest in DG due to its positive effect in strengthening energy security and the possible new business opportunities that can open up around this technology, several factors were found to hinder its diffusion in Finland. The changes required to allow this technology to prosper do not only concern elements of the energy infrastructure such as the electric grid, but encompass a wider range of societal factors that need to co-evolve in the same direction. For instance, novel business models will be able to thrive only if consumers' preferences change and new windows of opportunities are created for companies. The state can play a significant role in steering the process of transformation of the Finnish energy system. However, other actors such as the energy industry also need to play their part. At the moment conflicting interests and lack of a shared vision of the future of DG in Finland are preventing positive synergies from unfolding. Supportive actions for small-scale DG cannot be based on policy incentives alone, although many welcome them. Measures for fostering growth should also be based on the lifting of market barriers that prevent the penetration of DG technology. A good example of what could happen in Finland, if along with policy support mechanisms, market barriers were not removed can be seen in wind power development. Although Finland for a few years has had a generous premium feed-in tariff, at the moment the wind power capacity installed is very low. The reasons are mainly connected to social acceptance and very complicated administrative procedures related to building permits. Thus, if the same is to be avoided for DG, much attention should be given to the removal of barriers as well as to the establishment of a favorable framework for technology diffusion.

4. Sustainability optimization of the local energy system

There are no verified and uniform criteria for the development of sustainability at system level for local energy systems. The Theme 3 study focused on the development of the sustainability of local energy systems. Two viewpoints were kept in mind during the study: decision making in local energy system planning (municipalities, villages etc.) and the business development of private companies (plant delivering, energy service and consultant companies). The objectives of the study are:

- to determine the most relevant criteria for the sustainability (environmental, economic and social) assessment of local energy systems;
- to form a generally applicable operation model for the sustainability assessment of the local energy systems;
- to verify the sustainability assessment model by testing it in demonstration cases;
- to support the development of the energy system and service products of the participating companies with the sustainability assessment of their demo cases
  - for example: development of energy villages for sustainable living based on local renewable energy sources and rational use of energy.

The local energy and sustainability theme contained the three separated working packages, WP1, WP2 & WP3. In WP1 the justified, applicable and comparable criteria set for the sustainability assessment of urban planning and local energy systems were defined. In WP2 LCA models for sustainability assessments of different local energy systems were developed. WP3 focused on testing and validating of the sustainability criteria and assessment model for the local energy systems of the demo-cases. The demo-cases that were used in this theme were:

1. Small-scale CHP, Eco-CHP demonstration plant, Taipalsaari , Ekogen Oy,
2. Bioethanol production, Bio-gasifier plant connected to bio-ethanol plant, Forssa, Envor Oy,
3. One-family house, Net zero-energy house, Hyvinkää,

4. Energy Village – Creating regional self-sufficiency, Närvijoki, Levon Inst./Vaasa UN.

The purpose of this study is to develop a general assessment framework for analyzing the overall sustainability (i.e. environmental, economic and social sustainability) of local, decentralized energy production systems. The framework consists of a several steps that should be considered when developing a sustainability of local energy production system (See Figure 4.1). The framework does not aim to be a detailed instruction for sustainability assessment, but rather provides a tool for decision-makers to sustainability assessment of different energy production options on a specific case.

4.1 Sustainability optimization framework

A framework, which was developed, was applied to assess different selected case studies. In the beginning three different case studies were selected for this purpose: combined heat and power production based on forest bioenergy, bioethanol production from crops and a net zero-energy house. Later, also Energy Village was selected as the fourth case study. These case studies are presented in Chapter 5 (Demonstrations).

The framework was implemented as a co-operation between researchers from MTT Agrifood Research Finland, Lappeenranta University of Technology and VTT Technical Research Centre of Finland Ltd. After drafting the framework, it was tested on the case studies and further reiterated to better serve the decision making process.

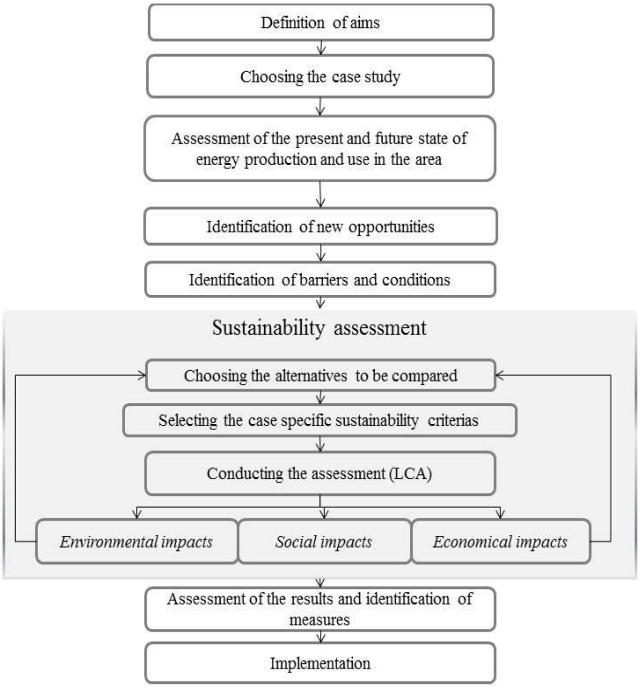


Figure 4.1. Proposed sustainability assessment framework.

The framework consists of steps, which include questions considering the system under study. Applying the framework for the maximum local sustainability, distributed energy production selection starts with defining aims of the study. The intended application of results impacts the scope of the study, the starting data needed and the interpretation of the results. The specific aims for the study can, for example, be determine the energy production system that causes the greatest greenhouse gas emission reductions or a solution that increases the use of renewable energy in the most cost effective way. Aim of the study can also be to bring out the environmental benefits of certain energy production systems when compared to alternative system or current situation. Some examples of possible aims are listed in Figure 4.2. In the goal and scope selection the sustainability aspects selected for the assessment are also mentioned. Examples of the sustainability aspects are presented with the case studies in the Chapters 5.1, 5.4, 5.5 and 5.8.

Determine the energy production system which…

- ...causes the greatests GHG emission reductions
- ...increases the use of renewable energy with most cost effective way
- ...causes the lowest environmental impacts
- ...boosts the local economy most
- ...improves the continuity and reliability of energy supply
- ...guarantees the affordable process for energy services
- ...enjoys the widest public acceptance

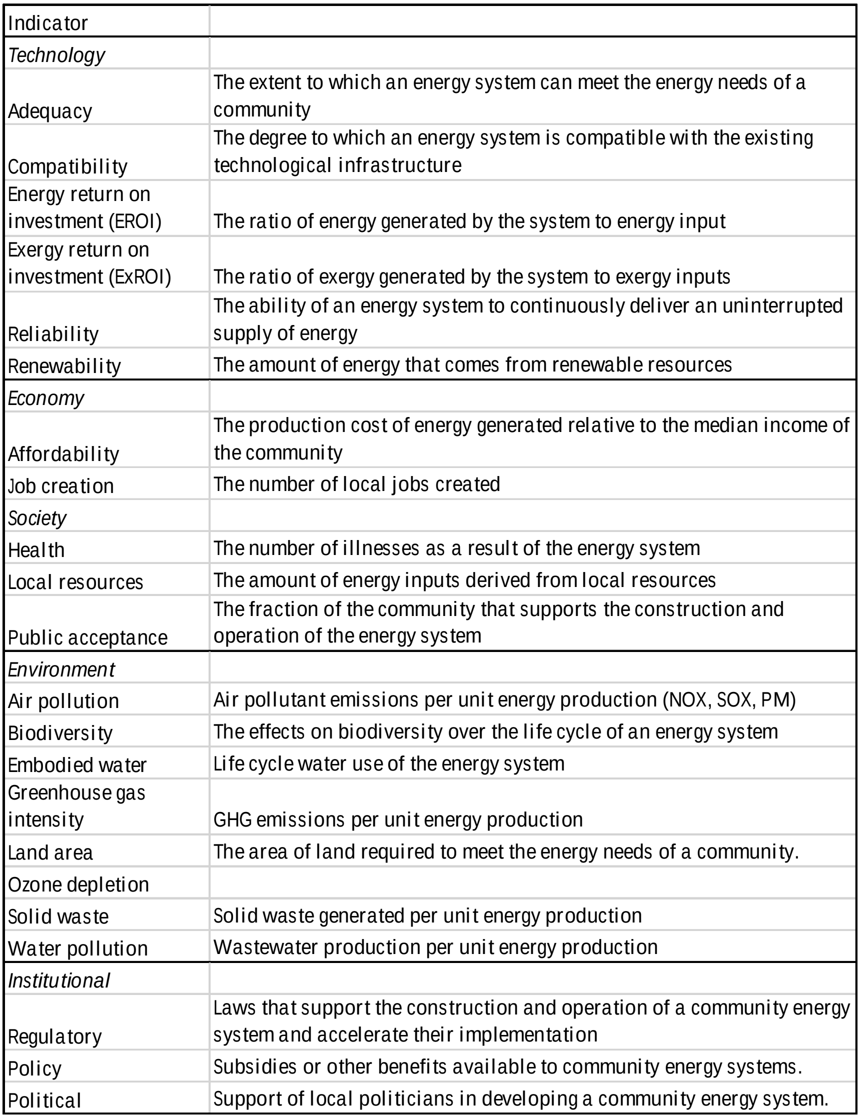
Figure 4.2. Examples of the aims.

The next step in the application of the framework is to choose the case study and system boundaries to be assessed. Setting the system boundaries properly is important for the degree of confidence in the results of the study and reaching the targets of the study. The subject of the study can be a single building, certain existing area, an area under planning or, for example, a single energy production unit where modifications intended to increase the renewable energy production are planned.

After the subject of the study is determined, the balance of energy production and consumption is formed based on the information available from the subject. Assessing the present and future state of energy production gives a comprehensive understanding of the situation where changes are planned. If the assessment is implemented in a single production unit, it is natural to outline the research area in the sphere of influence of this unit. If the assessment is planned for local the area, the possibilities of integrating energy flows with a local industry sector should be also reviewed.

In the identification of new barriers and opportunities, the solutions to meet the local energy consumption needs are mapped. The need for heat and cooling can be covered with heat pump solutions using waterways, wastewaters or geothermal energy. The existing district heating network might enable the cost- effective utilization of centralized heat production. Locating a wind or solar park in the area or improving a house stock might be the best way to reach the assorted targets. The aim of identifying opportunities is widely map different solutions and gain a high level of understanding of the overall picture. Identification of barriers is important in excluding and outlining the unsuitable and infeasible options for more-detailed consideration.

Sustainability assessment includes several stages whose aim is to produce more information about the sustainability of different options. When the stages just presented are finished, the options for comparison of alternatives need to be selected. The assessment is iterative (see Figure 4.1), and these selections might be needed to change after more knowledge is gained during assessment.



Indicator	
Technology	
Adequacy	The extent to which an energy system can meet the energy needs of a community
Compatibility	The degree to which an energy system is compatible with the existing technological infrastructure
Energy return on investment (EROI)	The ratio of energy generated by the system to energy input
Exergy return on investment (ExROI)	The ratio of exergy generated by the system to exergy inputs
Reliability	The ability of an energy system to continuously deliver an uninterrupted supply of energy
Renewability	The amount of energy that comes from renewable resources
Economy	
Affordability	The production cost of energy generated relative to the median income of the community
Job creation	The number of local jobs created
Society	
Health	The number of illnesses as a result of the energy system
Local resources	The amount of energy inputs derived from local resources
Public acceptance	The fraction of the community that supports the construction and operation of the energy system
Environment	
Air pollution	Air pollutant emissions per unit energy production (NOX, SOX, PM)
Biodiversity	The effects on biodiversity over the life cycle of an energy system
Embodied water	Life cycle water use of the energy system
Greenhouse gas intensity	GHG emissions per unit energy production
Land area	The area of land required to meet the energy needs of a community.
Ozone depletion	
Solid waste	Solid waste generated per unit energy production
Water pollution	Wastewater production per unit energy production
Institutional	
Regulatory	Laws that support the construction and operation of a community energy system and accelerate their implementation
Policy	Subsidies or other benefits available to community energy systems.
Political	Support of local politicians in developing a community energy system.

Figure 4.3. Example of sustainability criterias for local energy sustainability assessment (Hacatoglu et al. 2013).

The case-specific sustainability criteria are needed to be selected for the assessment and the selection should reasonably be done such a way that these are in line with the original aims of the study. Example of the sustainability criteria are shown in Figure 4.3.

Assessment can be made, for example, by using life cycle assessment (LCA), system analysis, a check list approach or a combination of these depending of the data quality requirements. For a comparison of alternatives with technical and environmental sustainability criteria, LCA models can be used. Some sustainability criteria measure, for instance, the impact on local residents, or support the need for qualitative methods and the need for those residents to be involved in the process with surveys or a public meeting at which their opinions can be heard and information can be gathered.

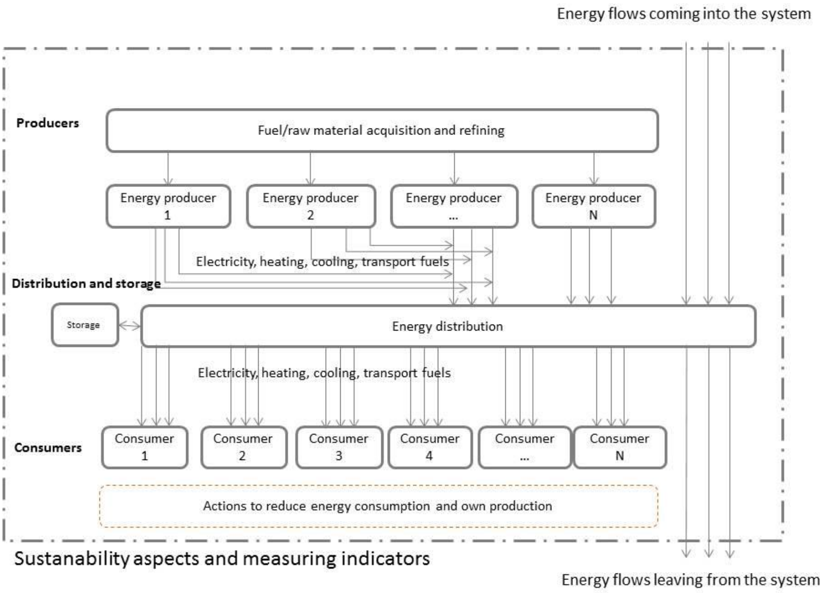


Figure 4.4. Information for sustainability assessment can be produced with modelling. Different production combinations and scenarios can be studied with for example LCA.

In sustainability assessment, there are several different aspects that need to be considered at the same time. Situations may occur, where the superiority of one option over another depends on the criteria selected. In selection of the locally best options for energy production, decision making matrices and weighting, methodologies can be used. In weighting the sustainability criteria are weighted relative to each other and also main criteria can be weighted. The weighting steps are based on value choices and are not scientifically based. In the case study of Energy Village, the weighting is made with the Analytic hierarchy process (AHP). In the case of Energy Village, a group of local people, energy entrepreneurs and experts form LUT and VU were selected to compare sustainability criteria in pairs. The weighting factors were then calculated based on the answers of this selected group. This process results are presented in Chapter 5.5.

4.2 Assessment of the results and identification of the measures

The purpose of this part of the work is to develop an assessment framework for analysing the overall sustainability of different local distributed energy systems. Assessment framework developed provides a tool for the decision making process and it can provide information for policymakers and other decision makers about different sustainability factors. The framework covers different aspects of the decision-making process from energy availability to the measuring of the sustainability impacts. The framework can be used such a way that case-specific sustainability aspects are considered, and thus the information provided for case-specific needs. Application of the framework is demonstrated through case studies at the same time that the suitability of one framework for different cases is assessed.

The assessment framework is developed for Finnish conditions, but the use is not limited to a certain geographical area. A systematic process helps one to gain a comprehensive view of the questions related to the assessment of different energy systems, and thus helps to include sustainability aspects in decision making.

5. Demonstrations

5.1 Bio-refinery plant connected to bio-ethanol plant

5.1.1 Sustainability assessment

We applied the sustainability assessment methodology developed in theme 3 to the bio-ethanol plant (see Chapter 4, Figure 4.1). This chapter presents step by step how the sustainability assessment of a bio-ethanol plant could follow that methodology.

1. **Definition of aims:** The aim is to produce liquid bio-fuels for transportation and achieve greenhouse gas emission savings compared to fossil fuels.
2. **Choosing the case study:** The case study will be bio-ethanol production from grain.
3. **Assessment of the present and future state of energy production and use in the area:** There is an EU obligation that 10% of transportation fuels should be bio-based in 2020. However, in Finland the target for bio-fuels will be 20% in 2020. Because of those targets, there is a need to increase bio-fuel production capacity in Finland.
4. **Identification of new opportunities:** There is a need to produce more bio-fuels compared to the current situation in Finland. Also, there are not any bio-ethanol plants using grain as raw materials.
5. **Identification of barriers and conditions:** An obstacle could be that there is not enough grains available in appropriate procurement area or the price is too high. Also, the emissions from cultivation in Finland are quite high, so there could be problems meeting sustainability criteria in Renewable Energy Directive (2009/28/EC).
6. **Choosing the alternatives to be compared**: Bio-ethanol will be produced from grains, e.g. barley, wheat or triticale. Energy for bio-ethanol plant could be produced with biogas, which uses distillers grain from ethanol production as a raw material, or with wood chip CHP plant (Figures 5.1 and 5.2). In the second case, the bio-methane could be used in transportation. Other alternatives could be that only heat is produced with wood chips, and electricity comes from national electricity grid (Figure 5.3). In that case, the electricity could be ordinary Finnish electricity or green electricity, e.g. hydro power.
7. **Selecting the case specific sustainability criteria:** Greenhouse gas emissions should be included to assessment because of EU Directive

2009/28/EC. Also, eutrophication should be included as cultivation causes eutrophication of water systems. Other relevant sustainability criteria in the case of bio-ethanol could be land use, biodiversity, effect on food price, and new jobs created in the area.

8. **Conducting the assessment (LCA):** Life cycle assessment could be done with LCA software, e.g. SimaPro.
9. **Assessment of the results and identification of measures:** The sustainability of different alternatives is compared according to results from LCA. There is also an opportunity to make some changes to process the plan in order to achieve the best results.
10. **Implementation:** If the sustainability assessment results are good, there is a need to carry out an environmental impact assessment. Also, all requisite permits need to apply, e.g. planning permission and environmental permit. After that, you could start to build a bio-ethanol plant.

This approach was quite suitable to assess bio-ethanol case study. All aspects in the methodology are such that need to be taken into account when starting to plan new bio-energy project. With LCA approach, it was possible to test how different aspects in the pathway would affect to the environmental performance of the whole chain. This comparison helped in choice of the best way to implement the project. Process arrangements are described in Figures 5.1, 5.2 and 5.3.

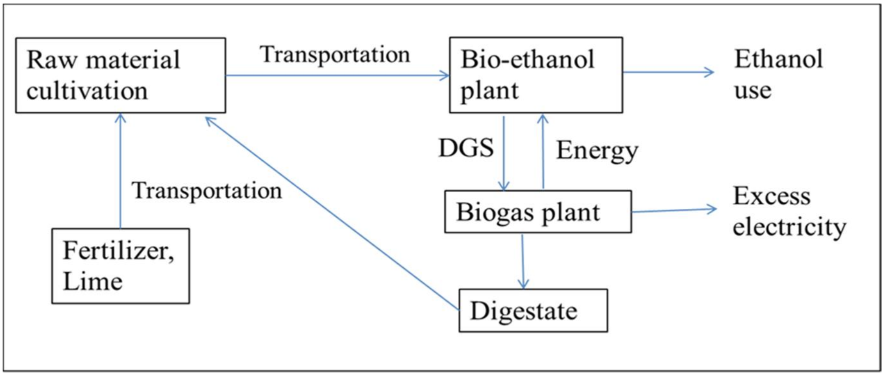


Figure 5.1. Bio-ethanol production when energy for bio-ethanol process is produced from distiller’s grain in the biogas process. Excess electricity from biogas CHP is sold to national grid and digestate is used as fertilizer in raw material cultivation.

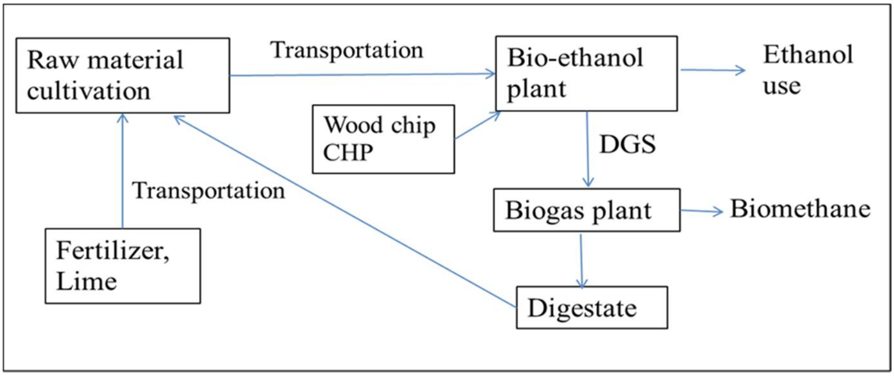


Figure 5.2. Bio-ethanol production when energy for the bio-ethanol process is produced in wood chip CHP. Distiller's grain is used as a raw material in the biogas process which produces bio-methane for transportation use. Digestate from biogas plant is used as a fertilizer in raw material cultivation.

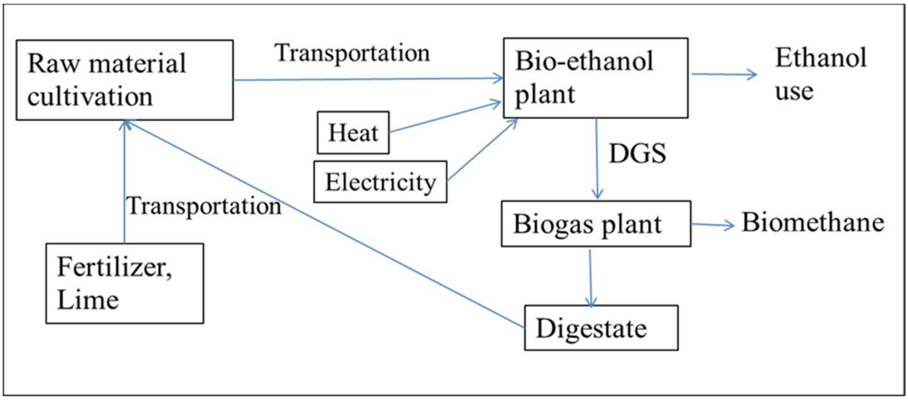


Figure 5.3. Bio-ethanol production when heat for the bio-ethanol process is produced with wood chips and electricity comes from the national electricity grid. Distiller's grain is used as a raw material in the biogas process which produces bio-methane for transportation use. Digestate from the biogas plant is used as a fertilizer in raw material cultivation

5.1.2 Mass and energy calculation model

The demonstration of a combined bio refinery is based on the Envor Oy bio refinery project, which comprises from both first generation bioethanol and residual biogas production. Research is done by student Mikko Hietaranta as his master thesis. The goal of this project is to produce annual amount of 100 000 tons of

99.8% ethanol for use as an additive in gasoline, as 5% can be added to common gasoline (E5) in the EU. In Finland, the most used types of gasoline contain 5% ethanol in 98E5 and 10% of ethanol in 95E10. The results of this model have been used with the sustainability assessment for the bio refinery not included with this report.

As a by-product, fermentation produces residues that can either be used as animal feed (DGS and DDGS) or processed to methane via anaerobic bio gasification process. This biogas process also produces anaerobic sludge as a by-product, which can be used as a fertilizer since it has a high content of soluble nitrogen and phosphorous.

The model is based on starch-based feed, preferably grain, such as triticale and wheat grain; the simplified operation is illustrated in Figure 5.4.

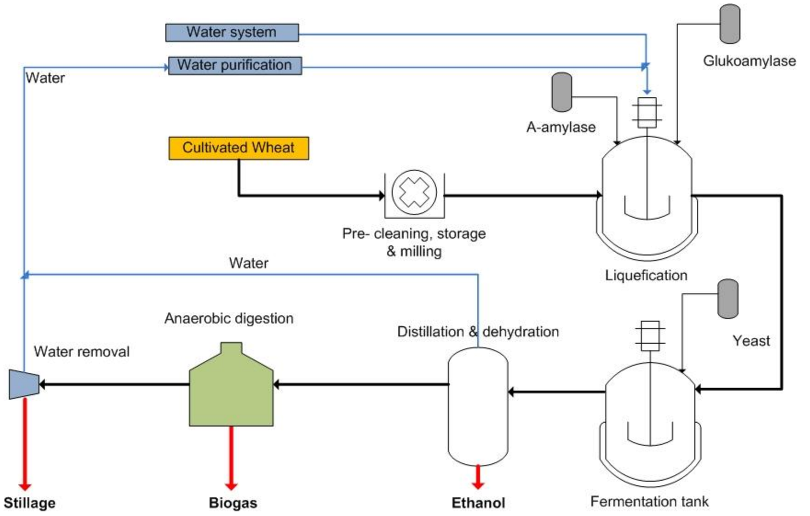


Figure 5.4. Simplified process model & mass flow for combined biorefinery.

Biorefinery was divided into 8 separate processes for the model; the division is presented in Figure 5.5.

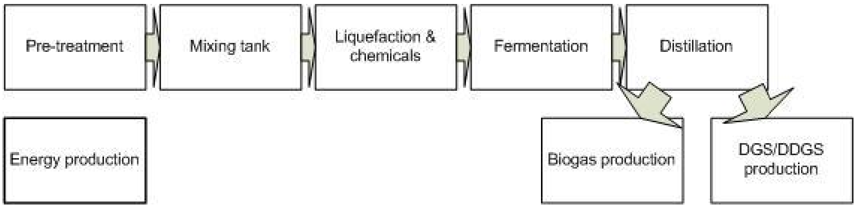


Figure 5.5. The division of processes for modelling.

From these processes Biogas production and DGS/DDGS production use the same substance, which is the stillage from distillation process that contains all dry matter left in the process, so they are considered as alternative processes. However, after consideration, DGS production as animal feed was left out and the view was focused more on energy production. Only energy production possibilities are included in this report.

The main objective for this modelling was to calculate three possible scenarios for the bio refinery:

1. Energy production from wood chips in a CHP plant, biogas sold
2. Energy production from produced biogas
3. Heat production from wood chips in CHP plant, biogas sold and electricity bought from grid

These scenarios are explained in more detail in Section 5.1.1. Sustainability assessment made by Taija Sinkko. The model was built on Microsoft Excel spreadsheet with data provided by Envor Oy and literature on the subject. It was essential to separate the main flow into water and dry matter flows and further to starch from the start because of multiple biochemical reactions affecting the flows physical characteristics, most importantly the flow's heat capacity. The accurate technical data and results are confidential and are omitted from this report. The descriptions of the processes and calculation methods have been included.

In pre-treatment, the grain is milled and cleaned from impurities; this process has no heating requirements. In mixing, the milled grain and water are combined to produce dough, and the heating requirement depends on the ambient temperature of water input. After this process, the volumes increase significantly along with electricity requirements.

In liquefaction the starch contained within the grain that has been exposed by milling and mixing water is degraded to sugars. The degradation is run by adding of enzymes and optimizing dough temperature for the enzymes to react as efficiently as possible. First, α-amylase is injected and temperature rises to 120 °C for fast cooking the starch to dextrose. Then temperature is lowered to 90 °C and glucoamylase is injected to break the dextrose into monohydrates; sugars like glucose. In this model the sugars formed were presumed to be glucose (Drapcho et al. 2008). The heating requirements for this process are high, as well as water consumption. The reaction for starch-to-glucose was calculated by following equation:

$$C_6H_{10}O_5 + X_{Glucose}H_2O \rightarrow X_{Glucose}C_6H_{12}O_6 + (1 - X_{Glucose})C_6H_{10}O_5.$$

Liquefied mash is cooled to 35 °C and fermented with added yeast. After this process, approximately 1/3 of the dry matter is converted to ethanol, 1/3 to carbon dioxide and 1/3 is left over (crust, unreacted starch etc.). Stillage with 20% dry matter contents is removed and moved to the anaerobic digestion process before binary distillation process of water-ethanol mixture.

The distillation process was modelled via the McCabe-Thiele method, which is ideal for binary distillation systems. First the vapour/liquid equilibrium is determined, then the minimum reflux ratio is calculated along with feed stage and the number of stages needed is determined from the plotted VLE and reflux lines. A number of the stages are the same as a number of plates needed for the distillation column, which gives size of the distillation column, and finally the total energy consumption of the distillation process can be determined (Jevric & Fayed 2002). An illustration of McCabe-Thiele method is given in Figure 5.6.

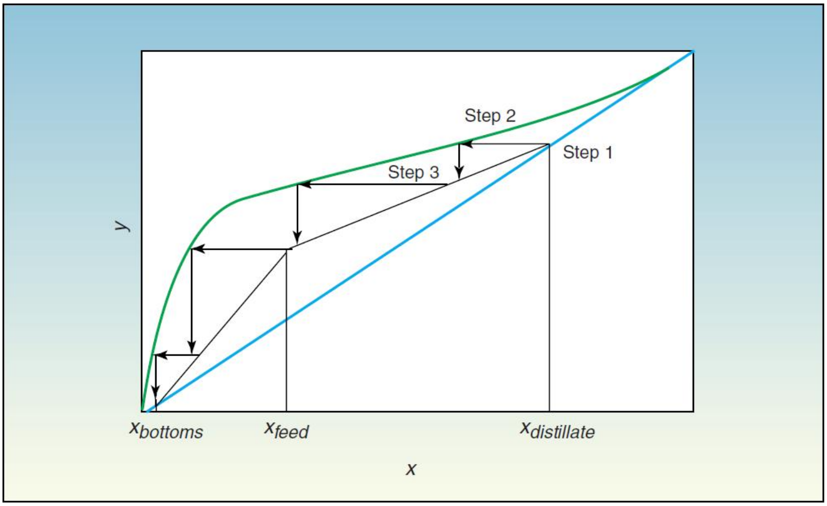


Figure 5.6. McCabe-Thiele calculation method for binary distillation systems (Jevric & Fayed 2002).

Distillation was the most heat consuming process, up to 80% of total consumption, while fermentation produced a slight amount of heat via yeast metabolism. Electricity consumption was connected to the mass flow volume, as pumping water and mash that has a high viscosity requires a large amount of energy.

Anaerobic digestion was modelled by biomethane potential data received from Envor, and it will not be included in this report. As a result of the stillage remaining from distillation was digested to methane with good efficiency and remaining anaerobic stillage is sling dried, leaving water to be purified and recycled back to the biorefinery. Anaerobic stillage is the main pathway of water loss from circulation, as drying matter over 30% DM content is not energy-efficient.

The total heat requirement for the plant was calculated to be 240 GWh annually with an electrical consumption of 15 GWh. The energy production from biogas was approximated to be 190 GWh thermal energy and 194 GWh electrical energy in annual production. From these, we can see that electricity is produced in excess, whereas thermal energy would need additional 50 GWh annual production. The results are presented in Figure 5.7.

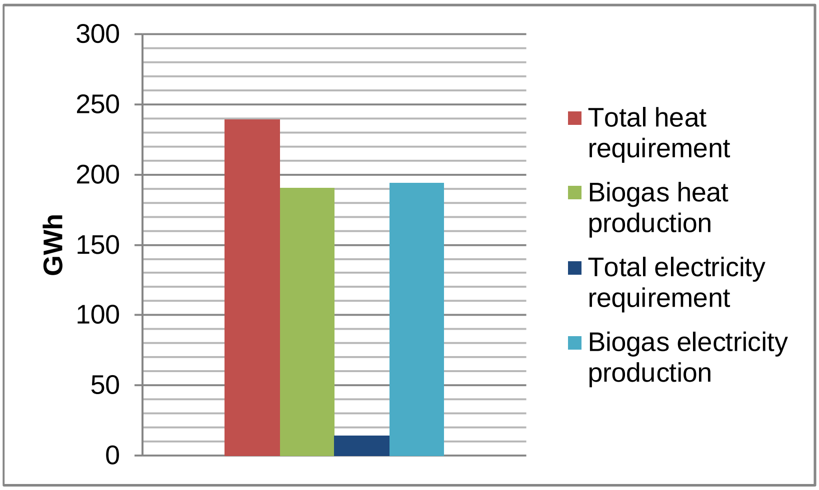


Figure 5.7. Annual energy requirements and biogas production capacity.

In order to meet the total heat and electricity production by wood-chip fuelled CHP plant, the total capacity of the plant would need to be 33 MW, as for scenario 1. For heat only, the need would be 31 MW plant, leaving the electricity to be bought from the grid as in scenario 3. The biogas to be used as an energy source for a 6 MW boiler would meet the annual heat demand which represents scenario 2. As DGS production for animal feed was omitted from the alternatives, the mass flows of each scenario plants are identical. The results are illustrated in Figure 5.8.

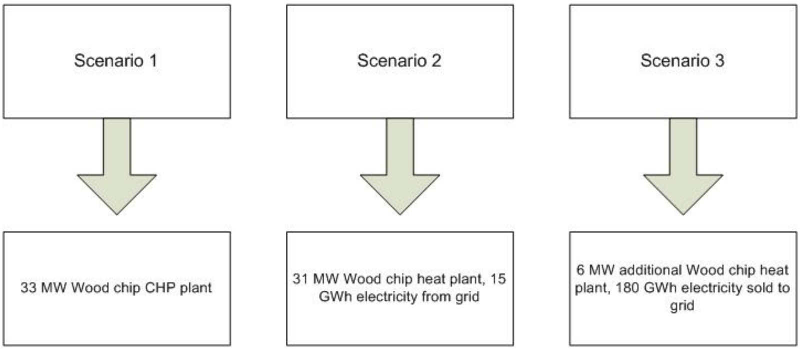


Figure 5.8. Energy production results for all scenarios.

With all of the previous scenarios, the annual ethanol production would be 100 000 tons, which would require 374 000 tons in total of grain, chemicals and additives. The water consumption of the plant is over 1000 000 tons annually, but can be recycled with high efficiency, although it could not be evaluated as the water purification system information was not available. With a drying efficiency of 30% DM, the annual anaerobic stillage production would be 240 000 tons and could be returned back to the grain production fields. The final energy consumption is determined by the efficiency and amount of heat exchangers within the refinery's mass circulation, as thermal energy is the main subject of consumption.

5.2 Geoenergy

A test platform for studies and testing of bedrock, water, soil, sediment energy or energy under asphalt and concrete surfaces is located at Vaasa UN in Vaasa.

At the moment sediment energy and asphalt energy measurements are going on. Vaasa Suvilahti Housing Fair 2008 area is one of the demonstration areas of regional energy solutions. Facilities for TRT-measurements and DTS-measurements are available.

Equipment has been developed effective enough to heat block houses, hospitals, hotels, libraries, schools, kinder garden etc. Cooling besides or instead of heating is becoming more important. The general public attitude is positive to geoenergy, because the energy output does not cause harm to the environment.

The establishment of the geoenergy research platform is one of the priorities at the University of Vaasa. We have designed the infrastructure to study bedrock, soil, water, sediment and asphalt heat. The structure allows the basic research and product development to be utilized on the platform. For those purposes, a TRT-car (TRT Thermal Response test) has already been built for studying energy wells. The acquired DTS (distributed temperature sensing) equipment allows continuous monitoring of energy wells. Advantages of geoenergy to companies are listed in Table 5.1. Use of the sediment heat as a regional system was demonstrated for the first time at Vaasa Housing Fair 2008.

Table 5.1. Advantages Geoenergy for companies and DESY partners.

	For companies	For DESY partners
Technology	• A platform to test different technical solutions • Publicity and PR-values • Possibility to compare different technical solutions	• Window for hybride solutions • New potential technical solutions
Local Energy Planning	• A company can be a part in larger project without creating it all itself • Possibility to develop own products also in regional scale.	• Unique entirety. • Regional solutions • Different points of view, plus and minus sides, barriers and bottlenecks • Regional impacts of sustainable energy management • Possibility to generalize procedure or model
Business Concepts	• Business model for own technical solutions • Business models • Own solutions alone or as a part of larger system	• Regional economy; details and entirety
Sustainability	• Possibility to develop own technical solutions • Possibility to get knowledge which could be difficult or expensive to get • PR-value; community responsibility	• Sustainable development; entirety and detailed parameters; social and environmental impacts, economy • Promote independence of fossil fuels and prevent climate change

5.3 Eco Energy Centre

5.3.1 Hybrid energy system plan and operation

Eco Energy Centre is a building group (Fig. 5.9), which has a micro heating network serving heating of the buildings (Sipilä et al. 2014). The total floor area of those buildings is 1500 m^2. Heating demand is 219 MWh/a. The buildings have a radiator heating system served by a direct electricity heat boiler.

The energy system is changed to a ground heat pump (40 kW_{th}) with 4 boreholes per 200 m each. Later a 15 kW solar PV or a 20 kW wind power equipment will be installed. Electricity car loading should be possible. Electricity trade is also an option in the future.

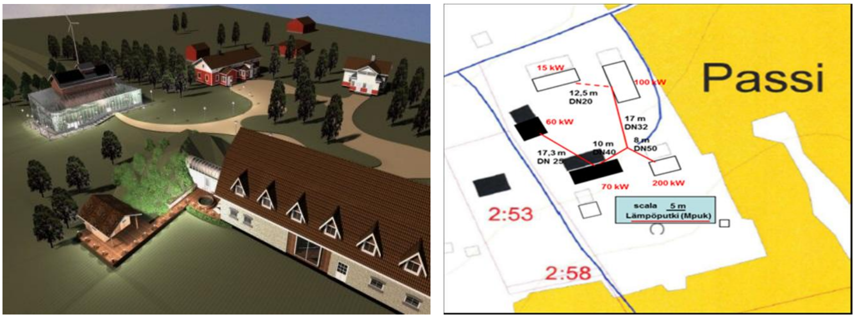


Figure 5.9. Visualisation of Eco Energy Centre.

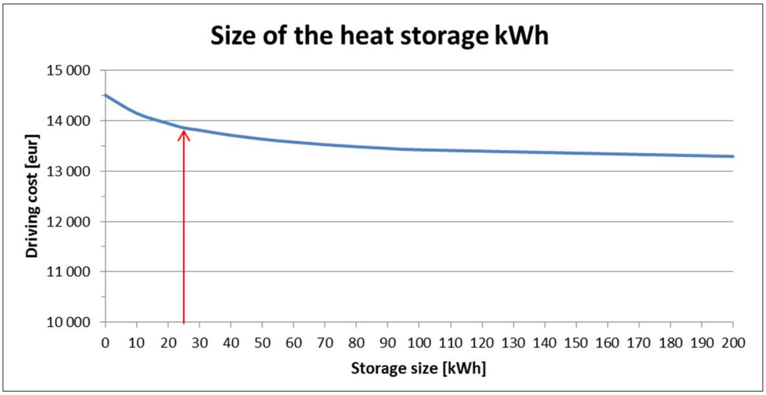


Figure 5.10. Optimising of heat storage for the hydride energy solution in Eco Energy Centre.

A steel tank with a volume of 1000 l and capacity of 25 kWh (ΔT= 30 °C) is installed as a short-time heat storage (Fig. 5.10). Figures 5.11–5.12 show solar radiation and wind circumstances in the area of Karjalohja, Southern Finland.

The following figures (5.13–5.16) present 1 week (w 20) simulation in a normal year, when solar PV or wind power is used with heat pump and electricity purchase is included as well. The money saved gives 6.5 years pay-back time with 5% of interest compared to the direct electricity cost of heating. If Solar PV panels of 15 kW are included, the pay-back time is 9 years. Wind power 20 kW with a heat pump also gives a pay-back time of 9 years.

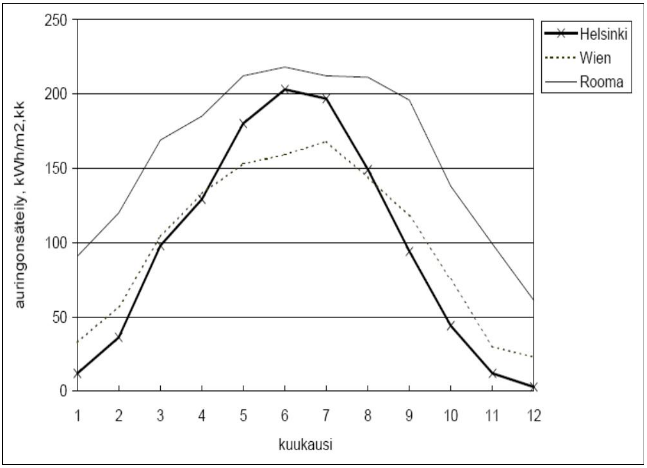


Figure 5.11. Solar radiation in Southern Finland.

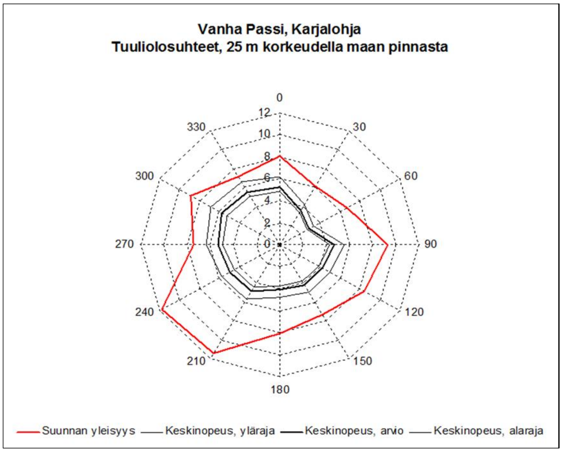
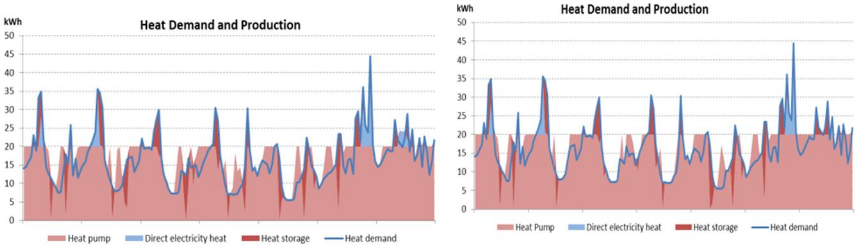
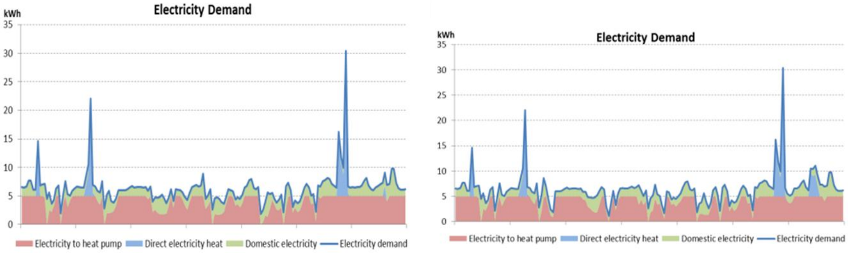


Figure 5.12. Wind circumstances in Karjalohja.



a) b)

Figure 5.13. Heat demand and production when solar (a) or wind (b) is available in week 20, April.



a) b)

Figure 5.14. Electricity demand and generation when solar (a) or wind (b) is available in week 20, April.

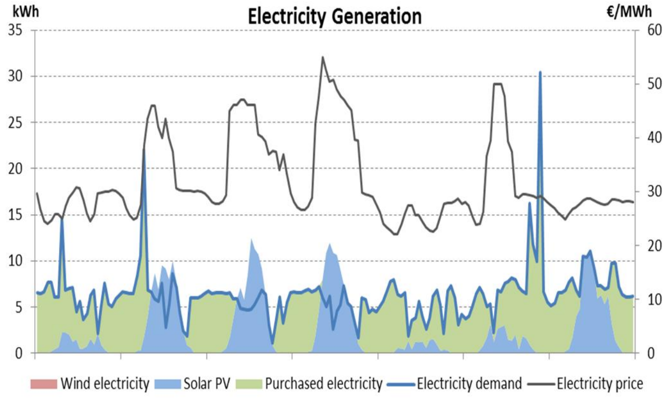


Figure 5.15. Heat pump, heat storage and solar PV in week 20, April.

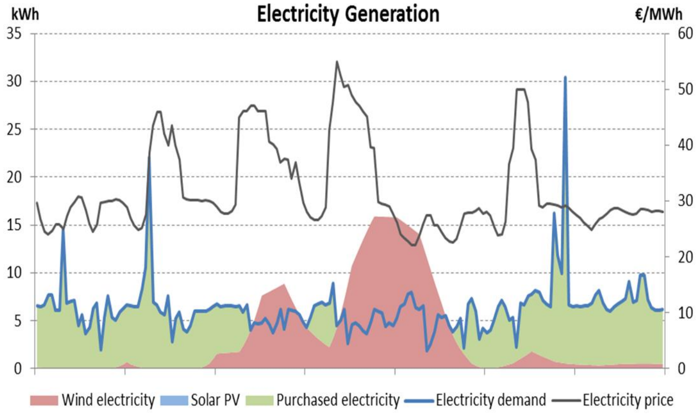


Figure 5.16. Heat pump, heat storage and wind power PV in week 20, April.

More weeks are shown in Appendix A.

5.3.2 Sustainability assessment of the hybrid system

The sustainability assessment for this case only considered greenhouse gas emissions. Four different cases were assessed. In Case 1, there are ground-source heat pumps with storage and 100 m^2 (15 kW) solar panels. Case 2 is the same as Case 1, but there is no heat storage, and in Case 3 there are ground-source heat pumps with storage but no solar panels. In addition, a reference case was studied where only electric heating was used.

The greenhouse gas emissions of electricity production were calculated using the monthly statistics from Energiateollisuus ry (see Figure 5.17). This electricity production profile was used to calculate the impacts resulting from the grid electricity used by the different cases. An average of the fuel mix 5-year period between 2006–2011 was used.

In order to calculate the electricity production of the solar panels, information from the NASA servers for coordinates 60°38', 24°51 was used. Impact of cloudiness was also taken into account. Electricity production per hour was calculated using the HOMER optimisation tool (http://homerenergy.com).

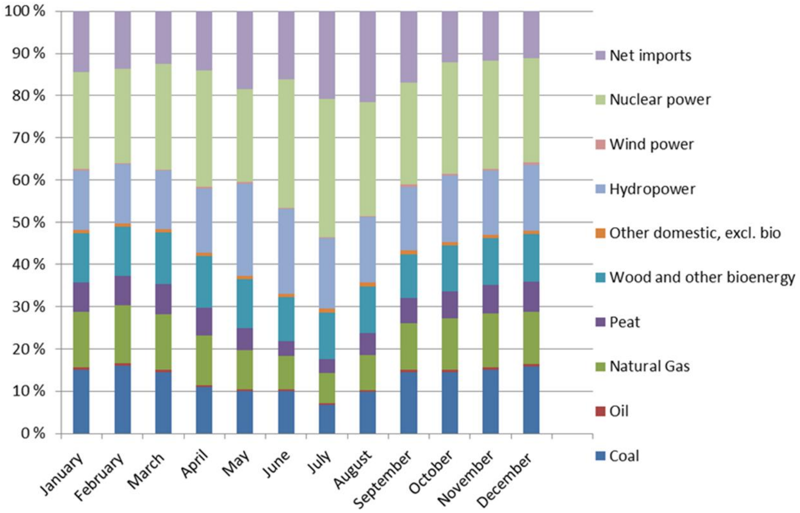


Figure 5.17. Average monthly fuel mix of the Finnish electricity production.

In addition to emissions from electricity production, also greenhouse gas emissions from the manufacturing of ground-source heat pumps and solar panels were included in the study. Emissions related to the production of the heat pumps were also taken from Saner et al. (2010). As the heating demand in Saner et al. (2010) was approximately 8% of the heating demand in the Karjalohja case, data from Saner was extrapolated to be representative of it. On the other hand, it produces excess electricity from March to September through solar panels.

Data concerning the manufacturing of solar panels were taken from the Eco invent database (Eco invent Centre 2010). An average of three different panel types was used (single crystalline silicone, poly crystalline silicone and CIS).

Emissions were calculated over 20 years. It was assumed that the life-time of the solar panels would be 20 years as well.

Results and discussion

The highest emissions were caused by the reference case, while the lowest was found in Case 1 (Fig. 5.18). However, the difference between Cases 1–3 was minor, reflecting the fairly low importance of solar panels and heat storage. Emissions were mainly reduced due to the introduction of ground-source heat pumps. Total emissions in the reference case were 895 526 kg CO_2 eq., while they were 588 796, 600 162 and 618 931 kg CO_2 eq. in Cases 1, 2 and 3, respectively.

Emissions caused by the manufacturing of solar panels were relatively low, approximately 15 tons CO_2eq. Manufacturing of ground-source heat pumps caused higher emissions, approx. 120 tons CO_2eq. Net saving in emissions resulting from ground source heat pumps was thus approx. 277 tons CO_2eq.

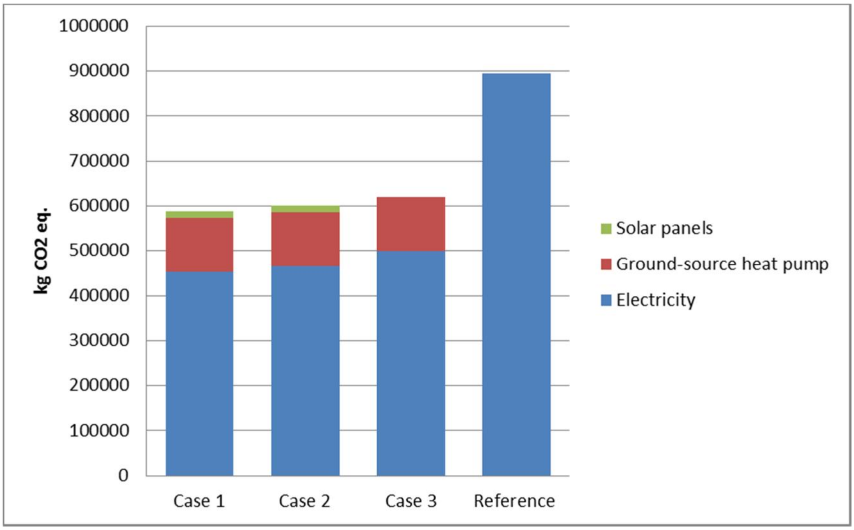


Figure 5.18. Total GHG emissions in the different cases.

Monthly GHG emissions in the different cases excluding production of heat pumps and solar panels are presented in Figure 5.19. The relative difference between cases 1 and 3 (i.e. the role of solar panels) is the greatest from April to June. In July, the difference was only 3% due to the low electricity consumption. The largest absolute difference between the two scenarios was in March when the electricity consumption is high but there is also already more solar radiation available.

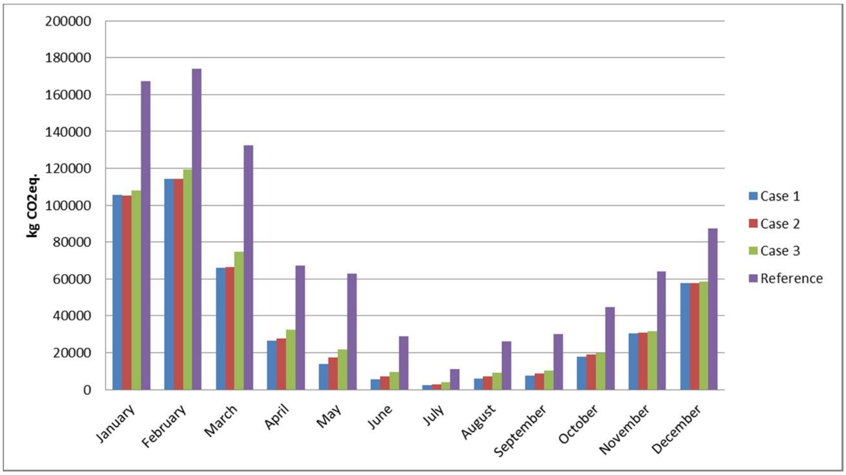


Figure 5.19. Monthly GHG emissions in the different cases (excluding production of heat pumps and solar panels.

5.4 Eco-CHP demonstration plant

5.4.1 Introduction to the concept

The Eco-CHP case demonstrates a small-scale combined heat and power production unit (CHP) developed by Ekogen Oy in collaboration with Lappeenranta University of Technology. Ekogen Oy's CHP plant is based on the combustion of wood pellets with a fuel power of 500 - 1000 kW in an Ariterm multijet boiler. The CHP-unit can also use wood chips as fuel in the future. The heat from the combustion gases is transferred to the air via a heat exchanger and used to produce electricity in an externally fired Turbec T100 micro gas turbine (EFMGT). The use of hot air as the working fluid in the micro gas turbine system ensures a long lifetime for the turbine blades and low maintenance operation. The unit generates a total of 100 kW of electricity and 300 kW of heat in the form of hot water.

The key idea of mobile small scale CHP units, is the efficient production of electricity and district heating water close to the consumer with renewable fuels harvested near the plant. Funding for the capital investment is also easier to achieve due to the high modularity of the CHP-unit. The units are also extremely user friendly. After the construction phase and an initial testing period of one such CHP-unit, the unit can be remotely operated and staff will only be needed on site during fuel supply and weekly inspections (Ekogen 2012).

The first CHP-unit built by Ekogen Oy was in 2012 and is located in the Saimaanharju region in the municipality of Taipalsaari (Figure 5.20). The total heat demand of the local district heating network is on average 7000 MWh/a (Neuvonen 2014). The CHP-unit replaces a part of the heat that would otherwise be produced with the combustion of imported natural gas, thus increasing the regional energy self-sufficiency.

Figure 5.20. Ekogen CHP-unit in Saimaanharju.

The research done by student Henri Karjalainen, as his Master's thesis work at the University of Jyväskylä, focused on two main objectives: firstly building the CHP-unit model (Figure 5.21) and running process simulations with it, and secondly connecting the model to the area simulation model constructed by Miika Rämä at VTT Otaniemi (Figure 2.18). A simplified version of the complex process diagram regarding the material and energy flows of the CHP-unit is shown in Figure 5.21.

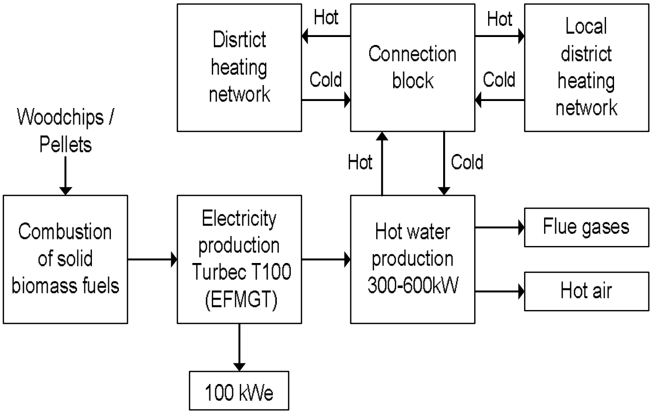


Figure 5.21 The simplified process diagram of the modelled CHP-unit and the connection block between the CHP-unit and the hybrid energy network system.

5.4.2 Steady-state modelling of the CHP unit

Initially, the material and energy balances of the building blocks shown in Figure 5.21 were modelled with an Excel spreadsheet calculation. The spreadsheet calculations were then compared with data provided by Lasse Koskelainen (Ekogen Oy) and found to be within the limits of error. In the second phase of the project, the model was converted to work in MATLAB for more comprehensive simulations based on the separate feedback and ideas exchanged with Ekogen Oy and VTT. After the model had been transferred from Excel to MATLAB, it was initially tested by simulating the effects of fuel moisture content and air to fuel ratio on the adiabatic combustion temperature of woody biomasses. The simulation was done for wood pellets and woodchips, but due to only a small deviation in dry matter composition between the two fuels (Table 5.2), the simulation results are only displayed for wood pellets (Figure 5.22). All the simulations made by the model are standardized to a reference- and fuel temperature of 25 °C, and no heat losses are taken into account. Also the temperature of used combustion air is 312 °C, which is preheated in the EFMGT process from the initial temperature of 25 °C.

Table 5.2. The dry matter composition of woodchips and pellets used in simulations.

Composition (% w/w)	C	H	N	S	O	Ash
Woodchips	50	5.7	0.3	0.04	41.96	2.0
Pellets	52	6.0	0.2	0.02	40.28	1.5

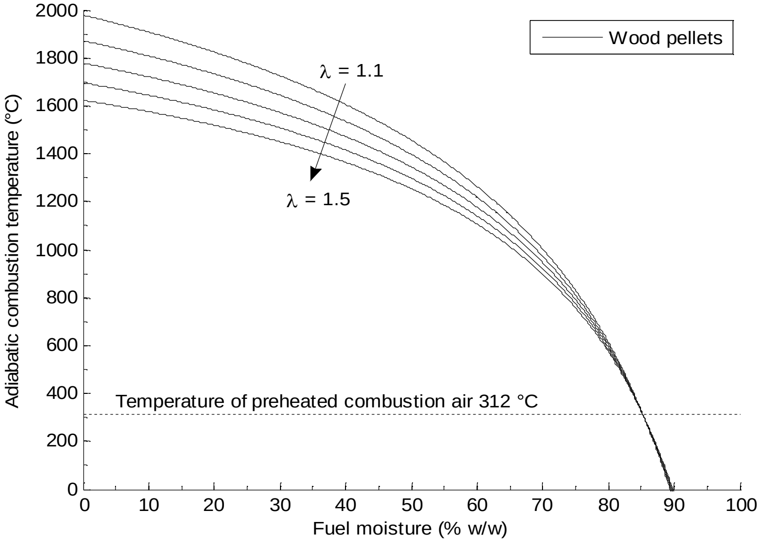
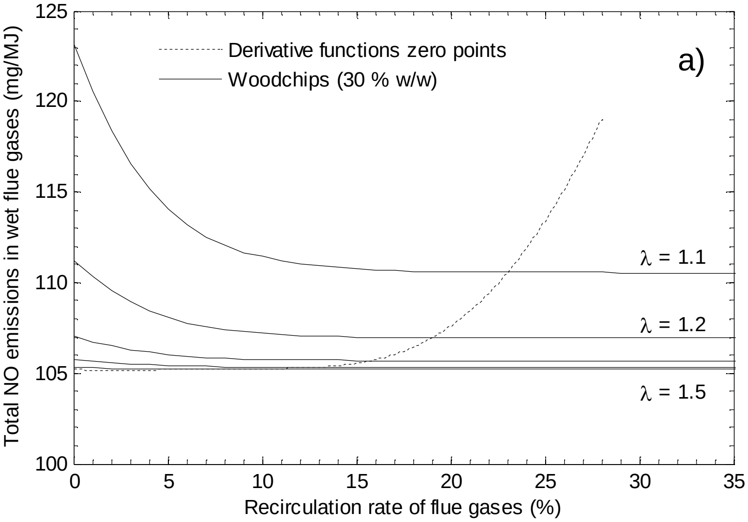


Figure 5.22. The adiabatic combustion temperature of wood fuels as a function of fuel moisture and air to fuel ratio (λ).

The results for simulated adiabatic combustion temperatures seem to agree with adiabatic combustion temperatures for woody biomasses found in literature (Salzmann et al. 2001). After the initial simulation, the second objective was to find an air to fuel ratio which would minimize the formation of thermal NO in the boiler. This would in turn reduce one variable from further simulations. The effect of the air to fuel ratio and flue gas recirculation rate on the total NO emissions was simulated, and the results are displayed for woodchips and wood pellets in Figure 5.23.



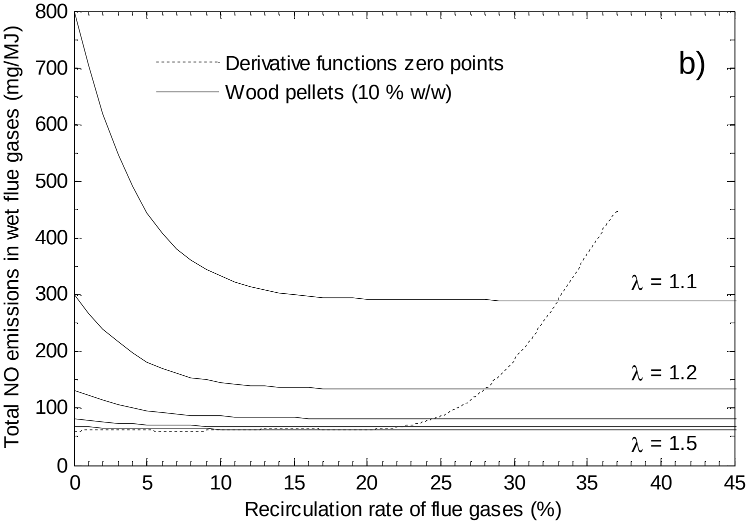


Figure 5.23. The effect of flue gas recirculation rate and air to fuel ratio on the formation of total NO emissions for woodchips (a) and pellets (b). The total flue gas residence time in the grate furnace was 1.215 s for both of the fuels.

The right hand sides of the dashed lines in Figure 5.23 represent a region where there is no reduction in thermal NO formation with an increasing recirculation rate of flue gases for a given λ. From the given figures, it was easy to deduce, that for both wood chips and wood pellets an air to fuel ratio of 1.5 minimizes the formation of thermal NO in the grate furnace. This in turn frees the gas recirculation parameter to control the temperature of flue gases exiting the boiler to the first heat exchanger. The material of the heat exchanger placed after the grate furnace has an imaginarily picked maximum thermal resistance temperature of 1150 °C. This sets restrictions on the flue gas temperature exiting in the furnace. A simulation shown in Figure 5.24 was made to ascertain the effect of flue gas recirculation on the flue gas exit temperature for both fuels with an air to fuel ratio (λ) of 1.5. The two dashed lines in Figure 5.24 represent the temperature boundaries of minimum temperature for thermal NO formation 1400 °C (Lau J.H.W 1995) and the maximum temperature tolerance of the heat exchanger 1150 °C.

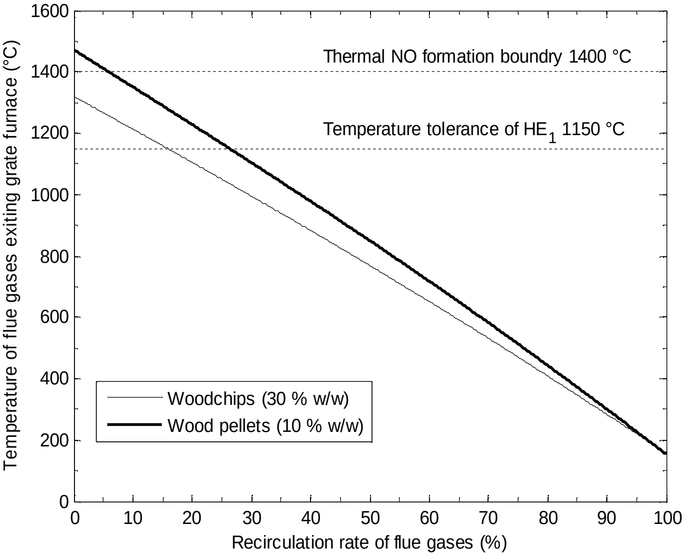


Figure 5.24. Temperature of flue gases exiting the grate furnace as a function of flue gas recirculation rate for wood chips and wood pellets with moisture contents of 30% w/w and 10% w/w respectively.

At the turbine inlet of the EFMGT process, the working fluid (air) with mass flow of 0.7833 kg/s must reach an extremely high temperature of 950 °C to achieve its theoretical net electricity production of ~ 100kW (Kautz & Hansen 2007). To insure heat exchange between the hot flue gases and the air of the EFMGT process, the temperature of the flue gases led to the heat exchanger should exceed the temperature of the process air exiting the heat exchanger (950 °C).

When we take into account the maximum temperature resistance set for the heat exchanger (1150 °C), we derive from Figure 5.18 that an exit temperature of ~ 1050 °C can be achieved for the flue gases with gas recirculation rates set to

23% and 30% respectively for woodchips and pellets. All the heat exchangers in the model were modelled as counter current heat exchangers, and it was assumed, that the heat exchangers would never reach 100% heat exchange effectiveness. To achieve a reasonably high heat exchange effectiveness of 75–80% and a maximum electricity production of 100kW, we need a fuel power set to 820 kW when the flue gas exit temperature was set to 1050 °C. From this information, it was possible to determine the fuel consumption (kg/h) of wood chips and pellets in achieving 820 kW fuel power as a function of fuel moisture content (Figure 5.25). However, this fuel power is larger than the fuel power used in Ekogen Oy's calculations. This was predictable with the parameter values described earlier. The combined effect of larger fuel power and the estimation of no heat losses in the model lead result in a heat production of ~600 kW of hot water, which is quite large in comparison to Ekogen Oy's presented values of 300 kW of hot water.

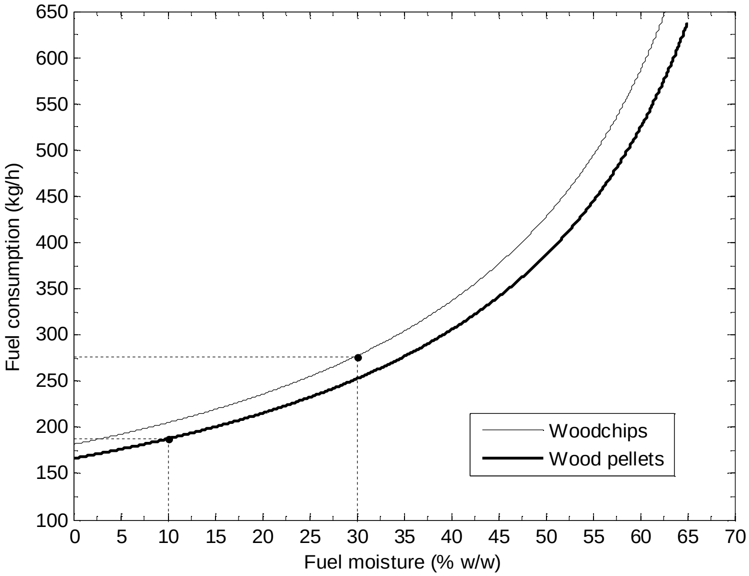


Figure 5.25. Fuel consumption as a function of fuel moisture. The dash lines represent the fuel consumption of 10% and 30% moisture content pellets and woodchips respectively in achieving 820 kW fuel power.

The flue gases components formed in the steady state combustion of woodchips and pellets with a fuel power of 820 kW are shown in Figure 5.26. Part a) represents the major flue gas components in wet flue gas flow (g/MJ). Part b) represents the minor flue gases emissions in dry flue gas flow standardized in 6% O_2. The two dashed lines in part b) represent the NOx and SO_2 emission limits for small scale (1–50 MW) solid wood fuel combustion in Finland (The Regulation 2013).

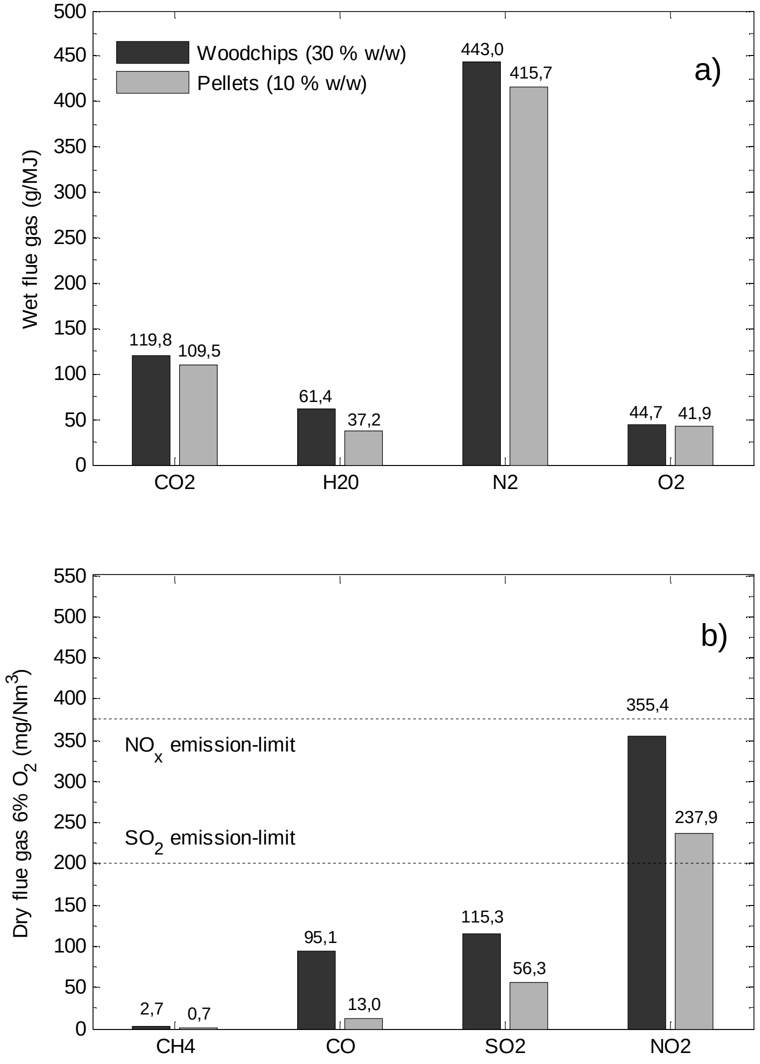


Figure 5.26. Flue gas emissions from combustion of pellets and wood chips.

5.4.3 Connecting the CHP-model to the hybrid energy network

The connection block between the CHP-unit and the hybrid energy network was designed to work in such a way that the primary objective of the CHP-unit was to produce the needed heat energy for the local district heating network (LDHNW) and to produce the maximum amount of electricity (~100kW) with the micro gas turbine process. The secondary objective of the CHP-unit is to purge the remaining excess heat to the district heating network (DHNW). With this in mind, the efficiency of the CHP-unit working at previously determined process parameters for steady state conditions (air to fuel ratio λ = 1.5, temperature restrictions, fuel power 820kW) can be analyzed and is divided into 4 different cases. The difference between the four cases of efficiencies originates from whether there is or is not use for the excess hot water purged to DHNW and for the excess hot air from the EFMGT process. The results for the efficiency of the CHP-unit during one simulation can be found in Table 5.3.

Case numbers
1) No need for excess hot water or hot air
2) No need for excess hot water but use for excess hot air
3) There is use for excess hot water but not for excess hot air
4) There is use for excess hot water and hot air

Table 5.3. The efficiencies of 4 different cases for the CHP-unit working under steady state conditions.

EFFICIENCY	UNIT	CASE 1	CASE 2	CASE 3	CASE 4
Thermal	%	24.6	27.8	73.3	76.5
Electrical	%	11.4	11.4	11.4	11.4
Losses	%	63.9	60.8	15.2	12.1
Total	%	100	100	100	100
CHP-unit	%	36.1	39.2	84.8	87.9

The water flows in the connection block during a simulation when there is need for the heat produced by the CHP-unit in the LDHNW is presented in Figure 5.27. However, during periods when there is no use for the heat produced by the CHP-unit, the simulation operator can use a switch that has been built inside the model to bypass (turn off) the CHP-unit when needed. During these periods, the model calculates only the water transfers necessary between the LDHNW and the DHNW. Occasionally the LDHNW can also act as a heat producer when the solar thermal collectors in the area model produce more hot water than the buildings consume. This excess heat can be purged to the DHNW through the connection block, and the water flows of one such simulation are shown in Figure 5.28.

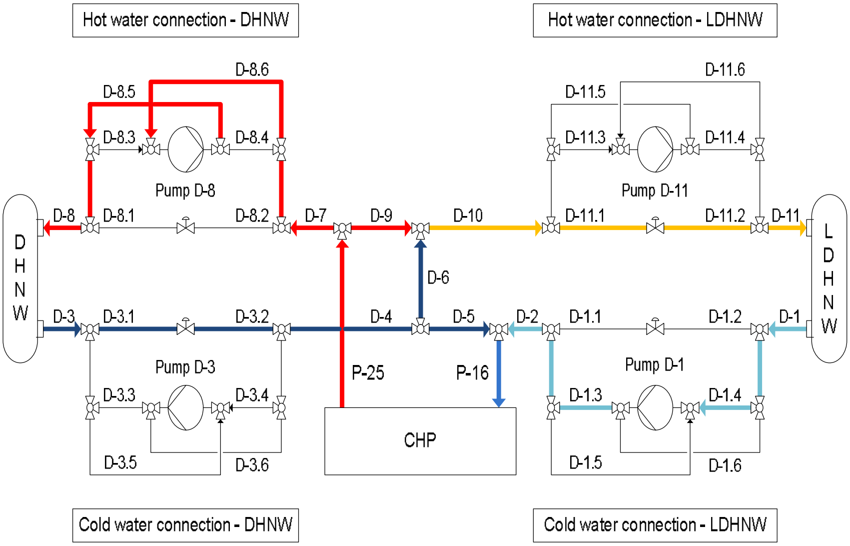


Figure 5.27. Water flows during simulation when the local district heating network (LDHNW) is in need of hot water. The excess hot water produced by the CHP-unit is purged to the district heating network (DHNW).

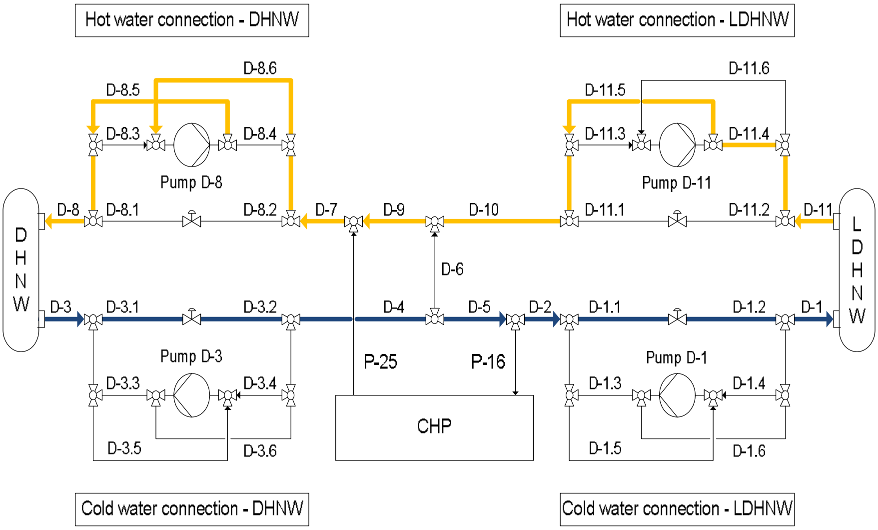


Figure 5.28. Water flows during a simulation when LDHNW is not in need of hot water and has excess hot water production with solar thermal collectors. CHP-unit is bypassed and water flows through the connection block happen between the two networks.

5.4.4 Life cycle assessment

The life cycle assessment (LCA) that was made by Gabi 5, included the following environmental impact categories: global warming, eutrophication and acidification. The global warming is calculated as CO_2 equivalent ($CO_{2,eq}$), eutrophication as phosphate equivalent (Phosphate,eq) and acidification as sulfur dioxide equivalent ($SO_{2,eq}$). The functional unit was the fuel use of Ekogen plant in one year (15 800 GJ/a) when calculating the yearly emissions from the Ekogen plant. In addition, a comparison was made to calculate how the Ekogen plant reduced the emissions of the district heat production in Saimaanharju. In this case, the functional unit was the total heat need of the Saimaanharju area in one year (7000 MWh/a). The system evaluated in this study is shown in Figure 5.29.

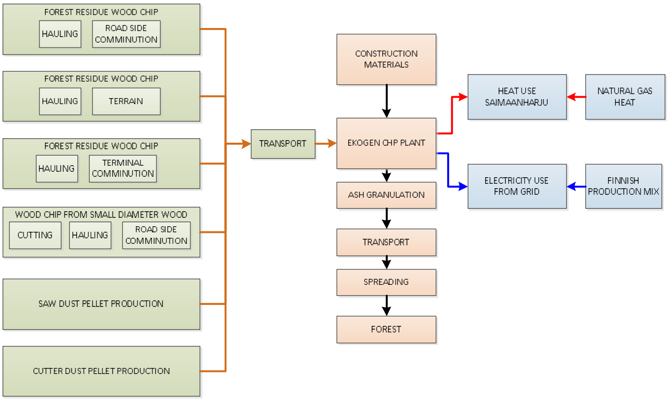


Figure 5.29. Flowchart of studied system including Ekogen plant.

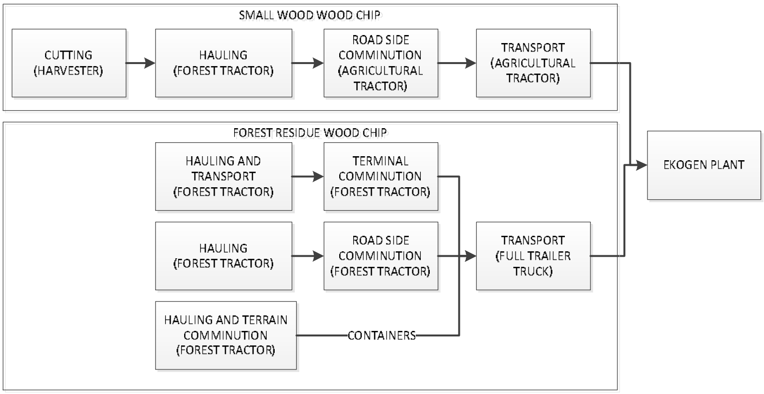


Figure 5.30. Wood chip production chains.

Following fuels were used in the LCA study: wood chip (WC) from forest residues, wood chip from small diameter wood and pellet from cutter dust as well as sawdust. The system evaluated in this study is shown in Figure 5.30. Land use change (LUC) emissions are not included in the calculations.

The information for the small wood chip production chain is obtained from a local supplier in Taipalsaari municipality (Biowin) (Brofeldt 2013). The forest residue wood chip chains are based on average chains in Finland according to Wihersaari & Palosuo (2000). The diesel consumption of wood chip production chains are presented in Table 5.4. The emissions of harvester, agricultural tractor, forest tractor and full trailer truck are from the LIPASTO database (Lipasto 2012). The emissions of working machines and transport vehicles are shown in Table 5.5.

Table 5.4. Diesel consumption in producing small diameter wood and forest residue wood chip and properties of these fuels (Wihersaari & Palosuo 2000, Laitila et al. 2010, Mascus 2013, Brofeldt 2013, Kartunen et al. 2010, Laitila et al. 2012, Rieppo & Örn 2003 and Heikkilä et al. 2005).

Wood material	Small diameter wood	Forest residue			
Comminution site	Road side	Terrain	Road-Side	Terminal	
Cutting	0.0026				l diesel/kg
Haulage	0.0010		0.083	0.00560	l diesel/kg
Comminution	0.0010	0.18[1]	0.14	0.00267	l diesel/kg
Transportation	0.0010	0.044	0.044	0.00111	l diesel/kg
Total	0.0056	0.22	0.26	0.00937	l diesel/kg
Moisture	36	40	40	40	%
Heating value LHVar	11.6	10.7	10.7	10.7	MJ/kg

[1] Includes hauling

Saw dust pellet requires heat in the production process since the raw material is wet and has to be dried, whereas cutter dust is already dry enough for pellet production. In addition, electricity is needed in the pellet production process (Hagber et al. 2009). The pellet fuel is transported on average 108 km in Finland (Tilastokeskus 2012).

Table 5.5. Working machine and transport vehicle emissions (Lipasto 2012).

Emission	Harvester	Forest tractor	Agricultural tractor	Full trailor truck	Heavy delivery lorry
	g/l diesel	g/l diesel	g/l diesel	g/l diesel	g/l diesel
CO	5.4	5.2	8.3	0.4	0.16
HC	1	1.1	2.8	0.05	0.02
NOx	11	12	22	8.5	3.40
PM	0.27	0.43	1.2	0.09	0.04
CH4	0.15	0.15	0.15	0.005	0.08
N2O	0.071	0.07	0.072	0.07	0.08
NH3				0.01	0.012
SO2	0.017	0.017	0.017	0.02	0.008
CO2	2607	2607	2624	2491	1197

The transport is assumed to be done by Euro 5 class full trailer truck, and the emissions for diesel use are from the Lipasto database (Lipasto 2012). The energy need in pellet production and transport as well as pellet properties are gathered to Table 5.6.

Table 5.6. Saw dust and cutter dust pellet production electricity and heat consumption and pellet properties (Hagber et al. 2009, Motiva 2013, Tilastokeskus 2012).

Raw material	Saw dust	Cutter dust	
Heating value	17	17	MJ/kg
Moisture	10	10	%
Electricity use	0.04	0.02	MJ/MJ fuel
Heat use	0.2		MJ/MJ fuel
Transport	0.0022		l diesel/kg

The emissions from producing the construction materials for the Ekogen plant were also included into the LCA, but it was not possible to determine the energy consumption and emissions from the plant constructing phase. The lifetime of the plant is assumed to be 20 years, and the yearly emissions are divided evenly for that time. The construction materials of the plant and emissions from producing them are presented in Table 5.7.

Table 5.7. Ekogen plant construction materials and masses (Koskelainen 2013, Gabi 5, Juhl 2013, Paroc Group 2013, Ecoinvent Centre 2010).

Material	Mass kg	GWP $kg_{CO2,eq}/kg$	Acidification $kg_{SO2,eq}/kg$	Eutrophication $kg_{Phosphate,eq}/kg$
Steel	20 098	2.35	0.0068	0.00048
Furnace	12 490	1.26	0.036	0.0011
Reinforced concrete	15 000	0.55	0.00079	0.000087
Total	47 588			

The emissions from combusting wood chips and pellet are presented in Table 5.8. Nitrous oxide (N_2O) is easily disintegrated in high, over 930 ^oC, temperatures (Wihersaari & Palosuo 2000). According to Winter et al. (1999), the concentration of H-radicals in combusting hydrogen rich biofuels, low nitrogen contents and relatively high NH_3 levels explain the very low N_2O emissions from biomass combustion. Since the fuel temperature coming from the furnace of the Ekogen plant is higher than 1000 ^oC (Koskelainen 2013), the N_2O emissions are assumed to be negligible.

Table 5.8. Wood chip and pellet combustion emissions (Wihersaari & Palosuo 2000, Vesterinen et al. 1985, Koskelainen 2013, Raiko et al. 2002, Alakangas 2000).

CH_4	0.0008	g/MJ fuel
NO_x	0.114	g/MJ fuel (as NO_2)
SO_2	0.044	g/MJ fuel

Ash from combustion is assumed to be granulated using electricity, transported with a full trailer truck and spread to the forest with a forest tractor (Wihersaari & Palosuo 2000). Values from the Lipasto database for full trailer truck class Euro 5 (Lipasto 2012) were used for vehicle emissions. The energy requirements of ash treatment and spreading are shown in Table 5.9.

Table 5.9. Energy use in ash granulation and spreading (Wihersaari & Palosuo 2000).

Ash granulation	0.0153	MJ electricity/kg
Transport	0.00235	l diesel/kg
Spreading	0.005	l diesel/kg

The emission factors for electricity were determined using the Finnish production mix – plan from Gabi 5 and applying the average electricity production mix in Finland between 6/2006–9/2013 shown in Figure 5.31. The heat needed for saw dust pellet process was renewable heat from solid biofuel, and the emissions were obtained from Gabi 5. Also, values of emissions from producing heat with natural gas and obtaining diesel were from Gabi 5.

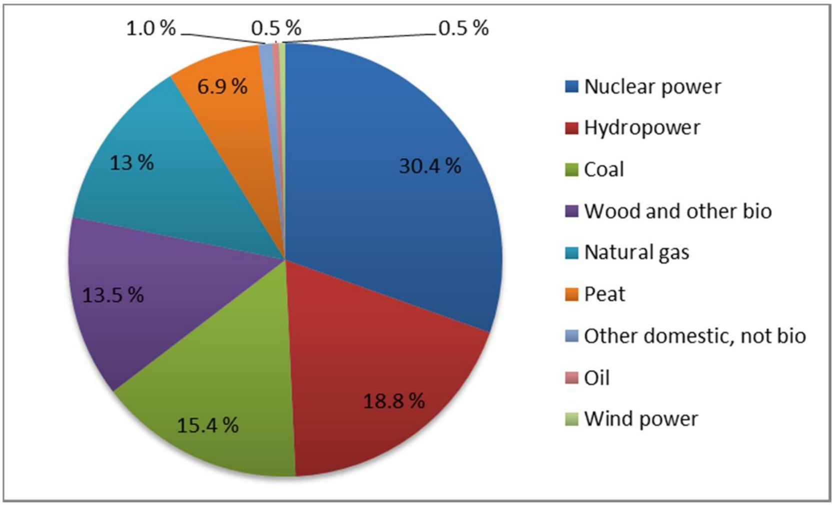


Figure 5.31. Average electricity production mix in Finland 6/2006–9/2013 (Soimakallio 2013).

Centralized and dispersed district heat delivery GHG comparison

A rough comparison of GHG emissions was made between a case, where Ekogen produces district heat in Saimaanharju with saw dust pellets and a case where the district heating transmission line would be built to transfer same amount of district heat from the Kaukas biopower plant, which is located in Lappeenranta city. The distance from the biopower plant to Saimaanharju is 13.8 km, and the heat power delivered by Ekogen is 400 kW (app. 3 000 MWh/a) and the heat power of Saimaanharju plant is 3 MW (app. 7 000 MWh/a).

Biopowerplant uses mostly wood-based fuels. In 2010, wood-based fuels comprised 77%, peat 21% and natural gas 2% of the fuels used (Lappeenrannan Energia). The total efficiency of the power plant is 86%, which is made up from electric efficiency 27%, process heat efficiency 36% and district heat efficiency 23%. The district heat transmission lost is assumed to be 15% (Energiataloudellinen yhdistys 1989).

The building of the Ekogen plant (construction materials), the Kaukas plant and the district heat network are included in the GHG emission calculation. The assumed emission from the building of the Kaukas plant was 4.1 $g_{CO2,eq}$ per kWh produced energy and the assumed lifetime is 30 years (Zuwala 2012). The manufacturing of district heat network pipes was assumed to be 1 333 $_{kgCO2,eq}$/100 m pipe (Fröling et al. 2004), and network construction emissions 2 200 $kg_{CO2,eq}$/100 m pipe (Fröling & Svanström 2005). The nominal lifetime of the network was assumed to be 30 years (Person et al. 2006).

Sensitivity analysis

The nitrogen included in the wood is lost to the atmosphere in combustion. In some cases, it might be reasonable to replace the lost nitrogen to forest by fertilizing forest by nitrogen. Therefore, emissions related to producing, transporting and spreading the nitrogen fertilizer to forest are included in the sensitivity analysis. The fertilizer is assumed to be transported with a Euro 5 class heavy delivery lorry with a capacity of 10 t for a distance of 100 km and spread by forest tractor (0.05 l diesel/kg) (Wihersaari & Palosuo 2000). The emissions of heavy delivery lorry and forest tractor are from Lipasto database (Lipasto 2012).

Ekogen plant results and discussion

The Ekogen plant emissions causing global warming, eutrophication and acidification when using 4 400 MWh/a of wood-based fuel and producing 790 MWh/a electricity and 3 000 MWh/a heat were calculated. The emissions are shown in relation to produced energy in Figure 5.32, Figure 5.33 and Figure 5.34 and in relation to produced energy (allocated to electricity and heat) in Figure 5.35, Figure 5.36 and Figure 5.37. From the GHG emission point of view, obtaining the fuel causes the most significant part of the emissions, being responsible for approximately 90% of the emissions. The emissions from obtaining the fuel are caused by the diesel use of working machines in the case of wood chips, and heat and electricity use in pellet production. From the GHG emission point of view, obtaining the fuel causes the most significant part of the emissions, being responsible for approximately 90% of the emissions. The emissions obtaining the fuel are caused by diesel use of the working machines in the case of wood chips, and heat and electricity use in pellet production.

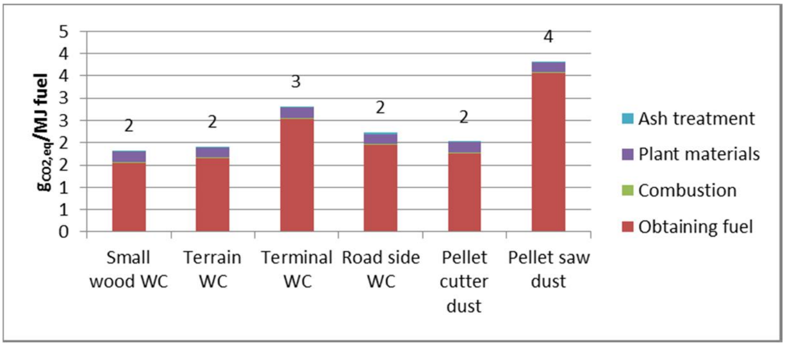


Figure 5.32. Ekogen plant GHG emissions in relation to produced energy.

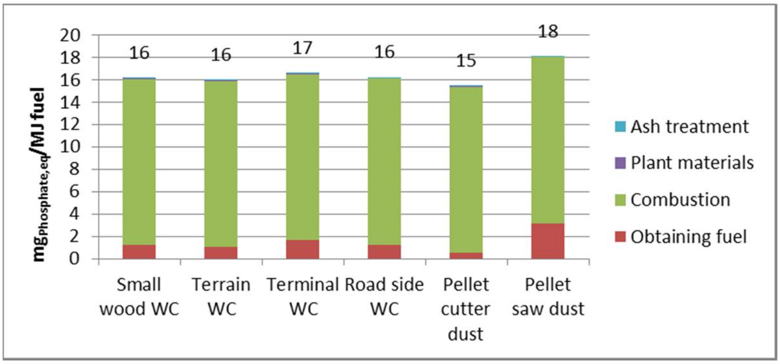


Figure 5.33. Ekogen plant emissions causing eutrophication in relation to produced energy.

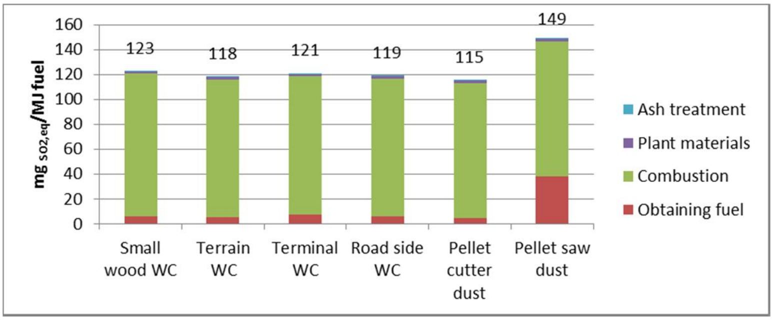


Figure 5.34. Ekogen plant emissions causing acidification in relation to produced energy.

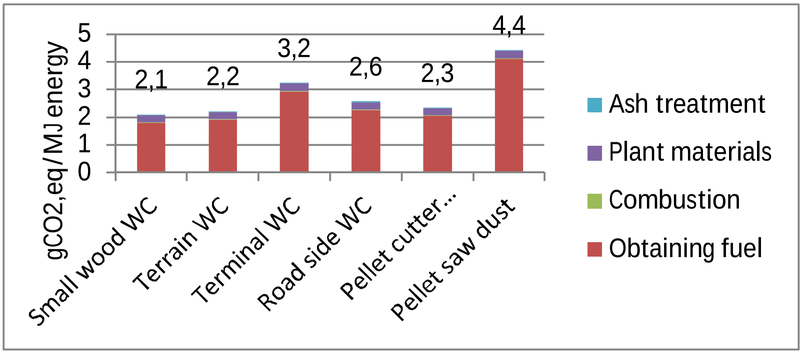


Figure 5.35. Ekogen plant GHG emissions in relation to produced energy.

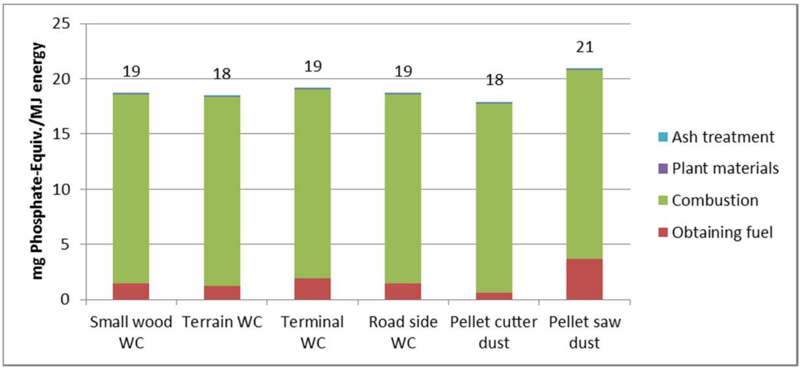


Figure 5.36. Ekogen plant emissions causing eutrophication in relation to produced energy.

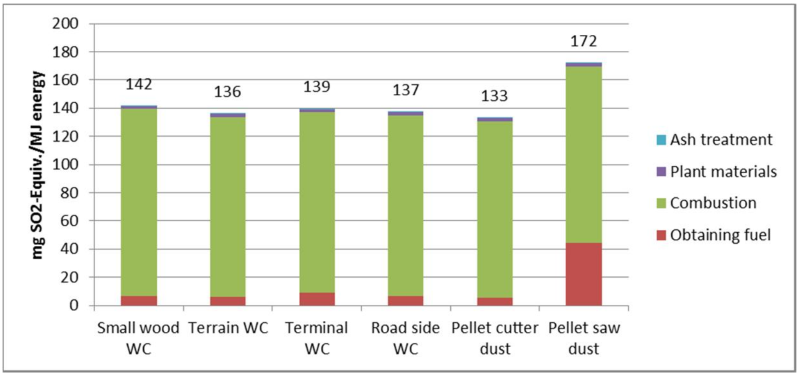


Figure 5.37. Ekogen plant emissions causing acidification in relation to produced energy.

Combustion is responsible for the main fraction of emissions causing eutrophication and acidification (70–90%). The emissions causing eutrophication are resulting from NOx emissions, and emissions causing acidification are caused by the sulfur content of wood fuels.

Obtaining the fuel was responsible for the majority of GHG emissions and therefore it was worthwhile looking into the causes for emissions in fuel obtaining chains. The emissions in relation to fuel energy are shown in Figure 5.38, Figure 5.39 and Figure 5.40. In the case of wood chip production from small wood, the cutting produces most of the emissions. In producing wood chips produced from forest residues (Terrain WC, Terminal WC and Road side WC), there is no need for cutting and emissions mainly come from hauling and comminution. In all chains the transport of the wood fuel causes the least emissions.

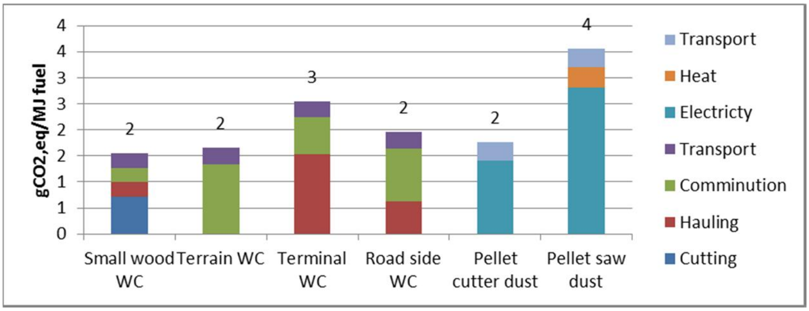


Figure 5.38. Ekogen plant GHG emissions from obtaining fuel in relation to fuel energy.

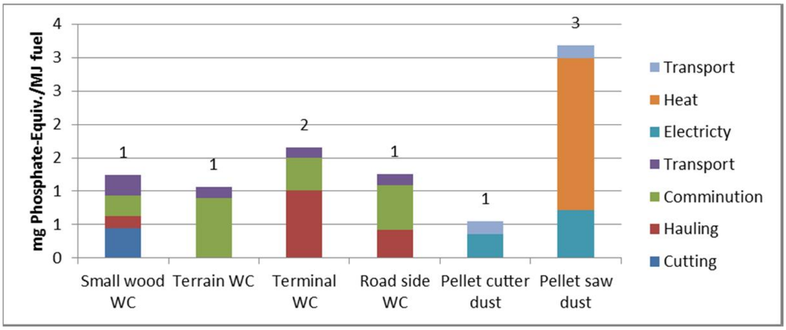


Figure 5.39. Ekogen plant emissions causing eutrophication from obtaining fuel in relation to fuel energy.

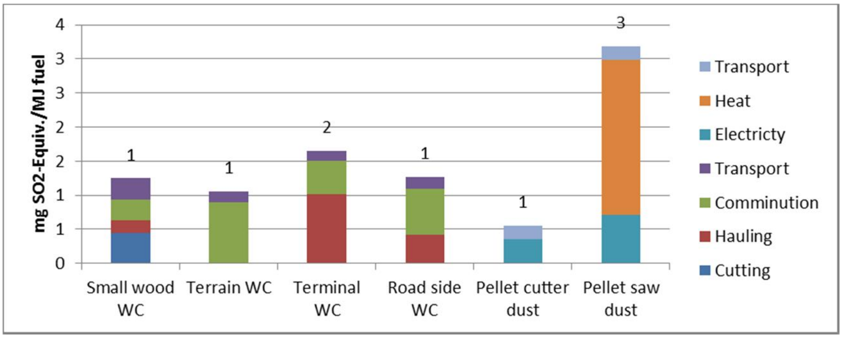


Figure 5.40. Ekogen plant emissions causing acidification from obtaining fuel in relation to fuel energy.

The Ekogen plant produces heat that can displace heat produced, for example, with natural gas (like in Saimaanharju), and the electricity can be directed to the Finnish electricity grid to displace average electricity production. The displacement of production will then lead to emission reductions. The yearly emissions and emission reductions as well as total emissions when producing 790 MWh/a electricity and 3 000 MWh/a heat are shown in Figure 5.41, Figure 5.42 and Figure 5.43. Producing heat and electricity in the Ekogen plant, and displacing electricity produced with Finnish energy production mix and heat produced with natural gas would result in net reduction of GHG emissions, but would increase the emissions causing eutrophication and acidification.

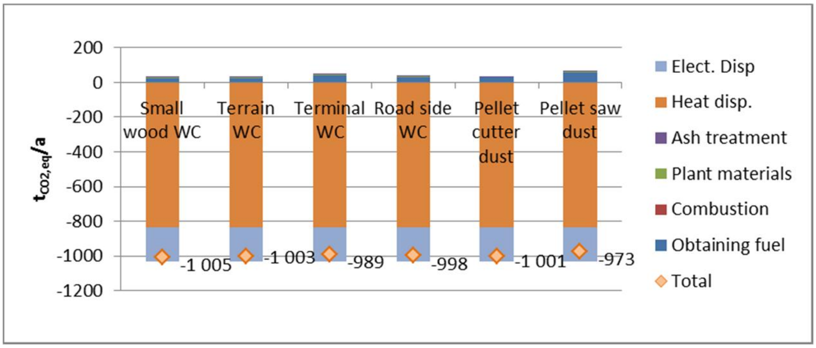


Figure 5.41. Yearly GWP of Ekogen plant with different fuels.

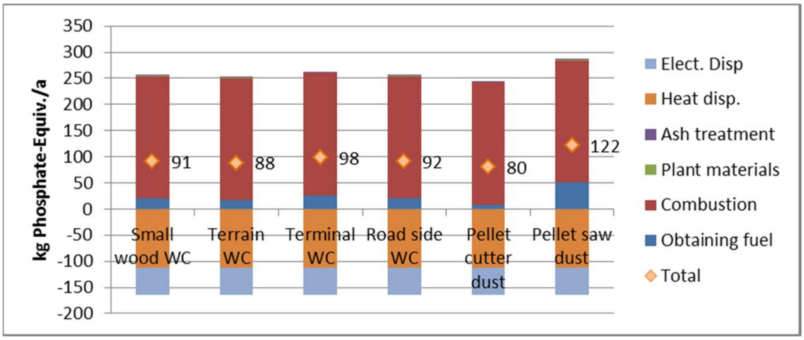


Figure 5.42. Yearly eutrophication potential of Ekogen plant with different fuels.

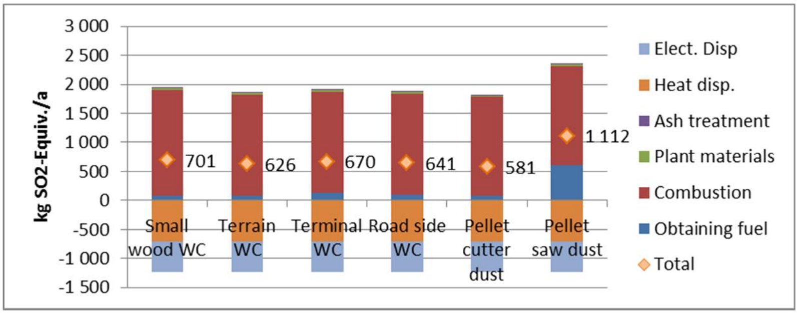


Figure 5.43. Yearly acidification potential of Ekogen plant with different fuels.

Saimaanharju heat production

The Saimaanharju area needs annually approximately 7000 MWh/a heat for district heating purposes. The situation where all this heat is produced with a natural gas boiler was compared to a situation where the Ekogen plant produces part of it (3000 MWh/a) and the rest is produced with a natural gas boiler. The Ekogen plant also produces electricity (790 MWh/a) and taking into account the emission reductions from displacing average grid electricity reduces the overall emissions. The yearly emissions from producing district heat to Saimaanharju with the different fuels are shown in Figure 5.44, Figure 5.45 and Figure 5.46. The emissions are also normalized using the yearly emissions from 25 European Countries, Figure 5.47. In addition the emissions in relation to produced heat (7000 MWh/a) are shown in Figure 5.48.

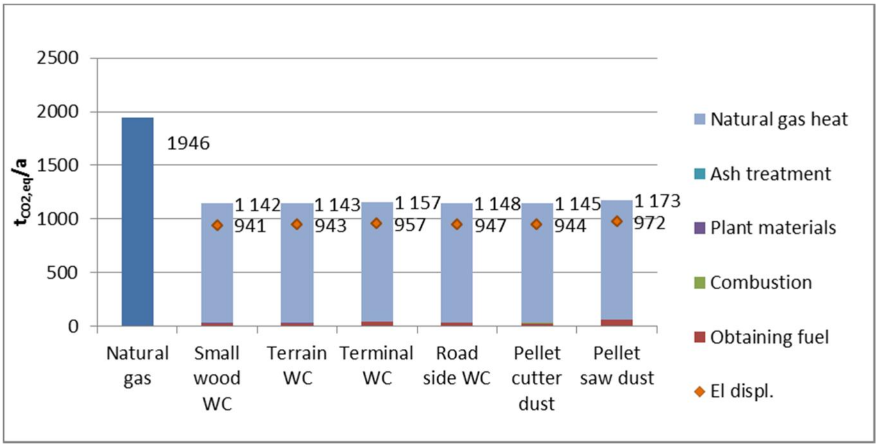


Figure 5.44. Comparison of yearly GHG emissions from producing Saimaanharju district heat with natural gas only and different biofuel and natural gas combinations.

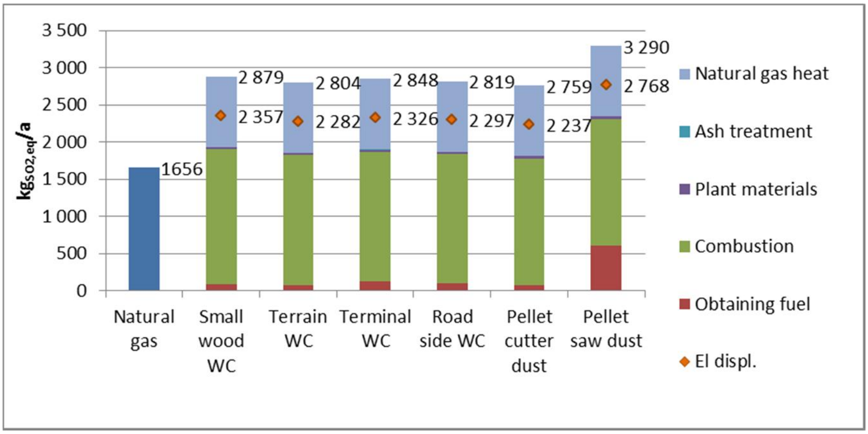


Figure 5.45. Comparison of yearly emissions causing acidification from producing Saimaanharju district heat with natural gas only and different biofuel and natural gas combinations.

The yearly GHG emissions from Saimaanharju heat production would be 40% lower without the emission reductions from displacing electricity, which is almost the same percentage as the share of heat to the Saimaanharju area that is produced with the Ekogen plant, 43%. This means that in comparison to natural gas heat, the heat produced from the biofuels examined is almost GHG emission-free.

When the electricity displacement is included, the emission reduction is increased and is approximately 50%. In this case, the electricity displacement is responsible for 20% of the emission reduction potential, which is approximately the same as the share of electricity from the sum of produced heat and electricity. The share of the emission reduction potential of produced electricity is close to the share it has from the produced energy because the emission factor of natural gas heat, and grid mix electricity is approximately the same and the energy production of Ekogen plant does not produce much GHG emissions.

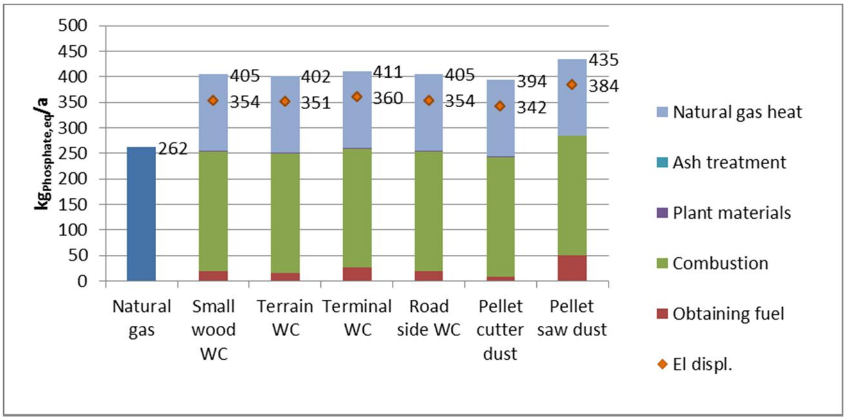


Figure 5.46. Comparison of yearly emissions causing eutrophication from producing Saimaanharju district heat with natural gas only and different biofuel and natural gas combinations.

The emissions causing acidification are increased when part of the heat is produced with the Ekogen plant. The main reason is emissions from combustion emissions which are responsible for 60% of the total emissions when biofuels are used apart from the situation where saw dust pellet is used, in which case the combustion is responsible for 50% of the total emissions. The emissions of SO_2 and NO_2 are equally contributing to the combustion emission, each being responsible for half of the total $SO_{2,equivalent}$ emissions. The SO_2 emissions are coming from the sulphur content of the fuel which was assumed to be 0.04% for wood and this resulted in SO_2 emissions of 43–48 mg_{SO2}/MJ (Alakangas 2000; Raiko et al. 2002). The NO_x emissions were assumed to be 114 kg_{NO2}/MJ (Wihersaari & Palosuo 2000; Vesterinen et al. 1985).

The combustion is also the main reason that emissions causing eutrophication are increased when also using biofuel for heat production. The combustion is responsible for 53–59% of the emissions. In this case, the NOx emissions are alone responsible for the increased emissions. These emissions could be reduced by flue gas recirculation.

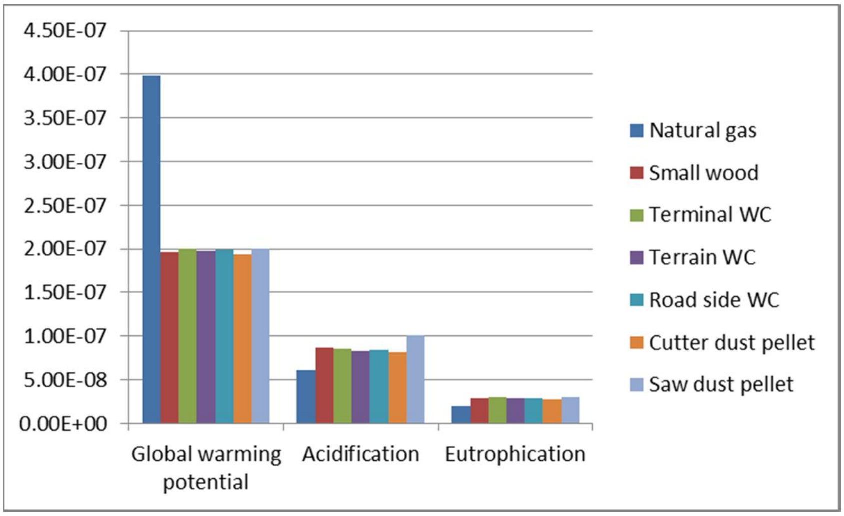


Figure 5.47. Normalized values (EU-25) of yearly emissions causing global warming, acidification and eutrophication Saimaanharju district heat with natural gas only and different biofuel and natural gas combinations.

The normalized values for emissions causing global warming, acidification and eutrophication shows that the change in relation to yearly emission of EU-25 is most significant in GHG emissions. The reduction of GHG emissions is more significant than the increase in emissions causing acidification and eutrophication.

The GHG emissions in relation to the heat produced are lower when part of the heat is produced with biomass, but emissions related to eutrophication and acidification are increasing. The heat production emission factors of natural gas in relation to the heat produced are 77 $g_{CO2,eq}$/MJ heat, 66 $mg_{SO2,eq}$/MJ heat and 10 mg $_{Phosphate,eq}$/MJ heat. When utilizing biomass also as a fuel, the emission factors are 45–47 $g_{CO2,eq}$/MJ heat, 109–131 $mg_{SO2,eq}$/MJ heat and 16–17 mg $_{Phosphate,eq}$/MJ heat. If the electricity displacement is also taken into account, the emission factors would be decreased: GHG emissions 17–18%, emission causing acidification 16–19% and emission causing eutrophication 12–13%.

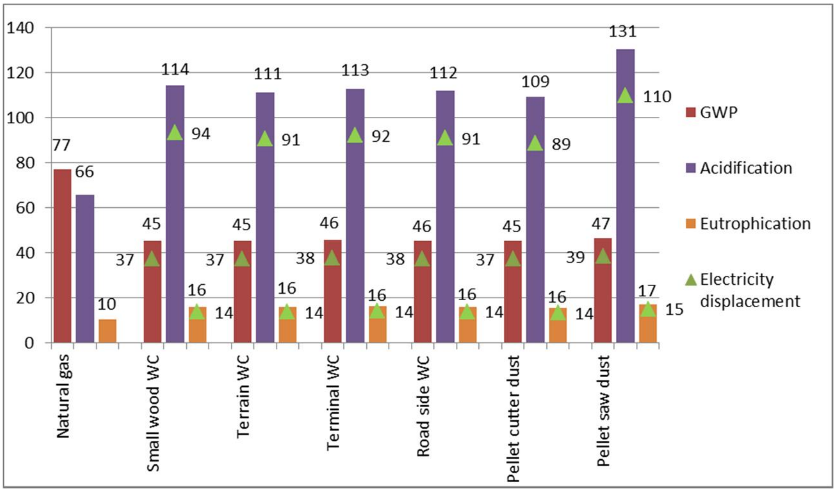


Figure 5.48. Emissions causing global warming ($g_{CO2,eq}$/MJ heat) eutrophication ($mg_{Phosphate,eq}$/MJ heat) and acidification ($mg_{SO2,eq}$/MJ heat) when producing heat for the Saimaanharju area with only natural gas compared to situations where 43% of heat with different biofuel in the Ekogen plant and rest with natural gas.

Centralized and distributed district heat delivery GHG comparison

The results from comparing the case where Ekogen produces district heat in Saimaanharju to a case where the Kaukas biopower plant delivers heat via a transmission line seemed to be unrealistic. In order to get the water temperature in the district heat network to be 92 °C at Saimaanharju, the inlet temperature has to be 100 °C and heat power approximately 2 MW. In this case, the heat loss would be 480 kW. Heat loss is approximately same amount as Ekogen can deliver heat (400 kW) and 25% of the calculated heat power (2 MW). It is not possible to deliver such a small heat power (400 kW) for such a long distance (13.8 km) (Rämä 2013)

The GHG emission calculation results are also in favour of the Ekogen plant. Using energy allocation, the calculated emission factor of district heat produced by the Kaukas power plant is 27 gCO_2,eq/MJ, and the emission factor of the Ekogen plant is 6.7g/MJ (using saw dust pellet). The difference results from the peat use in Kaukaa power plant and also the higher fuel need due to the district heat losses. The emissions from obtaining peat are not included, which would increase the emission factor of the Kaukas plant. If the Ekogen plant, the Kaukas plant and district heat transmission pipe construction emissions are included, the emission factor of Ekogen plant is 6% higher (4.7 $g_{CO2,eq}$/MJ) and Kaukas plant 6% higher (28 $g_{CO2,eq}$/MJ).

The results indicate that the Ekogen plant that uses only renewable energy and has a high total efficiency is a better option than distributing heat for a long distance from a plant that has a similar total efficiency and uses partially fossil fuels or similar fuels (such as peat). This is mainly due to emissions from combusting the fossil fuel in the power plant and district heat losses in the network. In addition, delivering a similar amount of heat to what the Ekogen plant produces from a power plant via district heat transmission line for long distances does not seem possible due to heat losses.

Sensitivity analysis

Replacing nitrogen lost to the atmosphere in combustion of the fuels examined would increase the emissions of Ekogen CHP plant. The GHG emission would be increased 49–72% in the case of wood chip fuels and 7–13% in the case of pellet fuels. The emission causing eutrophication would be increased by 6–8% in the case of wood chip fuels and 1–2% in the case of pellet fuels. The emission causing acidification would be increased less than 0.2%. The Saimaanharju heat production emissions which include the natural gas heat production and heat production by the Ekogen CHP plant would be less impacted. The GHG emissions, which are mainly caused by natural gas heat production, would increase by 0.4–2%. The emission causing eutrophication and acidification, which are mainly caused by Ekogen CHP plant are increasing 1–8% and less than 0.2%, respectively.

5.4.5 Current status, future aspects and references

Initial validations for the CHP model were made by comparing simulation results to literature values, which were found to be consistent with one another and are presented in detail in the Master's thesis of Henri Karjalainen (Karjalainen 2015). The manuscript of the thesis was sent to Ekogen Oy for revision and acceptance during the writing of the final DESY report and before the publication of the thesis in spring 2015. However, no validation for the model against experimental data could be made with Ekogen Oy during this phase of the work.

The CHP-model was successfully connected to the local heating network model during November 2014, and results for simulations with the CHP model attached to the network are presented in Chapter 2.4.1.

At the current state, the CHP-model works only either in a steady state condition with a fuel power of 820 kW or as a turned off CHP-unit. The model could be further developed and used to simulate the effect of lower fuel powers on the electricity production. This in turn would make the model more dynamic and adaptable to changing process conditions. In its current state, the model can be used to evaluate whether or not the CHP-unit is of sufficient size for the specific local area network in terms of heat consumption. The model was also built with MATLAB in such a way that, with slight modifications, it could be altered in the future to work only as a heat production unit without the EFMGT system, or modified to work with totally different fuels such as biogas.

5.5 Energy Villages – Regional energy self-sufficiency

Creating regional energy self-sufficiency in Ostrobothnia, Levón Institute/Vaasa UN. Totally 14 villages are taking part in this research project in Vaasa. As a demo case for DESY, Närvijoki village has been choosen to be studied with LUT.

5.5.1 Sustainability assessment – case Närvijoki

The general assessment framework for overall sustainability assessment of local, decentralized energy production systems are also being tested in a small village called Närvijoki. The village of Närvijoki located on a city of Kurikka, South-Ostrobothnia of Finland, about 42 km from the city centre. The nearest cities are Seinäjoki (72 km) and Vaasa (57 km). Through the village flows the river called Närpiönjoki, which has several rapids.

The industrial and commercial activity in the area includes furniture production, a small sawmill with its own wood drying facilities, a transportation business with a bus and a taxi operation and farm tourism. The agricultural sector also has animal husbandry activities producing meat and dairy.

The population in Närvijoki is approx. 220 citizens. The area is sparsely populated (Figure 5.49) with population density of 3.9 km^2. The area of heated buildings is approx. 32 575 m^2, and 72% of these are residential buildings. Buildings are heated with individual heating systems or with electricity. The main fuel sources used in these heating systems are wood (chopped firewood 21%, wood chips 21%) and light fuel oil (14%). The share of electric heating is 34% and ground heating pump systems 10%. The area does not have an existing district heating network.

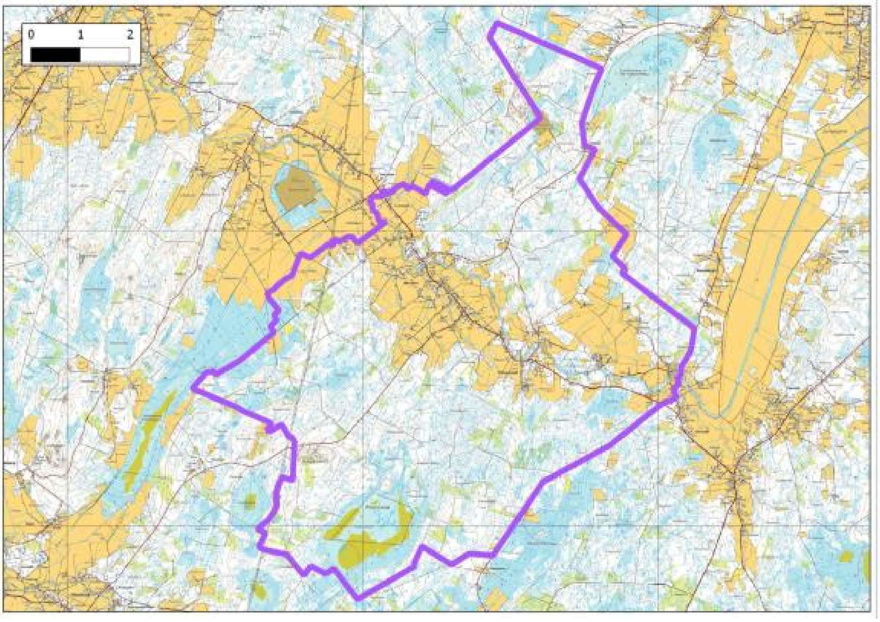


Figure 5.49. The area of Närvijoki village.

The estimated annual electricity consumption of the area is 780 MWh and the heat demand for housing around 3000 MWh/a, when an average heating demand value of 120 kWh/m^2/a is used. Households are using direct electricity heating, heat pump systems, wood, peat and light fuel oil for heating purposes. 48% of the households are using either oil or electricity for heating. Estimated fuel consumption of the passenger traffic in the area is about 750 000 liters of diesel and gasoline fuel, of which 9% are biofuels.

The aims of the sustainability assessment were discussed with the representative of the local people and some experts from Vaasa University related to the ongoing Energy Village project in the area. The main sustainability aspects mentioned in this discussion were increasing their own electricity production and reducing the use of fossil transport fuels in the vehicles with a transition from diesel- and gasoline-based transportation to electrical vehicles. The village is interested to increase energy self-sufficiency in the studied area and improve the employment and welfare inside the area.

Due to the fact, that Närvijoki is sparsely populated, the large share of the use of renewable wood fuels in household and industry heating and ambitions to electrify the transport, the sustainability assessment is focused on the possibilities of producing electricity in the area from renewable sources. The estimated electricity consumption of the heating of buildings, other electricity use and transport, if

100% of estimated diesel and gasoline use is converted to the corresponding amount of electricity consumption (see Figure 5.50). Tank-to Wheel efficiencies (the fuel or electricity used in the vehicle operation to produce kinetic energy) for converting transport energy needs from fossil fuels to electricity are 15% for gasoline, 18% for diesel and 77% for electricity (Biomeri Oy 2009, Handa & Yoshida 2007). Electricity consumption of building using ground heat pumps is estimated based on the Coefficient of performance value: COP=2. The assessment follows the framework shown in Chapter 4 (Local sustainable energy and self-sufficiency). The utilization of framework is presented in Table 5.10.

Table 5.10. Framework implementation in Närvijoki case.

Definition of aims	Discussion with the local people and experts: increasing the self-sufficiency and welfare of the community
Choosing the case study	Based on local circumstances and aims: increasing the local electricity production
Assessment of the present (and future) state of energy production and use in the area	Data collection: energy consumption of heating and electricity use, used fuels, industrial and commercial activity
Identification of new opportunities	Energy production potentials of different renewable electricity sources are calculated
Choosing the alternatives to be compared	Based on production potentials: scenario setting
Selecting the case specific sustainability criterias	Literature
Conducting the assessment	LCA study and data collection for sustainability aspects that cannot be assessed with LCA
Assessment of the results and identification of measures	Weighting factors are determined with a group including experts and local people

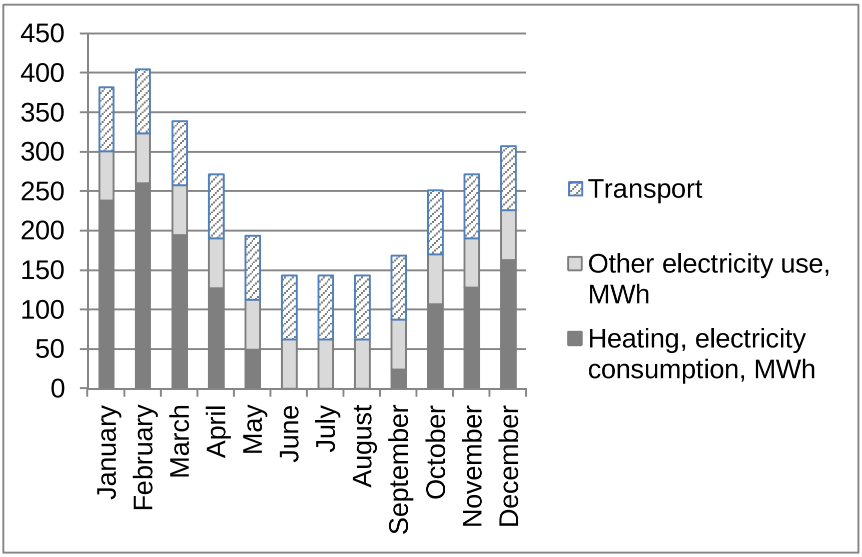


Figure 5.50. Estimated electricity consumption of the studied area.

5.5.2 The renewable energy production potential

The energy production potential of different renewable energy sources was calculated taking account of the hydropower potential of the old hydroelectric power plant of Riihikoski (average flow rate 6 m^3/s, fall 5 m), wind power potential of one 3 MW and 140 m wind mill located in the Pirttikylä area (based on information from Finnish Wind Atlas), Small-scale CHP based on a locally available forest biomass estimation of 10.5 GWh (electricity efficiency 12%, heat 48%), solar power potential if 25% of the building gross floor area would be covered with solar panels (local irradiation based on Photovoltaic Geographical Information System) and biogas potential if all the cultivated crops and animal manure were used for biogas production and converted to electricity with 42% efficiency. The result of the production potential compared to the electricity consumption (shown in Figure 5.50) is shown in Figure 5.51. It is assumed that the hydroelectric power plan can operate only half the year due to ice conditions and flooding.

Results show that only the wind power option could meet the electricity need alone. Other renewable electricity production options need other production to supply the energy need around the year. Production of small-scale CHP is assumed to stay at the same constant level during the year. The lower availability of manure during summer due to pasture slightly reduces the amount of biogas production during summer. Production of solar power depends on irradiation levels, which are higher during summer and lower during winter. Wind power produces more electricity during winter, when electricity consumption is highest due to electrical heating needs. A hydropower plant is assumed to be in operation only during summertime.

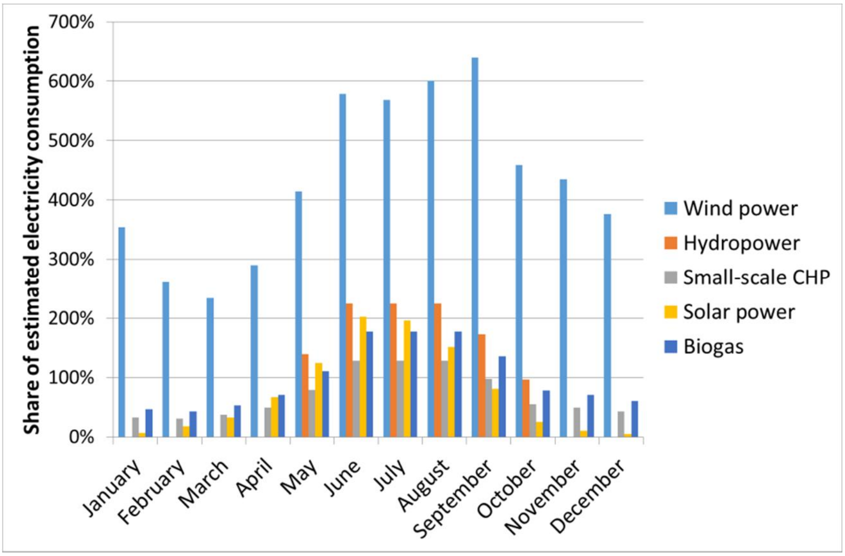


Figure 5.51. Renewable electricity production potential of the area studied, when compared to the estimated electricity consumption, %.

5.5.3 Scenario setting

For sustainability assessment, three different scenarios are first created and then modelled. In the first scenario, the hydropower plant in Riihikoski is utilized and one 3 MW wind power tower is established to produce the rest of the electricity needs of the village. Excess electricity is produced and sold to the grid reducing the impacts from grid electricity production. The electricity production profile used in the assessment of first scenario is presented in Figure 5.52. In the second scenario (Figure 5.53), hydropower is supported with solar and biogas electricity and some electricity is bought from or sold to the grid (the amount of electricity production varies monthly). The third scenario uses biomass in electricity production in CHP and biogas options and also uses solar panels (Figure 5.54). The electricity production with a CHP plant or with biogas also produces heat. The impact of heat production is not included to the LCA, because utilization of this heat is not certain due to the missing district heating network and scattered location of residential buildings. In scenarios 2 and 3, heat pumps are used to reduce the electricity needed for heating and thus reducing electricity intake from the grid. The assumption is made that 50% of the need of electricity heating is replaced with a geothermal heat pump system, and this reduces 25% of electricity consumption of heating. The impact on electricity consumption is presented with dashed lines in Figures 5.53 and 5.54. The LCA model is built in such a way that, when the consumption in the area exceeds the production, the remainder is imported from the process FI: Electricity grid mix, which presents the Finnish average grid electricity production and corresponding amounts of emissions or other impacts are calculated in the inventory. When more electricity is produced than is consumed, excess electricity is exported to the grid and corresponding amount of impacts of avoided grid electricity production are reduced from the inventory. The consumption and production are then balanced per annum. With this approach, the result is founded on the annual balance of production and consumption, and does not highlight the unbalanced periods within the year. In practice, storage properties of biomass-based options such as the production of biogas electricity and biomass CHP enable the adjustment of production, if the storage of used biomass is arranged.

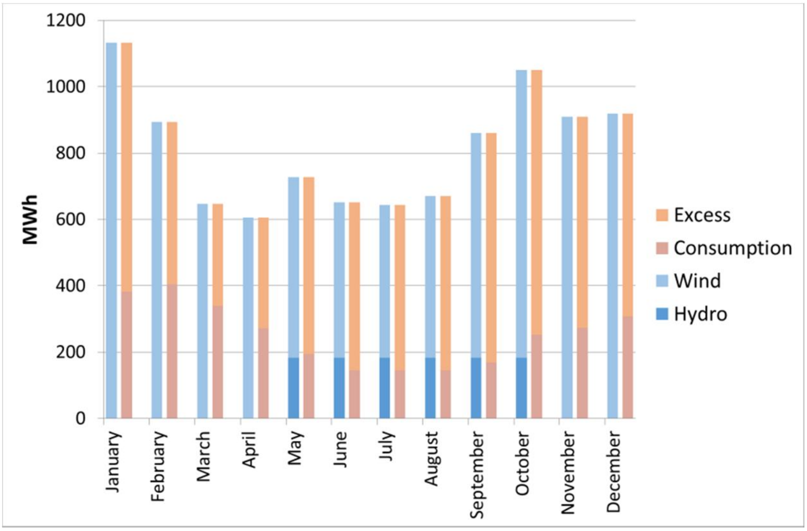


Figure 5.52. The electricity production profile of scenario 1.

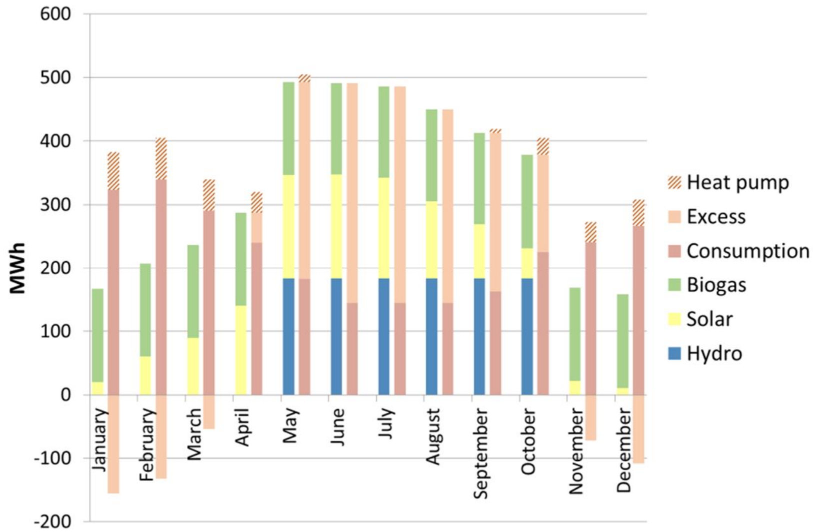


Figure 5.53. The electricity production profile of scenario 2.

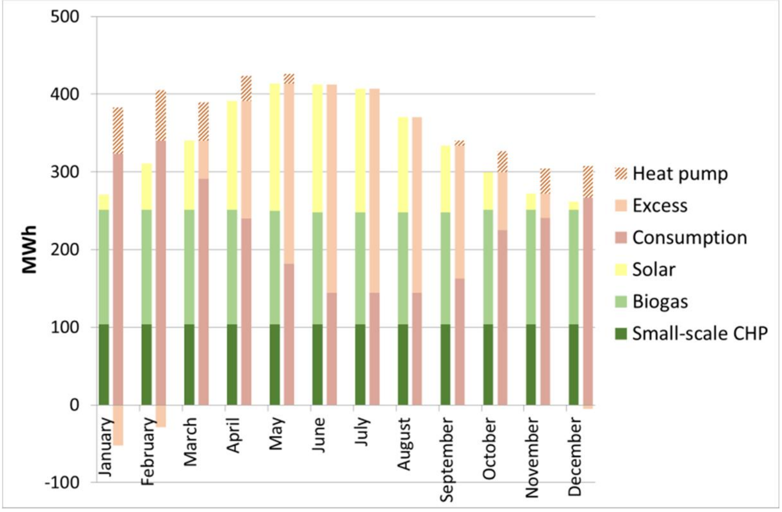


Figure 5.54. The electricity production profile of scenario 3.

The sustainability assessment mainly follows the criteria-set presented in Hacatoglu et al. (2013) and Table 5.11. The results for environmental indicators are calculated with LCA software GaBi 6.0 by using the unit processes shown in Figure 5.55. Other sustainability criteria are assessed based on the literature. When the performance of each scenario is determined, the rank order of these scenarios inside individual criteria is known. Finally, the most sustainable scenario is selected by using weighting factors for different criteria. The weighting factors are created with a web-survey, where a group of selected people has determined the order of criteria from most to least important in this case. In the survey and the analysis of the answers, the analytic Hierarchy Process AHP (Saaty 1984) is used.

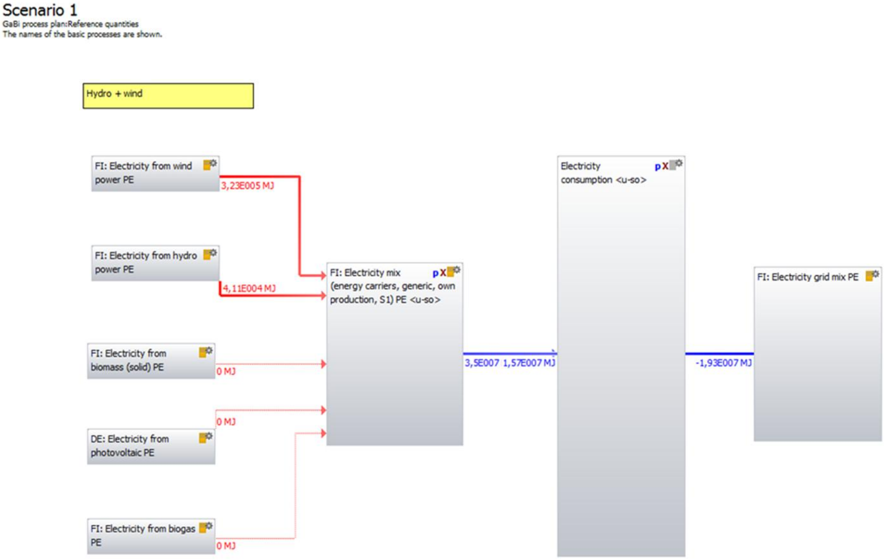


Figure 5.55. Model for scenario 2 calculations.

The values for the heat pump system used to reduce electricity consumption in heating are taken from the literature: Nitkiewitz & Sekret (2014) In addition, the LCI information for refrigeration R134a production is adopted from the CPM database and other materials from GaBi. The operational lifetime is 20 years, the annual leak rate for R134a is 2% during use phase and end of life recovery rate is 85% (Zottl et al. 2011). For other energy production systems, data available in life cycle software is used. For wind power, the following stage phases are considered: production, transportation, erection, operation (including maintenance), dismantling and removal of the wind turbines. The operational life of the wind turbine and cables is 20 years. The data set for hydro power includes the infrastructure and end-of-life of the power plant with a life time of 60 years. The background system for electricity production from biomass includes the biomass production, transportation and mixing and power plant construction, operation and end of life emissions. The type of biomass used in this process is not documented. The background system for electricity from biogas is similar to that for biomass including biogas production and biogas power plant construction, use and end of life operations. The data set for electricity production with photovoltaic technologies is based on the share of different Photovoltaic technologies installed in Europe and includes construction, use phase and end of life operations. The operations lifetime for electricity from biomass, electricity from biogas and electricity from photovoltaics is not documented. The manufacture of the photovoltaic panels is assumed to locate in Germany. In the datasets, the LCI results of the electricity production processes are shown in the provision of 1 kWh electricity.

The economic indicators presented in Table 5.12 are affordability and job creation. Affordability is measured by comparing the costs of different scenarios. The costs of energy production are calculated based on the investment and operation costs. Investment costs are divided with a 20 year lifetime, and annual operation costs are summed with the result. The summed costs are then compared between different scenarios. For wind power, values 1550 €/kW for investment and 22 €/MWh for operation and maintenance is used based on values published in Mikkonen (2011). The investment costs used for small scale hydropower are 1 M€, and operation costs 2.84 snt/kWh (PR Vesisuunnittelu 2009). For solar power, only the investment cost, 26 000 €/20 kW (Leinonen 2014) is included in the assessment. The investment costs of biogas electricity include both the investments in the biogas plant and the gas motor. The investment costs are assumed to be 300 €/t/a biomass for the biogas plant (Havukainen et al. 2012) and 416 €/kW for gas motor (Uusitalo 2014). For the operation cost of biogas plant a price of 38.5 €/MWh for biogas is used based on Havukainen et al. (2012). For the investment costs of small scale CHP, values given by the equipment supplier are used (Koskelainen 2012). In operating costs, fuel costs, operation and maintenance are included. For the ground heating pump, the average investment cost of 19 840 € (VAT 24%) for 20 MWh/a heat production is used based on Gaia Consulting (2014). As an operating costs, only electricity consumption (45 €/MWh electricity) is included. In small scale bio-CHP production, and biogas electricity production also produces a significant amount of heat. In the investment and operation cost calculations, the costs are allocated to electricity based on the factor F_e shown in equation (5.1).

$$F_e = \frac{\frac{E_e}{\eta_e}}{\frac{E_e}{\eta_e}+\frac{E_h}{\eta_h}} \qquad (5.1)$$

where η_e refers to the efficiency of stand-alone electricity production (39%), η_h refers to the efficiency of stand-alone heat production (90%), E_e refers to the produced electricity in combined heat and power production and E_h refers to the produced heat in combined production. With this method, 69.8% of costs are allocated for electricity production.

The job creation potential of different scenarios is calculated based on data available considering the number of man-years needed for establishing and operating the energy production systems. The annual man-year results of different scenarios are calculated by dividing the man years caused from infrastructure building and installation work with 20 year time period and annual operation working time is summed to this result. The summed impact on job creation is then compared between different scenarios. For a 3 MW wind power unit the values of 2.1 man-years for infrastructure building and 0.5 annual man-year for operation is used based on Teknologiateollisuus (2009) and Lindroos et al. (2012). The job creation potential for small scale hydropower was assumed to be 4.5 man-years for planning and building and 0.025 man-year for operation and maintenance based on personal communication (Närvä 2014). Production of forest biomass for small scale CHP creates work approx. 0.23 man-year/GWh (Paananen 2005, Halonen et al. 2003) and operation of the plant 0.057 man-year/GWh (Koskelainen 2012). Work creation of foundation building, heating, plumbing and electrical installation is assumed to be about 0.00086 man-year/MWh based on Planora Oy (2013) and the assumption that material costs form half of the contract price. For solar power, only the installation work was included and the value of 3.75 man-hours work per one panel system were used (Maehlum 2014). For biogas production, job creation estimation of 1 man-year/GWh were used (Halonen et al. 2003). In the estimation of job creation impact of ground heating pump systems, a value of 0.17 man-year/GWh of new production (Gaia Consulting Oy 2014) was used

Results

The results for sustainability indicators of renewable energy production scenarios are calculated by using a normalization method with the characterized database scores on impacts. The CML 2001 (Nov. 10) values are used for characterization of global warming potential, ozone layer depletion potential, eutrophication potential and freshwater aquatic ecotoxicity potential. The Ecoindicator 99, Hierarchical approach is used for characterization of human health carcinogenic effect. The weights obtained from the web survey are used for weighting. In calculation method, internal normalization is used by scaling the environmental impact results of the scenarios within each impact category to sum up to 1. The normalized impact score of a scenario *n*, E_n are estimated by Equation 5.2

$$E_n = \sum_i w_i \left(\frac{b_{in}}{\sum_n b_{in}}\right) \tag{5.2}$$

Where w_i refers to the weighting factor of impact category *i* and b_{in} refers to the characterized impact assessment score of a scenario *n* with respect to the impact category *i*.

5.5.4 LCI and LCIA results

The life cycle inventory and impact analysis results for the three energy production scenarios studied are presented in Table 5.11. The scenario 1 with wind and hydro power obtains the best results when it comes to the new energy production share, share of renewability and the share of local electricity production. Scenario 1 seems also to be the least expensive option. Scenarios 2 and 3 are better than scenario 1 in job creation. The biogas electricity option, small-scale hydropower and small-scale CHP create more work compared to other production options. The EROI value is highest for scenario 1, scenario 3 comes in second and scenario 2 in third place. When different production options are assessed, the greatest EROI is for hydropower (84%) and the weakest EROI for solar panels, when other production forms are located between the EROI values 38% - 52%.

Scenario 3 has the highest impact on human health with carcinogenic impact. The best value in this impact category is found with scenario 1, where production of excess electricity to the grid reduces emissions from grid electricity production more than new production creates. The impact of avoided emissions from grid production is shown in Table 5.11 creating negative result values that are present also in many other impact categories. The highest impact on human health is caused by solar panels, and the least harmful option is to utilize heat pumps. Carcinogenic impacts of hydropower are smaller than those of biomass options (biogas or biomass electricity).

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In the Environment indicators, scenario 1 performs the best. The main reason for this is the high electricity production of the wind power solution and thus grid electricity emission reductions. Wind and hydropower options create less air and water emissions than options that utilize biomass in electricity production. The solar panel production chain causes more ozone depletion and particle emissionsthan other electricity production options. The highest Global warming impact is caused by biogas route. The biogas route also has significantly higher impact on eutrophication than other production options.

Table 5.11. Life cycle inventory and impact analysis result.

Indicator	Measure	Scenario 1	Scenario 2	Scenario 3
Technology				
Adequacy	Share of the new energy production/overall energy production	321 %	141 %	146 %
Compatibility	Not assessed	N/A	N/A	N/A
Energy return on investment (EROI)	Energy production/Primary energy demand	42 %	26 %	27 %
Exergy return on investment (ExROI)	Not assessed	N/A	N/A	N/A
Reliability	Not assessed	High	High	High
Renewability	Share of the renewable energy in local electricity	321 %	141 %	93 %
Economy				
Affordability	Production cost of electricity [€/a]	4,77E+05	4,38E+05	5,14E+05
Job creation	Amount of man-years (person working year) [man-year/20 a]	24	47	44
Society				
Health	EI99, HA, Human health, Carcinogenic effects [DALY]	-1,13E-02	3,00E-05	3,70E-04
Local resources	Share of the local electricity production [%]	321 %	145 %	151 %
Public acceptance	Not assessed	N/A	N/A	N/A
Environment				
Air pollution	Nitrogen oxides (NOx) [kg]	-4,65E+03	1,77E+03	2,45E+03
	Suplhur dioxide [kg]	-4,99E+03	1,40E+03	1,82E+03
	Particles to air [kg]	-5,94E+02	6,77E+01	1,64E+02
Biodiversity	Not assessed	N/A	N/A	N/A
Embodied water	Water [kg]	-4,54E+09	7,08E+09	-2,60E+09
Greenhouse gas intensity	Global warming potential [kg CO2-Equiv.]	-1,97E+06	2,51E+05	2,02E+05
Land area	Land transformation [m2]	N/A	N/A	N/A
Ozone depletion	Ozone Layer Depletion Potential [kg R11-Equiv.]	1,68E-04	3,10E-03	3,09E-03
Solid waste	(not assessed)	N/A	N/A	N/A
Water pollution	Eutrophication Potential [kg Phosphate-Equiv.]	-6,24E+02	3,18E+02	4,09E+02
	Freshwater Aquatic Ecotoxicity Pot. [kg DCB-Equiv.]	-5,55E+03	-5,47E+02	-1,16E+03
	Water (river water & sea water from technosphere, waste water)	-2,43E+06	2,02E+04	-4,23E+05
Institutional				
Regulatory	Compatibility with RED	Compatible	Compatible	Compatible
Policy	Consistence with fiscal policy (feed-in tariff, investment support,	Consistence	Consistence	Consistence
Political	Not assessed	N/A	N/A	N/A

Table 5.11 shows that scenario 1 is the most favourable option with 12 indicators, scenario 2 with two indicators and scenario 3 only with one indicator. The least favourable option seems to be scenario 2 based on eight indicator results. The

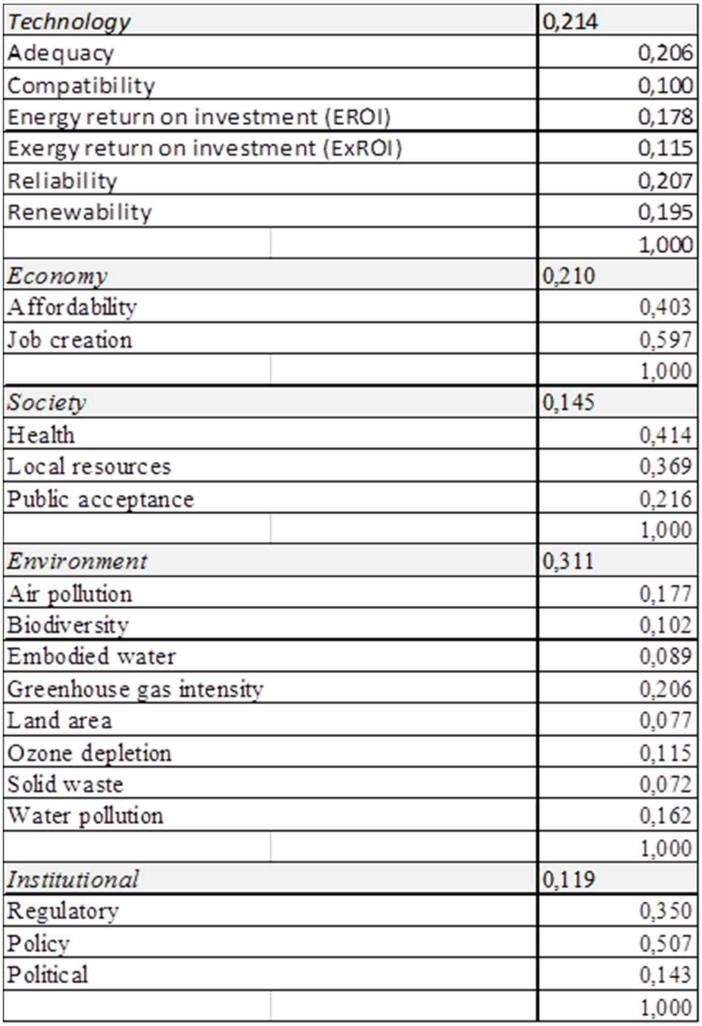
next step is to weight these different indicators against each other for final result calculations.

5.5.5 Weighting the sustainability criteria

Weighting of sustainability criteria was carried out with a questionnaire, where a predefined set of 22 indicators grouped into five main indicator groups was given to the panellists for evaluation (Table 5.12). In the questionnaire, these 22 indicators were evaluated by using the AHP method. The AHP method is a technique that is developed for organizing and analysing complex decisions. In the AHP method, the indicators and main indicator groups are systematically evaluated by comparing indicators to one another. The panellists are using their judgements about the relative meaning and importance of the selected indicators. The AHP calculation derives the numerical weight or priority of each indicator. The questionnaires were sent to 36 panellists and 14 answers were received (a response rate 39%). The panellists, the majority of whom had expertise in the local energy production as a researcher, entrepreneur or as a local people, where chosen from the University of Vaasa, Lappeenranta University of Technology, Närvijoki Village and from the company that produces small-scale CHP application.

The panellists regarded the environment as the most important main indicator group and greenhouse gas intensity was assessed to be the most important environmental indicator. Other important environmental indicators were air pollution, water pollution, ozone depletion and biodiversity. The lowest priority was given to the formation of solid waste, land area (needed for energy production) and water use. After the environment, the second important main indicator group was technology and the third were economy. Weighting factors created based on the questionnaire are shown in their entirely in Table 5.12.

Table 5.12. Weigting the sustainability indicators.



Technology	0,214
Adequacy	0,206
Compatibility	0,100
Energy return on investment (EROI)	0,178
Exergy return on investment (ExROI)	0,115
Reliability	0,207
Renewability	0,195
	1,000
Economy	0,210
Affordability	0,403
Job creation	0,597
	1,000
Society	0,145
Health	0,414
Local resources	0,369
Public acceptance	0,216
	1,000
Environment	0,311
Air pollution	0,177
Biodiversity	0,102
Embodied water	0,089
Greenhouse gas intensity	0,206
Land area	0,077
Ozone depletion	0,115
Solid waste	0,072
Water pollution	0,162
	1,000
Institutional	0,119
Regulatory	0,350
Policy	0,507
Political	0,143
	1,000

Weighting factors of individual criteria and main-criteria shown in Table 5.11 are used forming the final weighting factors. Final weighting factors are presented in Figure 5.56. The weighting factors are solved such a way that the factor value highlights the indicators importance (higher value means greater importance).

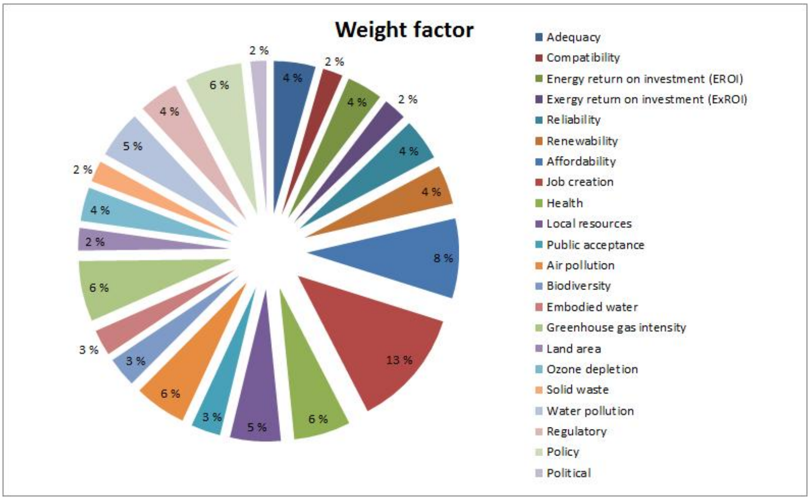


Figure 5.56 Combined weighting factors..

5.5.6 Overall results

The overall results of the sustainability scores of the three scenarios studied are calculated by combining the LCI and LCIA results and weighting factors presented in the previous Chapters 5.5.4 and 5.5.5. After the weighting factors are created, the results presented in Chapter 5.5.4 are first normalised by scaling within each criteria category and then weighted to get the final score for scenarios studied. The resulting scores are given in Table 5.13. Based on this case study, the most sustainable scenario for Närvijoki would be the scenario 1, where hydropower and wind power are used for electricity production. The sustainability of this scenario is enhanced by success in most of the selected criteria and also the high energy production amount that benefits from avoided emissions of grid production. Scenario 2 performed slightly better than scenario 3, which means that small scale hydro power is better solution than small scale CHP utilisation for energy production in Närvijoki case. Biomass options improve the compliance of electricity production, but with the cost of environmental impacts – especially with biogas electricity production.

The impact of heat production was not included in this study due to the scattered structure of residential areas, large share of biomass based on individual heating in households and lack of an existing distribution network for district heating. Thus, significant benefits of heat production with biomass were excluded from this study, and only biomass combustion and biogas electricity production were studied. The biogas was assumed to be combusted to electricity and then electricity was used for transport. Direct utilization of biogas were not studied.

Table 5.13 Overall resuts of the sustainability of three energy production scenarios in Närvijoki Village.

Indicator	Measure	Scenario 1	Scenario 2	Scenario 3
Technology				
Adequacy	Share of the new energy production/overall energy production	0,010	0,017	0,017
Compatibility	Not assessed	N/A	N/A	N/A
Energy return on investment (EROI)	Energy production/Primary energy demand	0,011	0,014	0,014
Exergy return on investment (ExROI)	Not assessed	N/A	N/A	N/A
Reliability	Not assessed	N/A	N/A	N/A
Renewability	Share of the renewable energy in local electricity	0,010	0,016	0,016
Economy				
Affordability	Production cost of electricity [€/MWh]	0,028	0,026	0,030
Job creation	Amount of man-years (person working year)	0,050	0,038	0,038
Society				
Health	EI99, HA, Human health, Carcinogenic effects [DALY]	-0,06	0,0002	0,002
Local resources	Share of the local electricity production [%]	0,013	0,020	0,020
Public acceptance	Not assessed	N/A	N/A	N/A
Environment				
Air pollution	Nitrogen oxides (NOx) [kg]	-0,596	0,227	0,314
	Suplhur dioxide [kg]			
	Particles to air [kg]			
Biodiversity	Not assessed	N/A	N/A	N/A
Embodied water	Water [kg]	-0,012	0,019	-0,0069
Greenhouse gas intensity	Global warming potential [kg CO2-Equiv.]	-0,03	0,004	0,003
Land area	Land transformation [m2]	N/A	N/A	N/A
Ozone depletion	Ozone Layer Depletion Potential [kg R11-Equiv.]	0,001	0,025	0,025
Solid waste	Not assessed	N/A	N/A	N/A
Water pollution	Eutrophication Potential [kg Phosphate-Equiv.]	-0,06	0,002	-0,004
	Freshwater Aquatic Ecotoxicity Pot. [kg DCB-Equiv.]			
	Water (river water & sea water from technosphere, waste water)			
Institutional				
Regulatory	Compatibility with RED	No difference		
Policy	Consistence with fiscal policy (feed-in tariff, investment support, taxation)	No difference		
Political	Not assessed	N/A	N/A	N/A
		-0,63	0,41	0,47

It nees to be kept in mind that this evaluation is made only for electricity production by using database information from life cycle software, and thus no site-specific information is used. Nevertheless, the results show how the sustainability optimization framework shown in Chapter 4 can be used in the decision making process, when different energy production options are compared by the means of selecting the most sustainable option.

5.6 Drop in the Sea – Integrated hybrid renewable energy solutions

Hybrid solutions, Ostrobothnia, Levón Inst./Vaasa UN; Jyväskylä, Jyväskylä UN. Integrated hybrid renewable energy solutions for island operation is a joint project between the University of Vaasa and University of Jyväskylä. The basic idea is to study energy solutions in island use. Mostly these solutions are also hybrid solutions. Two islands, Moikipää and Mikkeli, close to the city of Vaasa, have been chosen for this study as targets on the sea. Typical for these islands is that the previous user of the area has left there buildings behind, which are no longer used. The basic question is to find proper energy solutions for the next potential users (Table 5.14).

Table 5.14. Advantages of Energy island use for companies and DESY partners.

	For companies	For DESY partners
Technology	• A platform to test different technical solutions; remote control • PR-values • Possibility to test their solution also in quite demanding circumstances	• Window for hybrid solutions • New potential technical solutions • Hybrid solutions
Local Energy Planning	• A company has a possibility for testing island use of their energy systems • Possibility to develop own products in regional scale.	• Entirety unique. • Across the whole region • Different points of view, plus and minus, sides, barriers and bottlenecks • Regional impacts of sustainable energy management • Possibility to generalize procedure or model

Business Concepts	- Business model for own technical solutions - Own solutions alone or as a part of larger system	- Regional economy; details and entirety
Sustainability	- Possibility to develop own technical solutions - Possibility to acquire knowledge which could be difficult or expensive to acquire in other ways - PR- value	- Sustainable development; entirety and detailed parameters; social and environmental impacts and economy - Promote independence of fossil fuels and prevent climate change

5.7 Self-sufficient farms

Three farms – two grain farms and one dairy farm – located in central Finland close to Jyväskylä have been studied. They are active farms needing a lot of energy and also producing, for example, biomass usable for energy production. An overview of demonstration farms energy consumption and costs is given in Table 5.15.

First grain farm with total area of 61 hectares is located in Äänekoski. Out of the total area 26 hectares is field and the rest is forest. Electricity is provided from electric company and heat is provided with an Ariterms 35 kW log boiler. Distribution is done with warm water circulation using water filled radiators for heat exchanging. The barn is equipped with a wood-based heating system used for drying grain in the fall.

The second grain farm is located in Saarijärvi and has a total area of 180 hectares. Out of the total area, 60 hectares is field. Electricity is provided from an electric company and heat is provided with a light fuel oil burner. Heat is distributed with radiators using warm water circulation.

The dairy farm is located in Karstula and has 70 cows and 45 young cows. Total area is 133 hectares out of which 105 hectares are field. The cowshed is highly automatized and uses a fairly large amount of electricity. Electricity is provided from an electric company and heat is provided with a briquette boiler.

Research focuses on finding the most efficient hybrid energy solutions to provide electricity and heat for farms use. Research was done as a sub research project “Drop in a sea” by student Jorma Valta as his Master’s thesis.

Each demonstration farm’s energy profile was analysed and calculations were performed to obtain a levelized cost of energy (LCOE) price for different heating and energy possibilities.

In case of grain farm 1, which uses firewood for heating, the calculations were made against wood chip heating system and pellet systems. Results show that LCOE for own made firewood (19.02 € / MWh) is much cheaper than wood chips

(67.66 € / MWh). The pellet system resulted in even worse results due to the higher cost of fuel. Also, calculations were made to see if some benefit can be obtained from using solar collectors to heat up warm water. LCOE for this turned out to be 207.16 € / MWh.

Results clearly show that investments for heating system cannot be balanced against economic benefits. Return on investment (ROI) time (wood chips 71 years, solar collectors 66 years) is way too long compared to the estimated lifetime of the heating system.

Table 5.15. Energy consumption of farms.

	Grain farm 1	**Grain farm 2**	**Dairy farm**
Electricity			
- consumption [kWh/a]	7500	6500	120000
- base cost [€/m]	15.96	50,26	147.71
- price [c/kWh]	12.31	11.17	8.28
Total cost [electricity] €	**1115.16**	**1329.47**	**11708.52**

Heating			
- source	wood log	oil	briquette
- consumption	40 m^3	5000 l/a	20 t/a
- price	15 €/m^3	1.05 €/l	100 €/t
- maintenance [€/a]	150	160	100
Total cost [heating] €	750	5410	2100

Total cost [energy] €	**1865.16**	**6739.47**	**13808.52**

In case of grain farm 2, which uses light fuel oil for heating, the calculations were performed against wood chips, pellets and heat pumps. Results show that LCOE of the current heating system (107.00 € / MWh) is much higher than that of wood chips (77.69 €/MWh) or pellets (101.14 €/MWh). Heat pumps have two different installation options where one has a heat well drilled to ground (92.63 €/MWh) and another that used a pond nearby as a heat well (83.25 €/MWh). Also use of solar collectors to heat water was calculated (383.63 €/MWh).

Results state that replacing the heating system is economically feasible. While comparing ROI times results show that heat pumps would have slightly faster payback time (8.2 years) compared to those of wood chips (10.2 years) and pellets (14.2 years).

In the case of the dairy farm, the current fuel, briquette, is only slightly more expensive than wood chips and much cheaper than pellets. Also, the boiler installed on to farm allows use of wood chips and pellets as a fuel with small changes in the heating system. Therefore, a only calculated heating improvement was solar collectors, which resulted in a less economical alternative for the currently used electricity-based water heating.

Because of the modern automated cowshed, electricity usage in dairy farm is rather large and possibilities of obtaining some electricity from solar panels or small scale windmills were investigated. As a result, it was stated that the location has too little wind for a windmill to be economically feasible, and solar panels are too expensive, if there is a possibility to use electricity provided by electric company.

As a conclusion for this demonstration, it can be stated that replacing oil-based heat systems with renewable systems is economically justified. On the other hand, using solar panels or small scale windmills to produce electricity needs the correct installation environment and some development of equipment and technology.

5.8 Zero-energy building

5.8.1 Assessment of life cycle environmental impacts

The net zero-energy house assessed in this study is a one-family house situated in the town of Hyvinkää in Southern Finland. The house has two storeys. The first floor has an area of 97.5 m^2 and the second 78 m^2. In addition, there is 21 m^2 of storage space. The house is on a site of 1162m^2. Energy production of the house is based on solar power and ground-source heat pumps. During the summer months the house produces more electricity than it uses, while in winter it needs to purchase electricity from the national grid. The excess electricity produced in the summer is sold to the national grid and the house is therefore defined as a net zero-energy house.

The estimated total annual electricity consumption of the house is about 8460 kWh, of which 4510 kWh is consumed by household appliances, 2320 kWh by heating and 1630 kWh by heating of water. There are 60 m^2 solar panels and 6 m^2 solar collectors, which reduces the annual net electricity consumption of the house to about zero. However, timing of energy production in the house does not always match the demand (Fig. 5.57). As a result, electricity needs to be purchased during the winter months. On the other hand, it produces excess electricity from March to September through solar panels.

In this study, three different cases were compared:

1. Net zero-energy house (so called “BLOK-house”)
2. House built with 2012 standards and connected to district heating
3. House with same building materials as 1 but electric heating from the grid instead of solar power

Use of materials needed to build the houses where taken (Table 5.16) from (Kzrysztof et al. 2014 / Chapt.3/Vares). Information on the use of resources and emissions created in producing the raw materials were taken from LCA databases (mainly Ecoinvent Database) and other relevant literature.

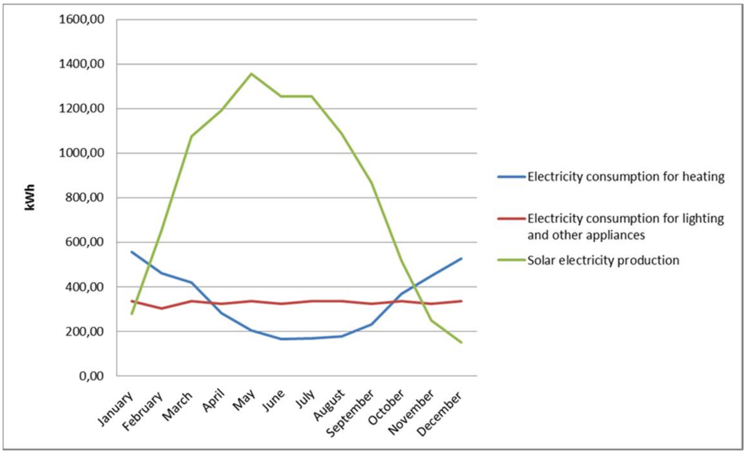


Figure 5.57. Annual electricity consumption for heating and lighting, and production of solar energy (kWh) of the house.

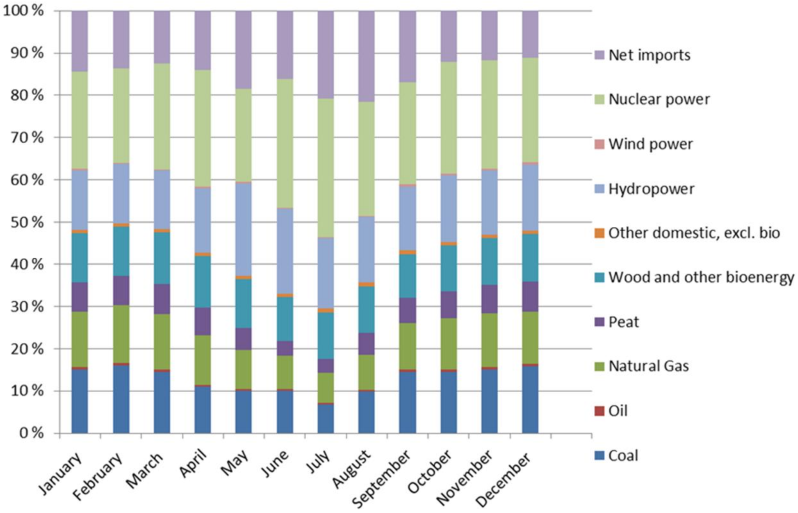


Figure 5.58. Monthly average electricity production profile (%).

The environmental impacts of electricity production were calculated using the monthly statistics from Energiateollisuus ry (Figure 5.58). This electricity production profile was used to calculate the impacts resulting from the grid electricity used by the different cases. In order to calculate the hourly electricity production of the solar panels, information from the NASA servers for coordinates 60°38', 24°51 was used. The impact of cloudiness was also taken into account. Electricity production per hour was calculated using the HOMER optimisation tool (http://homerenergy.com). It was assumed that the excess electricity produced by the solar panels replaces average electricity produced at the same time. For calculating the emissions savings from the electricity replaced, the same production profile was used as for purchased electricity.

The life cycle impact assessment was conducted using the Recipe life cycle impact assessment method (Sleeswijk & Huijbregts 2010). Results were normalised for Europe (Sleeswijk et al. 2010). The following environmental impact categories were studied in the impact assessment:

- Climate change
- Acidification
- Eutrophication (both fresh waters and marine waters)
- Respiratory effects
- Impacts on particulate matter formation

Table 5.16. Use of building materials in the cases studied (kg).

Material	Net zero energy house	House with district heating
Plastic mesh, filter cloth, vapour barrier	371	371
Wood studs, lattices, boarding, wooden stairs	7 173	5 373
Laminated veneer lumber	908	908
Parquet	1 240	1 240
Plywood	2 176	2 176
Bitumen roofing felt	671	671
Wool insulation material	5 805	4 028
Plastic insulation	2 570	2 205
Gravel, crushed stone, sand	113 836	113 836
Gypsum	12 735	12 735
Concrete, building mortar, plastering, filling	43 702	43702
Block of lightweight concrete	9656	9 656
Iron fitting	118	118

5.8.2 Results and discussion

The results show that the net zero-energy house has lower environmental impacts than Cases 2 and 3 in all the impact categories studied, except for aquatic eutrophication impacts. The high eutrophication impacts are caused by the high phosphorus emissions resulting from the solar panel production. . It should be noted that information on solar panel production was only based on one dataset. Thus, this finding may be biased.

The main reason for the higher emissions in Cases 2 and 3 is emissions from electricity and district heating production. Net CO_2 emissions of the BLOK-house were approximately half of those of the two other cases. There was not much difference between the total emissions caused by the other two cases (Fig. 5.59–5.62), although the share of the various processes differed between the cases. As the BLOK house produces more energy than it uses, it does not require any net electricity from the grid. Insulation materials caused somewhat more emissions in the BLOK house cases than in the district heating house, but this difference was not large.

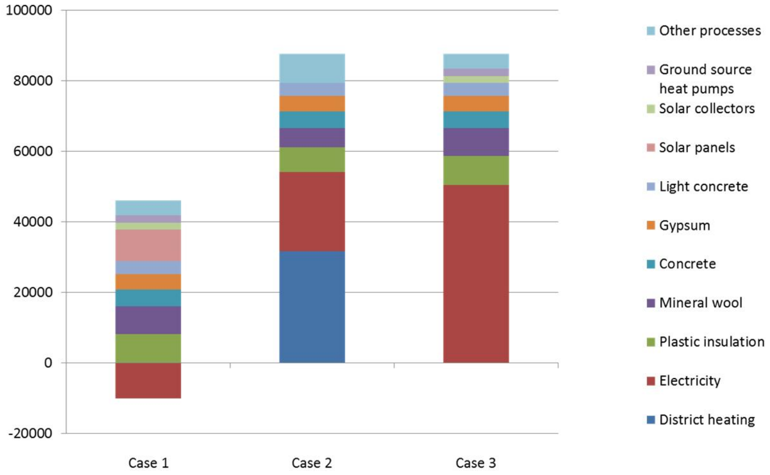


Figure 5.59. Carbon dioxide emissions of the different cases (t / 25 years).

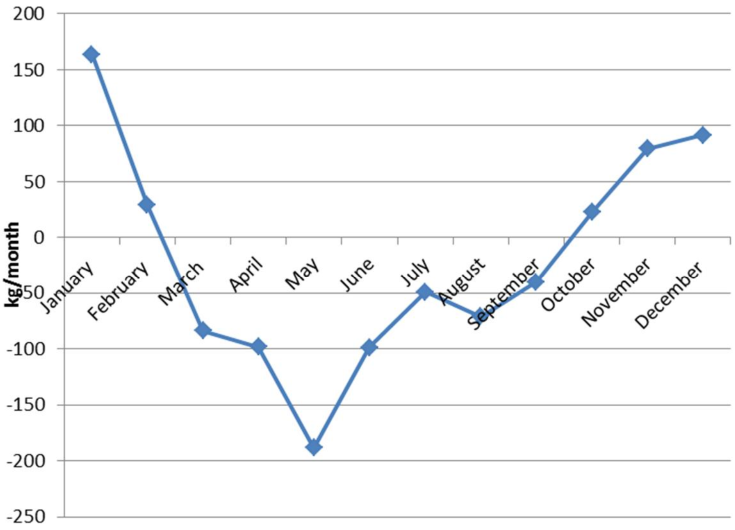


Figure 5.60. Monthly CO_2 emissions caused by the net zero-energy house (kg/month).

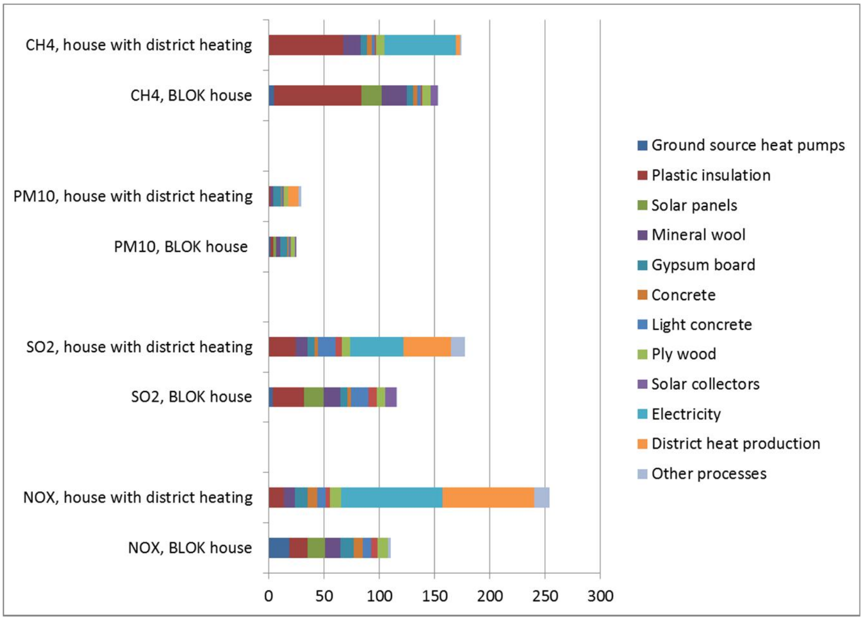


Figure 5.61. Emissions from different processes (kg/25 years).

When looking at the normalised values, the highest environmental impacts of the different cases were aquatic eutrophication (BLOK house), climate change and particulate matter (BLOK house without solar panels and house with district heating).

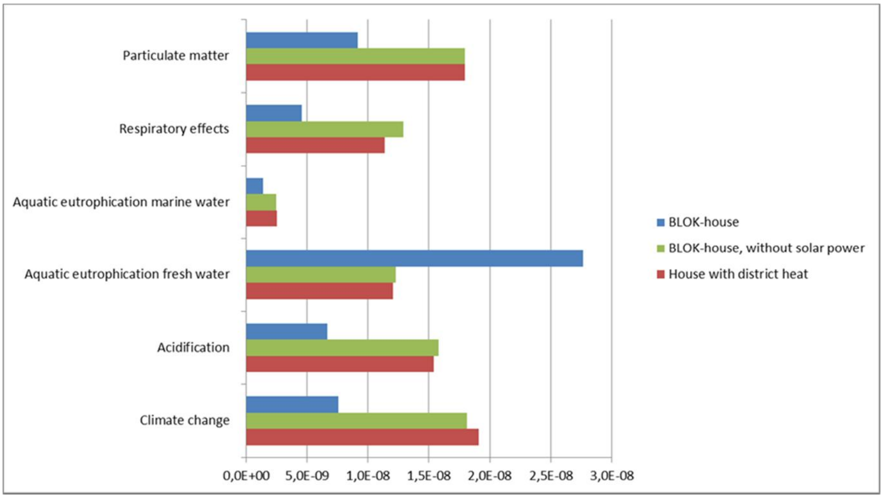


Figure 5.62. Life cycle environmental impacts of the three cases studied.

5.9 Hybrid heating system in a school centre

5.9.1 Present oil heating system

Heating systems of the School centre of Sakarinmäki in Helsinki is planned to be changed to a hybrid system. The old oil heating boiler will in future be as a peak boiler (changed to bio oil) and back-up for a new ground heat pump system.

5.9.2 Ground heat pump system

The ground heat pump systems consist of 21 boreholes of 300 m deep and one module of 275 kW heat pump. The calculated annual amount of heat is 955 MWh for heating of the school. All the following values are calculated for planning the systems by the contractor. Measurements are installed and will be documented later. Electricity demand of the heat pump compressor is 299 MWh. So renewable heat output from the boreholes is 656 MWh/a, representing 68.7% of the total production of the heat pump. The heat pump produces 955 MWh (79%) of the total heat demand of 1200 MWh in the school buildings.

The heat pump system consists of four compressors and two separated cooling circles, which can give 12 portals for quick controlled cooling power output.

The output water temperature of the boreholes is +3 °C and it is cooled 2 °C to -1 °C by a heat pump. Then the temperature of secondary side water is heated from 35 to 63 °C servicing that 275 kW heat output.

5.9.3 Solar heating systems

Part of the energy demand is produced by the total thermal power of a 150 kW solar collectors system. The solar collector area is 160 m^2, consisting of 10 m^2 solar modules. The ground area needed is 1200 m^2 (60 x 20 m). The solar collectors have been setup at a 45° angle. The annual calculated amount of solar heat is 117 MWh. The collectors can reach 63 °C of temperature, which is enough for hot tap water. The solar energy will cover the whole heating demand in summer.

Solar heat is charged into heat storages with the volume of 2 x 4000 m^3, where the temperature will be 63–70 °C. The solar heating system has 4 action modes:

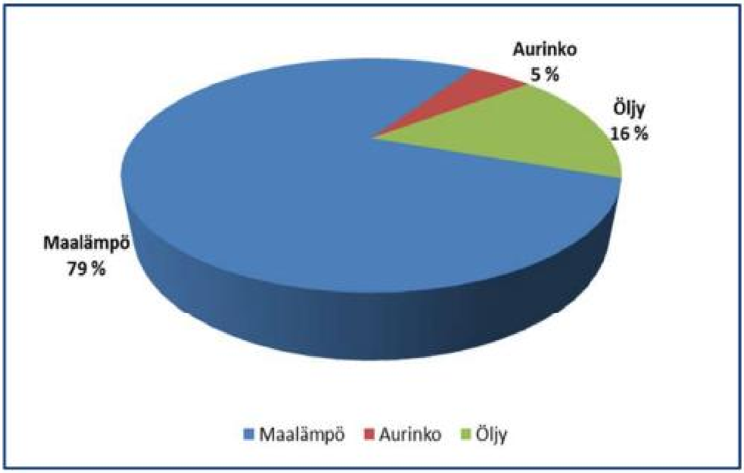
1. If the temperature in the heat storage is at least 63 °C, it is discharged by frequency controlled pump to the heating system of the buildings. If needed, the heat pump helps to keep that 63 °C output temperature.
2. If the temperature of the storage is less than 63 °C but more than the temperature in the return pipe, the storage can be discharged to the output side of the heat pump, which sets the right output temperature for the buildings.
3. If the output temperature from the heat storages is less than the return pipe temperature from the buildings, it can be used to heat the liquid coming from the bore holes before inlet to the heat pump, and COP can be made higher.
4. In summer the temperature of the solar collectors' liquid can rise to near the boiling temperature. The liquid can be cooled by charging the heat into the bore holes. Later, the heat pump can utilize the charged heat.

5.9.4 Change of oil boiler heating system

Oil heating system is equipped with heat storage. Temperature in the storage is operated as a function of outdoor temperature. Oil heating is used in winter, if other heat sources cannot provide enough heat power to the heating system. Annual heat energy of the boiler is about 16% of heat demand.

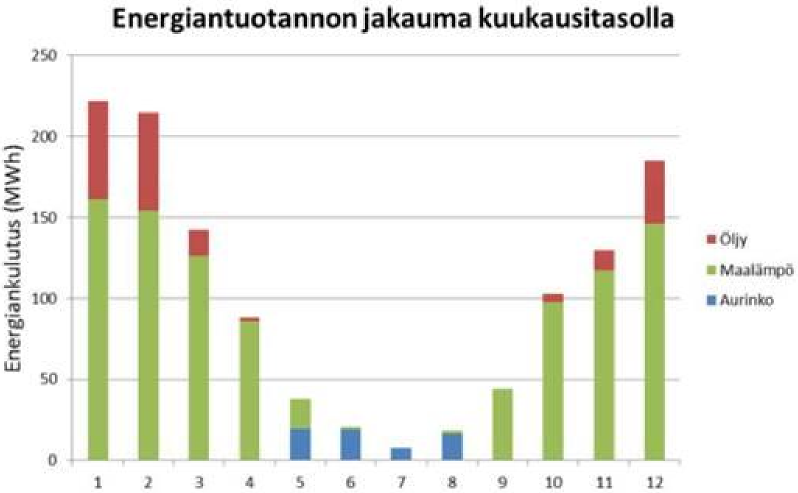
The annual deviation of produced heat 1200 MWh is shown in Figure 5.63.

Monthly heat production in a normal year is presented in Figure 5.64. The solar collectors and heat pump produce energy in five months, May to September. Solar heat led to bore holes is not included in summer months (Fig. 5.64), only solar heat led to pipe lines is shown. Oil heating is needed in seven months.



Kuva 1: Energiantuotannon prosentuaalinen jakauma vuositasolla

Figure 5.63. Annual deviation of the energy production in Sakarinmäki school centre (source: Helen).



Kuva 2: Energiamääräinen tuotannon jakauma kuukausitasolla

Figure 5.64. Monthly deviation of energy production in Sakarinmäki school centre (source: Helen).

6. Conclusions, recommendations and discussion

6.1 Conclusions

Decentralized energy production and markets for renewable energy technologies are continually expanding. The market growth is ensured, for example, by international and EU policies for renewable energy generation, the EU directives for increasing competition within the electricity industry and the rising prices of fossil fuels. Local energy production increases energy efficiency because of lower transport or transfer losses. Local energy production also increases local business, and energy production from local waste reduces waste management costs, thus enabling other local business and local employment. Local energy production also increases energy, electricity and fuel security by reducing import dependency.

Combined together, different technologies can form a strong hybrid solution adapted to local needs. Here, the technologies interconnect and work in symbiosis supporting each other, so that in some cases waste from one process is raw material or fuel for another. Many technologies operate on the side-flows or waste from other processes and provide side benefits such as, for example, reducing nutrient runoff or capturing carbon. By combining the correct technological solutions for the local needs, high primary energy efficiency can be achieved, thereby ensuring that local energy production potential is fully realized.

Possibilities and new solutions based on energy saving and the use of local energy sources were studied for a single-family house. The annual energy consumption of space heating and ventilation in the climate of Southern Finland is approximately 50 kWh/m^2 calculated per floor area. With an extremely well insulated envelope and effective heat recovery from exhaust air, it is possible to achieve the passive house level of 15 kWh/m^2. However, this is an expensive way of saving energy, because usually improvements in HVAC systems are more cost-effective than constantly improving the thermal insulation of the envelope from the Finnish reference values of the year 2012. The net zero-energy level is difficult to reach because of heating of hot water, if you do not also build solar heating system for heating or warm waste water recovering system.

A ground heat pump system offers a possibility of reducsing the electricity consumption of heating, including also the heating of hot water, of a new single-family house to the level of 30–40 kWh/m^2. With an exterior air heat pump and solar water heating, the corresponding energy consumption is 35–60 kWh/m^2.

The net zero-energy building resulted in lower environmental impacts than the other cases (district heating in Case 2, electricity in Case 3) in all other environmental impact categories except for eutrophication impacts. The high eutrophication impacts are caused by the high phosphorus emissions resulting from the solar panel manufacturing. In the other impacts studied, those caused by the net-zero energy house were only approx. 50% or less than those caused by the other two cases. The difference between Cases 2 and 3 was very small, although impacts were caused by different processes in the two cases.

Multi-criteria optimisation offers a possibility to compare various solutions with conflicting criteria. In this study, the criteria have been the energy efficiency number (E-number) and the total costs including the investment and the energy costs. When low energy consumption is preferred, the ground heat pump is the best solution from the ones studied. On the other hand, when low costs are preferred, the best solution is an exterior air heat pump supplemented with a solar heating system. If a ground heat pump is implemented, solar heating can support the heat pump by upgrading the temperature of the ground cycle liquid before input of the heat pump in spring and autumn. 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.

The cost efficiency of the measures studied, investment cost/annual energy saving, is 0.4–4.8 €/kWh. Generally the investments in heating and heat recovery devices are the most advantageous ones. The improvement of the exterior walls' and roofs' U-values from the reference values are the most expensive alternatives due to the high costs and low additional energy saving.

The Desy-model was developed in the project. The model can simulate buildings physics and HVAC systems. The area heating network, distributed heat production in the buildings and concentrated heat production connected to the network (solar, wind, boiler plants and CHP plants with many fuels and energy storages) are included in the model. It seems that distributed energy production is economical, if you can use all the energy yourself and the pay-back time of investment is less than 6–10 years. If you sell energy to a local network and pay taxes and transfer costs, it is not an economical investment to prosumer (consumer/producer) at that cost level.

Deep geothermal energy is one new possibility even in Finland. It has many apparent benefits, making it an excellent candidate to be an energy source in the future. Most importantly, it is after building practically emission free. The limiting parameter of geothermal energy's use in Finland is the low temperature of the ground. You have to go 6000–8000 m down into the ground to find a temperature of 100 °C. The cost of drilling holes grows rapidly as a function of depth. The average cost of drilling oil and gas cost follows an exponential curve quite well, at least to 6000 m level. The cost of drilling appropriate holes appears to be the main obstacle in the way of deep geothermal energy becoming viable.

Eco Energy Centre's original direct electricity heating with the water radiator system is changed to a ground heat pump (40 kW_{th}) with 4 boreholes per 200 m each. Later a 15 kW solar PV or 20 kW wind power will be installed. Electricity car loading should be possible. Trading in electricity is also an option in the future. A steel tank with a volume of 1000 l and capacity of 25 kWh (ΔT= 30 °C) is installed as a short-time heat storage. Solar PV or wind power is used with a heat pump and electricity purchase is included as well. The money saved by using heat pump gives a 6.5 years pay-back time with 5% interest compared to the cost of heating directly with electricity. If Solar PV panels of 15 kW are included, the pay-back time is 9 years. Wind power 20 kW with a heat pump also gives a pay-back time of 9 years.

The sustainability assessment for Eco Energy Centre only considered greenhouse gas emissions. Four different cases were assessed. Case 1 was ground-source heat pumps with storage and 100 m^2 (15 kW) solar PV panels. Case 2 was the same as Case 1, but there was no heat storage, and in Case 3 there were ground-source heat pumps with storage but no solar panels. In addition, a reference case was studied where only electric heating was used. The emissions from electricity production, also greenhouse gas emissions from the manufacturing of ground-source heat pumps and solar panels were included in the study. The highest emissions were caused by the reference case, while the lowest were caused by Case 1 (44% lower). However, the difference between Cases 1 and 3 was minor (5% higher compared to case 1), reflecting the fairly low importance of solar panels and heat storage. Emissions were mainly reduced due to the introduction of ground-source heat pumps. Emissions caused by the manufacturing of solar panels was relatively low, approximately 15 tons CO_2eq.. Manufacturing of ground-source heat pumps caused higher emissions, approx. 120 tons CO_2eq. Net saving in emissions resulting from ground source heat pumps was thus approx. 277 tons CO_2eq.

Three self-sufficient case farms (two grain farms and one dairy farm) with solar energy and wind energy were too expensive investments to be economical for a reasonable pay-back time compared to bio fuel used in the boiler. The time was even longer than the expected technical life-time of the farm's heating system. The grain farm using light oil for heating was economical to build heat pump using local water pool as heat source. The calculations were performed against wood chips, pellets and heat pumps. Results show that the cost level of the current heating system (107.00 €/MWh) is much higher than that of wood chips (77.69 €/MWh) or pellets (101.14 €/MWh). Two different installation options of heat pumps have been used where one has a heat source drilled into ground (92.63 €/MWh) and another used a nearby pond as a heat source (83.25 €/MWh). Also, the use of solar collectors to heat water was calculated (383.63 €/MWh). Results show that replacing the heating system is economically feasible. While comparing the return on investment time results show that heat pumps would have a slightly faster payback time (8.2 years) compared to those of wood chips (10.2 years) and pellets (14.2 years).

Based on the developed sustainability optimization framework, it is possible to compare different local hybrid energy production options from the wide sustainability perspective. It is possible to weigh the different sustainability criteria with local priorities and so to find the locally optimal solution for energy production system. Application of the sustainability optimization framework in practice still needs some development, but the experience of the test used is encouraging.

The environmental sustainability study of the Eco-CHP case showed that it is possible to reduce significantly the local GHG emissions by replacing even a part of the natural gas using heat production with a CHP plant using biomass. The impact of electricity production on GHG emission savings is considerable in Eco-CHP concept.

The overall sustainability study of the Energy Village case showed that, when several sustainability criteria are involved in the decision making process, it is beneficial to use a systematic approach for evaluation. The developed framework and other methods used in the study showed that there are differences between renewable energy production options, and also that local energy production potentials affects to the following sustainability results.

Expert views – and the scenarios constructed from them – demonstrate that there is considerable potential for small-scale production, but that future development can take very different paths, depending on how energy policy, citizen involvement, and business concepts evolve. If suitable environments do not emerge, it is possible that the field begins to stagnate, but in favourable conditions very large growth rates can be achieved.

Most important obstacles to the growth of distributed small-scale renewable energy sales include the underdevelopment of business concepts, the difficulty in finding reliable and independent information on renewable energy systems, the insufficient sales and installation services, the problems in selling small amounts of electricity, and the price of production systems.

6.2 Recommendations

Some recommendations for distributed energy systems are listed below:

- The cost-efficiency of various energy saving and energy production systems is very different. The measures should be balanced with the costs and energy saving obtainable
- Multi-criteria optimization between costs and energy consumption gives a good over-all picture of the possibilities
- Denser buildings areas and higher buildings in urban areas
- Easier way to be as a consumer/prosumer in connection with the district heating and electricity network

- Cooling possibility also on an area and micro scale
- Single and understandable taxation on decentralised energy production
- Easy license application for decentralised energy systems
- Easy connection technique to local networks (heat, cool and electricity)
- Saved energy is the best way to save cost and emissions
- Energy/power tariff development is needed, especially for distributed energy production
- Self-produced energy should be used to save energy demand by the consumer
- Sustainability of the new local energy solutions should be studied more carefully in future to be able to reach the demanding goals for e.g. greenhouse gas reduction. Holistic sustainability assessment and optimization can be done with the developed DESY sustainability optimization framework.

- There are several direct measures and actions that can be taken when promoting renewable energy growth in Finland. The current policy support concentrates on large scale energy production in a few RE sources (wood fuel, wind power, bio gas) and the expert panel in the study wished for a transition to support also small-scale production. Service-oriented business concepts together with adequate subsidies and administration were raised as potential means for creating growth in the distributed energy sector. This also calls for more networking and joint development between technology and service providers. There is also a need for independent information services that can provide valid information for choices e.g. for the most energy-efficient, suitable solution in the area.

- Measures for fostering growth should also be based on the lifting of market barriers that prevent the penetration of DG technology. A good example of what could happen in Finland if, along with policy support mechanisms market barriers were not removed, can be seen in wind power development. Although Finland for a few years has had a generous premium feed-in tariff, at the moment the wind power capacity installed is very low. The reasons are mainly connected to social acceptance and very complicated administrative procedures related to building permits. Thus, if the same is to be avoided for DG, much attention should be given to the removal of barriers as well as to the establishment of a favourable framework for technology diffusion.

- Despite the growing interest in distributed RE production due to its positive effect in strengthening energy security and the possible new business opportunities that can open up around this technology, several factors were found to hinder its diffusion in Finland. The changes required to allow this technology to prosper do not only concern elements of the energy infrastructure such as the electric grid but encompass a wider range of societal factors that need to co-evolve in the same direction. For instance, novel business models will be able to thrive only if consumers' preferences change and new windows of opportunities are created for companies.

6.3 Discussion

This report deals with the energy performance of various energy systems and ways to use local and distributed energy sources. In addition to the pure point of view of energy performance, the peak effects (powers) of the energy systems and their timing are also important, because they affect the capacity needed from the electricity network. This concerns clearly e.g. the concept of the net-zero energy building, which has the idea that the solar electricity system of the building in summer produces electricity for the own use and in addition to the network. The production into the network is then taken back from the network in the winter. In this way, it is possible to achieve a net-zero energy balance on an annual basis. However, in Finnish climate conditions, the production of solar electricity does not reduce at all the peak electricity demand from the network. The electrical utility has to provide the same peak effect independent of the electrical energy bought from the utility.

The relative movement of the electricity consumption to wintertime has disadvantages. This reduces the production of combined heat and power and the total efficiency of energy production. Also, energy sources which are more expensive and have poorer efficiency must usually be used in peak load conditions.

If power and district heating networks are used as a back-up for distributed energy production and some blackouts exist in their own production, the central energy system has a problem. However, a distributed energy system can give some security and reliability if distributed producers can support each other during some producer's blackouts and the energy network is available.

Ground heat pumps are designed to cover 30–60% of the peak heat load and 85–90% of the annual heat energy demand of a building. They can reduce about the same amount of both the peak heat load and annual energy consumption. However, air heat pumps can reduce a considerable proportion of annual energy consumption, but they reduce only slightly, if not at all, peak electricity consumption. Therefore, the same problems which concern solar electricity production also concern air heat pumps, when their effects are estimated from the point of few electricity networks in peak load conditions in winter. The peak heating loads can be reduced with an energy storage system in buildings, but they are mostly equipped with an electricity heated resistor unit as a reserve capacity.

Also smart control systems of electrical devices can considerably reduce the peak electricity consumption. However, the work from this point of few has not been studied.

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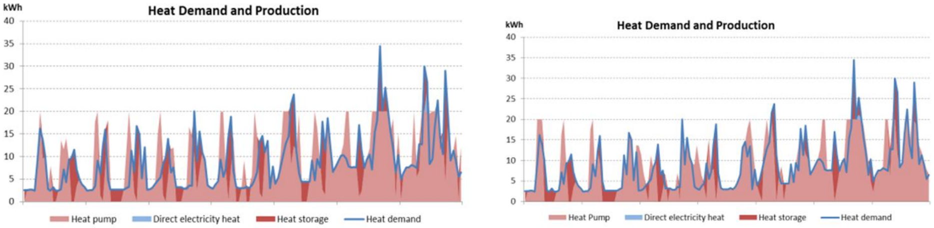
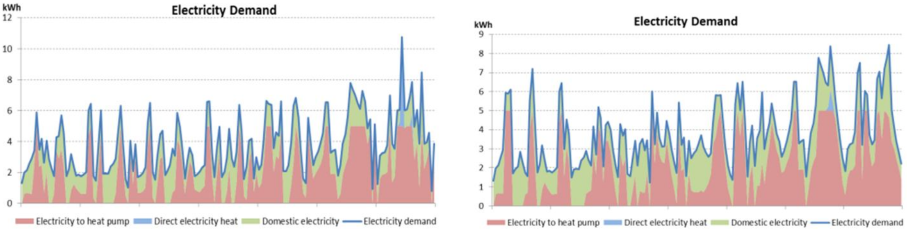
Appendix A: Eco Energy Centre



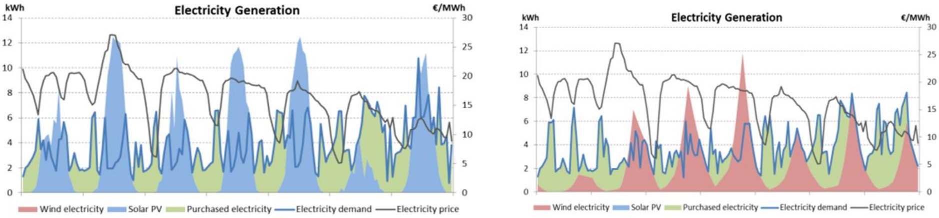
a) b)

Figure A.1. Heat demand and production when solar (a) or wind (b) is available in week 28, July.



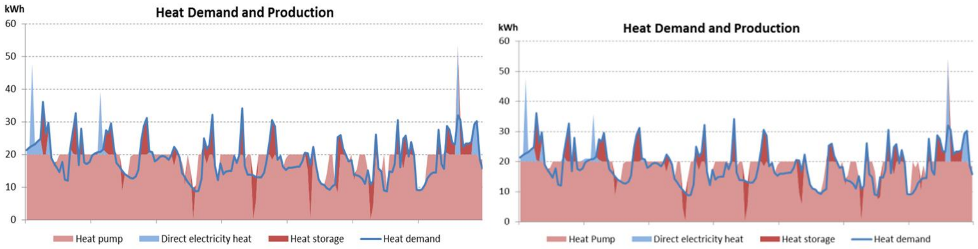
a) b)

Figure A.2. Electricity demand and generation when solar (a) or wind (b) is available in week 28, July.



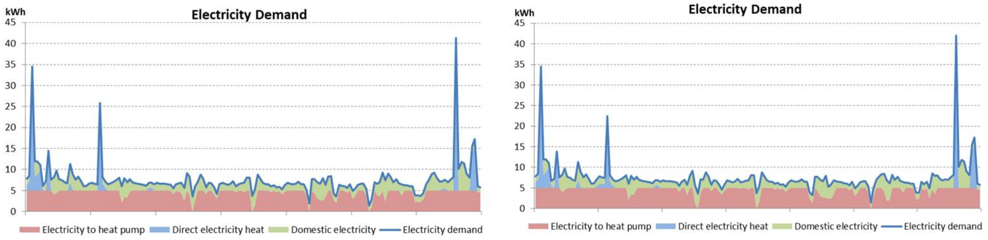
a) b)

Figure A.3. Simulation of heat pump, heat storage and solar PV (a) or wind (b) is available in week 28, July.



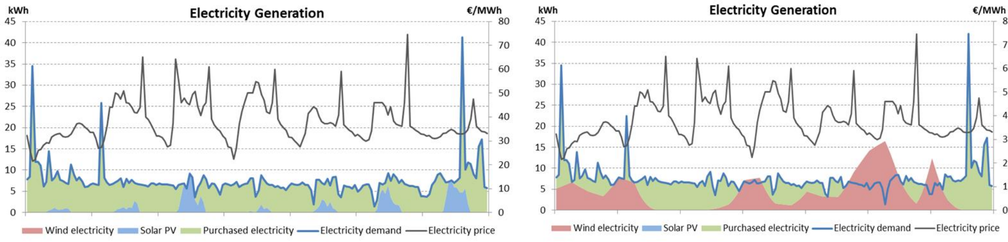
a) b)

Figure A.4. Heat demand and production when solar (a) or wind (b) is available in week 42, November.



a) b)

Figure A.5. Electricity demand and generation when solar (a) or wind (b) is available in week 42, November.



a) b)

Figure A.6. Simulation of heat pump, heat storage and solar PV (a) or wind (b) is available in week 42, November.

Series title and number

VTT Technology 224

Title	**Distributed Energy Systems – DESY**
Author(s)	Kari Sipilä, Miika Rämä, Esa Pursiheimo, Laura Sokka, Atte Löf, Rami NiemJukka Konttinen, Milena Rodriguez, Salvatore Ruggiero, Jussi Maunuksela, Mikko Hietaranta, Henri Karjalainen, Jorma Valta,Timo Kalema, Joni Hilpinen, Jarkko Nyrhinen, Jari Rintamäki, Maxime Viot,Mika Horttanainen, Sanni Väisänen, Jouni Havukainen,Erkki Hiltunen, Raija Koivisto, Birgitta Martinkauppi,Pasi Rikkonen, Vilja Varho, Saija Rasi, Taija Sinkko, Laura Koistinen
Abstract	Combining together different technologies can form a strong hybrid solution adapted to local needs. Local energy production also increases local business and local waste reduces waste management costs, thus enabling other local business and employment. Local energy production also increases energy, electricity and fuel security by reducing import dependency. Waste from one process can be a raw material or fuel for another. By combining the technological solutions for local needs, high primary energy efficiency can be achieved, thereby ensuring that local energy production potential is fully realized. The passive house level is possible to achieve with a well-insulated envelope and effective heat recovery from exhaust air. However, improvements in HVAC systems are more cost-effective than constantly improving the thermal insulation of the envelope. The net zero energy level is difficult to reach, because of heating of hot water, if you do not also build solar heating system or/and warm waste water recovery system. A heat pump system offers a possibility to reduce exterior energy for heating, including also the heating of hot water. The heat pump can also be supported by solar PV panels and COP of the heat pump is possible to increase by solar heating collectors. The net zero-energy building resulted in lower environmental impacts were approximately 50% or less than the district heating and direct electricity heating. Effective and cheap seasonal heat storage is required for good utilisation of solar heating. It is shown by simulations that district heating systems fed by solar heating does not need short-time heat storage. The heat network itself has enough capacity for heat storing. Expert views – there is much potential for small-scale production, but the future development can take very different paths, depending on how energy policy, citizen involvement, and business concepts evolve.
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Language	English, Finnish abstract
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Commissioned by	Tekes, ABB, Fortum, Valmet, Helen, Wärtsilä, Envor Group, Vantaan energia, Ekogen, St1, Savosolar, Gasek, HT-Enerco and Cleen
Keywords	distributed, decentralised, energy, system, renewable, local, energy source, energy storage
Publisher	VTT Technical Research Centre of Finland Ltd P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111

Julkaisun sarja ja numero

VTT Technology 224

Nimeke	**Lähienergia – DESY**
Tekijä(t)	Kari Sipilä, Miika Rämä, Esa Pursiheimo, Laura Sokka, Atte Löf, Rami Niemi, Jukka Konttinen, Milena Rodriguez, Salvatore Ruggiero, Jussi Maunuksela, Mikko Hietaranta, Henri Karjalainen, Jorma Valta, Timo Kalema, Joni Hilpinen, Jarkko Nyrhinen, Jari Rintamäki, Maxime Viot, Mika Horttanainen, Sanni Väisänen, Jouni Havukainen, Erkki Hiltunen, Raija Koivisto, Birgitta Martinkauppi, Pasi Rikkonen, Vilja Varho, Saija Rasi, Taija Sinkko, Laura Koistinen
Tiivistelmä	Hajautettu paikallinen energiantuotanto parantaa energiajärjestelmän kokonaishyötysuhdetta, koska pitkät polttoaineen kuljetusmatkat jäävät pois ja energiasiirtomatkat lyhenevät. Paikallinen tuotanto lisää liiketoimintamahdollisuuksia ja luo työpaikkoja, ja jätteestä tehty energia vähentää jätteen kuljetuskustannuksia. Paikallinen hajautettu energiantuotanto parantaa energiaturvallisuutta ja vähentää tuontienergian tarvetta. Yhdistämällä useampi energiantuotantotapa hybridituotannoksi muodostetaan paikallisiin tarpeisiin vahva energiantuotanto. Energiantuotantoa voidaan myös paikallisesti ketjuttaa siten, että toisen prosessin jäte-energia voi olla toisen prosessin energialähde. Passiivienergiatalon energian kulutusvaatimusta (15 kWh/v) vuositasolla on vaikea saavuttaa ainoastaan eristetasoa lisäämällä, vaan tarvitaan tehokasta ilmastointijärjestelmää ja lämmön talteenottoa poistoilmasta ja lämpimästä käyttövedestä. Nettonollaenergiatalossa tarvitaan lisäksi aurinkoenergiaa lisälämmön ja sähkön lähteenä. Lämpöpumpun ostosähkön tarvetta voidaan pienentää aurinkosähköllä sekä lämpöpumpun COP-lukua parantaa aurinkolämmöllä. Talon energiainvestointien kustannustehokkuus osoittautui parhaimmaksi lämmityksessä ja lämmön talteenotossa. Aurinkolämmön tehokas hyödyntäminen edellyttää riittävän tehokkaan ja edullisen kausivaraston kehittämistä. Nettonollaenergiatalon ympäristöpäästöt todettiin n. 50 % pienemmäksi kaukolämpöön ja sähkölämmitykseen verrattuna. Aurinkolämmöllä tuetun aluelämmitysjärjestelmän simuloinneilla havaittiin, että lyhytaikaista erillistä lämpövarastoa ei välttämättä tarvita, vaan paikallinen lämpöverkko pystyy hoitamaan sen tehtävän. Asiantuntijoiden arvioinnissa todettiin, että lähienergian hybridituotannolla on kysyntää, mutta sen mahdollisuuksiin vaikuttavat energiapolitiikka, kansalaisten asian tiedostaminen ja valmiiden lähienergiaratkaisujen tarjonta.
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Avainsanat	distributed, decentralised, energy, system, renewable, local, energy source, energy storage
Julkaisija	Teknologian tutkimuskeskus VTT Oy PL 1000, 02044 VTT, puh. 020 722 111

VTT TECHNOLOGY 224 Distributed Energy Systems – DESY

Distributed Energy Systems – DESY

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