Solar Calculations for the Raseiniai District Heating Plant

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Content:

1 Project description

The purpose of these calculations is to provide an analysis on whether heat production from solar collectors is economical feasible for the district heating (DH) plant in Raseiniai – or under which conditions solar heating could be feasible. The heat production in Raseiniai is based on solid biomass (wood chips), which gives a rather cheap heat production for the heat production today.

2 Prerequisites

2.1 Method

The calculations for the operation of the plant are performed in the software program energyPRO. energyPRO is a modelling software used for analysis of various types of energy systems on hourly basis. The strategy of the model is to minimize net production costs. The model is therefore on hourly basis operating on the cheapest heat production unit(s) in the system.

The data from energyPRO is afterwards extracted to an Excel sheet, for further process and economic calculations.

The time series for hourly data on outer temperature and solar radiation in Raseiniai area is extracted from the NCAR (National Center for Atmospheric Research) data set in energyPRO.

2.2 Solar radiation and weather data

In energyPRO it is possible to generate online data from either NCAR or CFSR. The NCAR (National Center for Atmospheric Research) reanalysis project provides climate data four times daily in a global grid since 1948 to present. The data used in the calculations is from CFSR. CFSR is an abbreviation for Climate Forecast System Reanalysis. Like NCAR, CFSR is based on a wide range of data sources, such as surface weather stations, weather balloons, airport reports, commercial aircrafts and satellite measurements.

The CFSR data has a global grid resolution of 0.3 x 0.3 degree and one hour time resolution. Time series from 1980 to 2010 can be downloaded. Time series from 2011 is available as CFSR 2. CFSR 2 has a grid resolution of 0.2 x 0.2 degree and 1 hour time resolution.

The CFSR data has the following data set:

- Air temperature [°C]
- Solar radiation [W/m^2]
- Wind speed [m/s]
- Precipitation [mm]
- Humidity [%]

In the calculation data for CFSR 2 is used for outside temperature and solar radiation in the region of Raseiniai. More information on solar radiation in Lithuania in Section 3.4.

2.3 Data from Raseiniai

Some of the prerequisites in the calculations are based on data provided by Raseiniai plant.

The plant in Raseiniai consists of three oil boilers and two solid biomass boilers with the following data:

Boilers	Producer	Capacity MW	Efficiency %	Fuel	Calorific value of fuel kcal/kg
Heat generation unit, boiler No 1	DKVR 4/13	2.7	90	Oil	9530
Heat generation unit, boiler No 2	DKVR 4/13	2.7	90	Oil	9530
Heat generation unit, boiler No 3	KVGM 20/150	20	90	Oil	9530
Heat generation unit, boiler No 4	VŠK-3	3	89	Solid biomass	2200
Heat generation unit, boiler No 5	VŠK-7	7	89	Solid biomass	2200

Table 1: Boiler data.

It is assumed that the oil boilers only are used as reserve capacity and will therefore not produce heat in these calculations. This means that the biomass boilers have full operational hours and will produce 100 % of the heat demand.

The price on woodchips is 54 Lt/MWh, corresponding to 40.0 €/ton. The energy content in the biomass is assumed to be 2.56 MWh/ton. The operational and maintenance costs are estimated to 5.6 €/MWh_{heat} on biomass boilers and 0.8 €/MWh_{heat} on the solar panels.

The temperatures in the district heating network are seen in Table 2.

Month	T_{return} [°C]	$T_{forward}$ [°C]
January	44.9	70.2
February	42.6	65.0
March	44.5	69.6
April	42.1	62.2
May	47.5	61.7
June	47.3	61.4
July	47.5	62.0
August	47.6	61.9
September	47.3	61.8
October	42.4	62.3
November	40.0	62.1
December	41.7	62.7

Table 2: Temperatures in the district heating network.

2.4 Heat demand

The annual heat demand that needs to be produced on the units from the Raseiniai-plant is given from the plant to be around 33,000 MWh on annual basis. From the calculations where the outside temperatures from the region are taken into account, the maximum heat power required is estimated to 11.9 MW on the coldest day in a year.

Hot water demand in non-heating periods is around 4,190 MWh per year.

2.5 Investments

The investment costs per area of solar collector will decrease as the collector area increases. The following investment costs have been used in the calculations for the collector field:

2,500 m^2: 300 €/m^2
5,000 m^2: 280 €/m^2
7,500 m^2: 255 €/m^2
10,000 m^2: 235 €/m^2
12,500 m^2: 230 €/m^2
15,000 m^2: 225 €/m^2
17,500 m^2: 215 €/m^2
20,000 m^2: 210 €/m^2

As well as with the investment in solar collectors, the investment costs in storage also vary with storage capacity. The investment in storage can be estimated from the following formula:

$$\text{Price of storage tank } [€] = 92\ [€/m^2] \cdot \text{Storage Volume } [m^3] + 181{,}000\ [€]$$

The investments in solar panels, storage tank and equipment for the solar area are based on investments in similar projects.

The investment in land is stated from Raseniai to be 4,400 - 5,800 €/ha. An average of 5,100 €/ha has been used in the calculations.

The necessary area of land can be calculated using the following formula:

$$d_{rows} = \frac{A_{land} \cdot s_{collector}}{A_{collector} \cdot f_{length} \cdot f_{width}}$$

Where,
d_{rows} = distance between rows [m]
A_{land} = land area [m^2]
$A_{collector}$ = total collector area [m^2]
$s_{collector}$ = side length of solar panel [m]
f_{length} and f_{width} = factprs for compensation of unused area in connection to the solar collector area, e.g. 3 % is added, i.e. f_{length} and f_{width} equals 1,03.

3 Technical characteristics for central solar heating

3.1 Solar collectors

Basically central solar heating is the provision of central heating and hot water from solar energy by a system in which the water is heated centrally by arrays of solar thermal collectors, i.e. central solar heating plants or CSHPs. The heated water is distributed through district heating pipe networks. For district heating systems the collectors are typically installed on the ground in long rows connected in series. In Danish systems the solar heating system normally takes in the return water and heats it up to the desired forward flow temperature. This is the process which is assumed in the calculations.

In the following, the basic coefficient for a solar collector is introduced: The formula for a solar collector is as follows (without Incidence angle modifier):

$$Y = A \cdot (G \cdot \eta_0 - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2)$$

Where,

Y: Solar yield, i.e. the heat production [W]

A: Solar collector area [m^2]

G: Solar radiation onto the solar collectors, [W/m^2]

T_m: The collectors' average temperature, [°C], that is an average between the temperature of the cold water entering the collector and the hot water leaving the collector

T_a: The ambient temperature [°C].

For the best results the ambient temperatures should be (at least) hourly.

The efficiency of the solar collector is defined by three parameters:

η_o: Intercept (maximum) of the collector efficiency [-]

a_1: The first-order coefficient in collector efficiency equation [$W/(m^2K)$]

a_2: The second-order coefficient in collector efficiency equation [$W/(m^2K)^2$]

These three parameters are available for collectors tested according to ASHRAE standards and rated by SRCC (ASHRAE, 2003; SRCC,1995), as well as for collectors tested according to the recent European Standards on solar collectors (CEN, 2001). Many examples of collector parameters can be found on the internet (e.g. in the Solar Keymark Database[*]).

In the calculations the following coefficients have been used, which is from a typically Danish solar plate collector:

$\eta_o = 0.815$

$a_1 = 2.43$ [$W/(m^2K)$]

$a_2 = 0.012$ [$W/(m^2K)^2$]

Furthermore, the model includes Incidence Angle Modifier, IAM or K_θ. The sun is not always located perpendicular to the collector plane; the incidence angle generally changes both during the course of a day

[*] www.solarkeymark.dk/CollectorCertificates

and throughout the year. The modifier coefficient is used since the transmittance of the cover glazing for the collector changes with the incidence angle. In other words the IAM is included to take into account that the reflections of the glass cover increases with higher incidence angle. For an incidence angle of 50° the incidence angle modifier K_{50} = 0.94. For the given incidence angle in every hour of the year the efficiency η_0 is multiplied by the corresponding IAM for the given incidence angle.

Central solar heating can involve large-scale thermal storage, scaling from daily storage to seasonal thermal energy storage (STES). Thermal storage can help increase the solar fraction, which is the ratio between solar energy gains to the total energy demand in the system. Ideally, the aim for applying seasonal storage is to store solar energy collected in the summer time to the winter month.

Compared to small solar heating systems, central solar heating systems have better price-performance ratios due to the lower installation price, a higher thermal efficiency and less maintenance.

Central solar systems can also be used for solar cooling in the form of district cooling. In this case, the overall efficiency is high due to the high correlation between the energy demand and the solar radiation.

3.2 Storage

Typically 20 – 25 % of the heat demand can be covered by solar heat in combination with a storage tank in a central solar system. For systems where higher shares of solar coverage is desired a seasonal storage should be considered. Normally for 40 % solar coverage and more, a seasonal storage is necessary.

A storage could be sized to have a capacity of 200-300 l per m^2 solar panel. The higher the share of solar heat, the more storage capacity is needed.

The system heats up the tank by means of the solar collectors and use this heat for space heating and/or domestic hot water. If the temperature of the water in top of the tank is too high, then cold water is used to shunt down to the desired temperature.

It is possible for some tanks (with several outlets) to extract heat at different heights. In such tanks water at the desired demand temperature level can be used (e.g. from the middle part of the tank) while maintaining high temperature water in the top of the tank if the temperature in the top of the tank is higher than what is needed. This is especially useful if you operate with very large storages, where it is important to maintain a good thermal stratification (e.g. for a 2,000 m^3 storage tank.)

3.3 The solar district heating system

A simple principle drawing of the solar collector field connected to a plant is seen in Figure 1. The system requires a series of parts, here among solar collectors and foundation for these, a house for the technical equipment, heat exchangers together with transmission pipes and pumps, thermal storage, a nitrogen plant and valves.

In addition it is necessary to hire professional contractors to do work in relation to the foundation of the land, pipe work together with planting and other land works.

The system also needs connection to the electricity grid for pumping together with control and supervisions of the system.

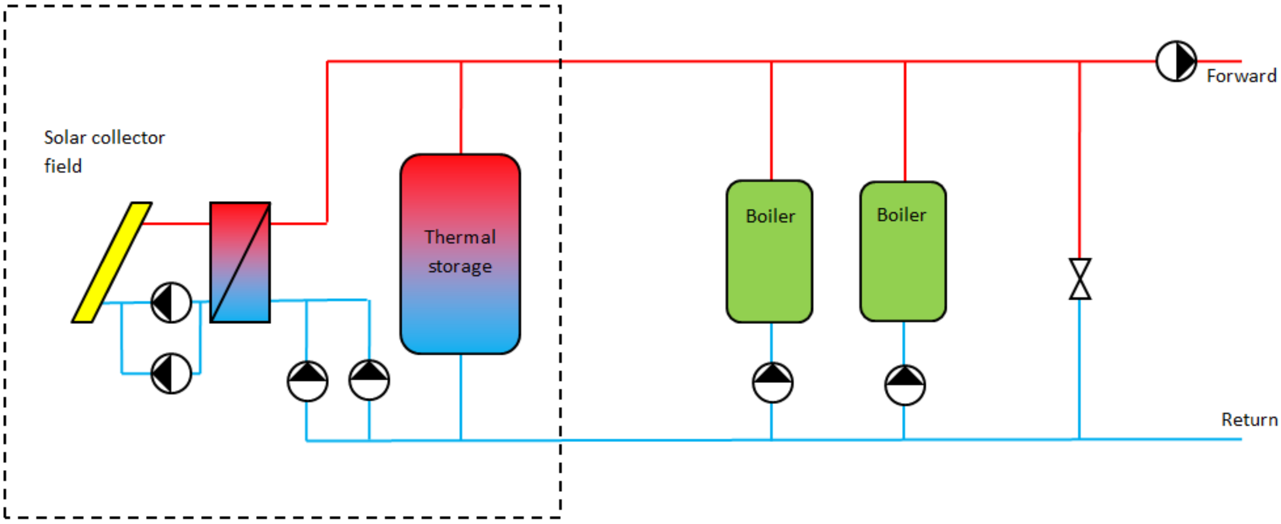

Figure 1: Principle drawing.

3.4 Solar radiation

The solar radiation in Lithuania ranges from 850 to 1,050 kWh per m^2, see Figure 4. The solar radiation in Lithuania is comparable to the solar radiation in Denmark, but is lower compared to the solar radiation in Southern Europe; see Figure 3, where the solar radiation is above 2,200 kWh/m^2 in some areas.

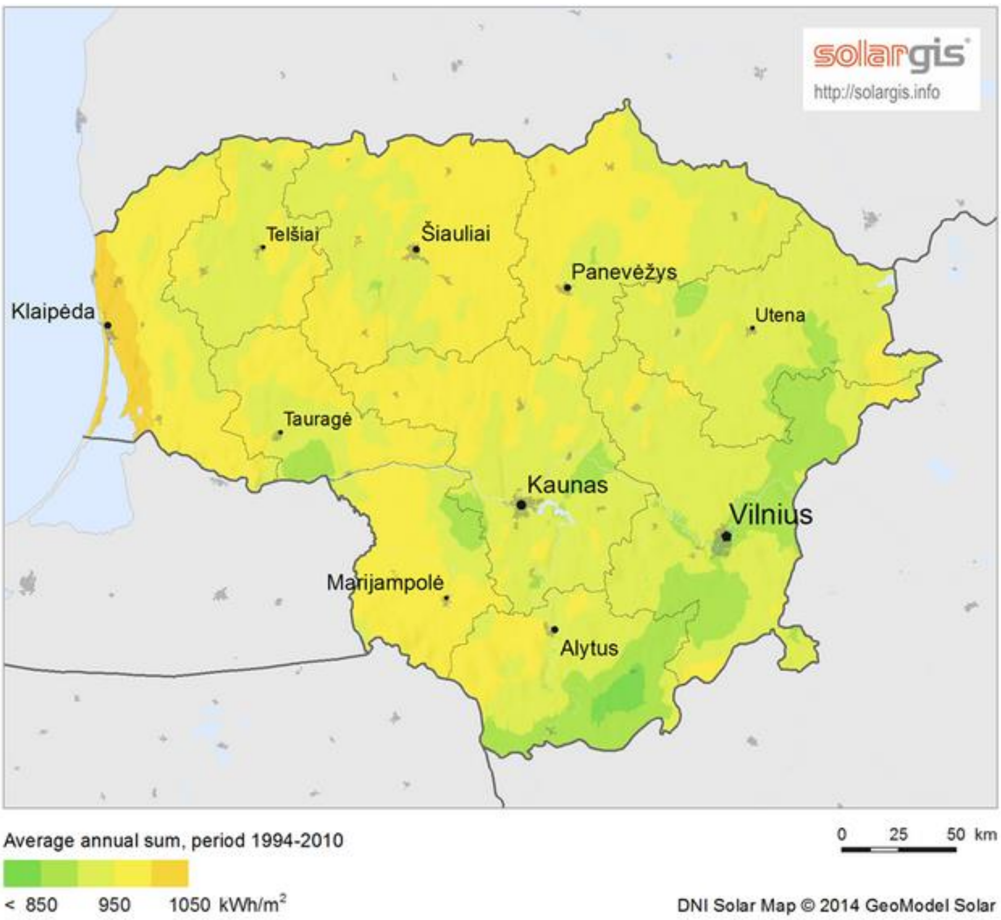

Figure 2: Solar radiation in Lithuania (Direct normal radiation), kWh/m^2 (http://solargis.info/).

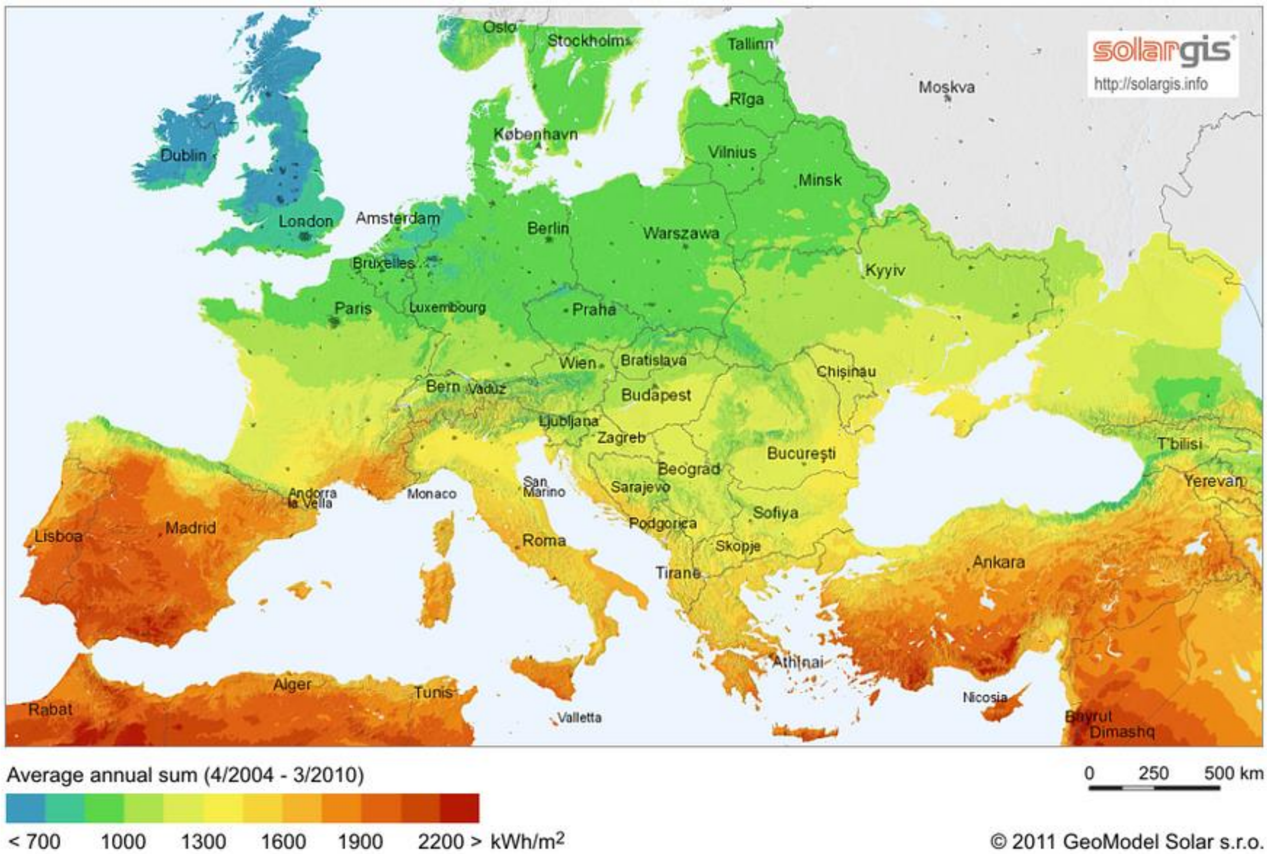

Figure 3: Solar radiation in Europe (Direct normal radiation), kWh/m^2 (http://solargis.info/).

4 Calculations

To perform the analysis a model has been setup of a reference scenario and scenarios with various coverage of solar from 5,000 m^2 to 20,000 m^2 with steps of 2,500 m^2. To roughly size the storage tank, ¼ m^3 per m^2 of solar collector is used in all calculations. This means the following scenarios have been calculated in energyPRO:

0. The reference situation, where the plant is operated based on the given data.
1. 2,500 m^2 of solar collectors connected to the Raseiniai DH plant.

2a. 5,000 m^2 of solar collectors connected to the Raseiniai DH plant.

2b. 5,500 m^2 of solar collectors and 1,250 m^3 storage in connection with the Raseiniai DH plant.

3. 7,500 m^2 of solar collectors and 1,875 m^3 storage in connection with the Raseiniai DH plant.
4. 10,000 m^2 of solar collectors and 2,500 m^3 storage in connection with the Raseiniai DH plant.
5. 12,500 m^2 of solar collectors and 3,125 m^3 storage in connection with the Raseiniai DH plant.
6. 15,000 m^2 of solar collectors and 3,750 m^3 storage in connection with the Raseiniai DH plant.
7. 17,500 m^2 of solar collectors and 4,375 m^3 storage in connection with the Raseiniai DH plant.
8. 20,000 m^2 of solar collectors and 5,000 m^3 storage in connection with the Raseiniai DH plant.

5 Energy results

In this section, the results from the calculations in energyPRO and Excel are presented.

5.1 Heat productions

The distribution of heat production based on biomass (wood chips) and solar is shown in Table 3.

		Reference	2,500 m^2 0 m^3	5,000 m^2 0 m^3	5,000 m^2 1,250 m^3	7,500 m^2 1,875 m^3	10,000 m^2 2,500 m^3
Heat production							
Biomass boilers	MWh	33,295	32,018	31,113	30,690	29,392	28,165
Solar heat	MWh	0	1,277	2,182	2,605	3,903	5,131
Total	MWh	33,295	33,295	33,295	33,295	33,295	33,295
Solar coverage	%	0%	3.8%	6.6%	7.8%	11.7%	15.4%

		Reference	12,500 m^2 3,125 m^3	15,000 m^2 3,750 m^3	17,500 m^2 4,375 m^3	20,000 m^2 5,000 m^3
Heat production						
Biomass boilers	MWh	33,295	27,091	26,170	25,348	24,616
Solar heat	MWh	0	6,204	7,125	7,947	8,679
Total	MWh	33,295	33,295	33,295	33,295	33,295
Solar coverage	%	0%	18.6%	21.4%	23.9%	26.1%

Table 3: Heat production in the calculated scenarios.

As seen in Table 3 the solar coverage varies from 3.8 % in scenario 1 to 26 % in scenario 8.

5.2 Biomass consumption

In the future biomass can be sparse resource. It can therefore be beneficial to supplement the heat production with long term sustainable resources such as solar heat. In the following it is seen how much fuel the different shares of solar heat can save of fuel on annual basis:

		Reference	2,500 m^2 0 m^3	5,000 m^2 0 m^3	5,000 m^2 1,250 m^3	7,500 m^2 1,875 m^3	10,000 m^2 2,500 m^3
Biomass consumption	MWh	37,408	35,973	34,957	34,481	33,022	31,644
	ton	14,622	14,061	13,664	13,478	12,908	12,369

		Reference	12,500 m^2 3,125 m^3	15,000 m^2 3,750 m^3	17,500 m^2 4,375 m^3	20,000 m^2 5,000 m^3
Biomass consumption	MWh	37,408	30,438	29,403	28,479	27,657
	ton	14,622	11,898	11,493	11,132	10,810

Table 4: Annual use of biomass.

The solar panels help reduce the fuel use by up to around 10,000 MWh annually, corresponding to around 3,800 tons of wood chips. The reduction in fuel use results in a reduction of the operation costs of the plant, which is shown in the next section.

5.3 Performance of solar collectors

The performance of the solar collectors varies with the share of solar heat in the heat production, since higher share often need a larger storage capacity per m^2 solar. In Figure 4 is seen the average production per m^2 solar collector in each scenario. The solar coverage is illustrated on the secondary vertical axis.

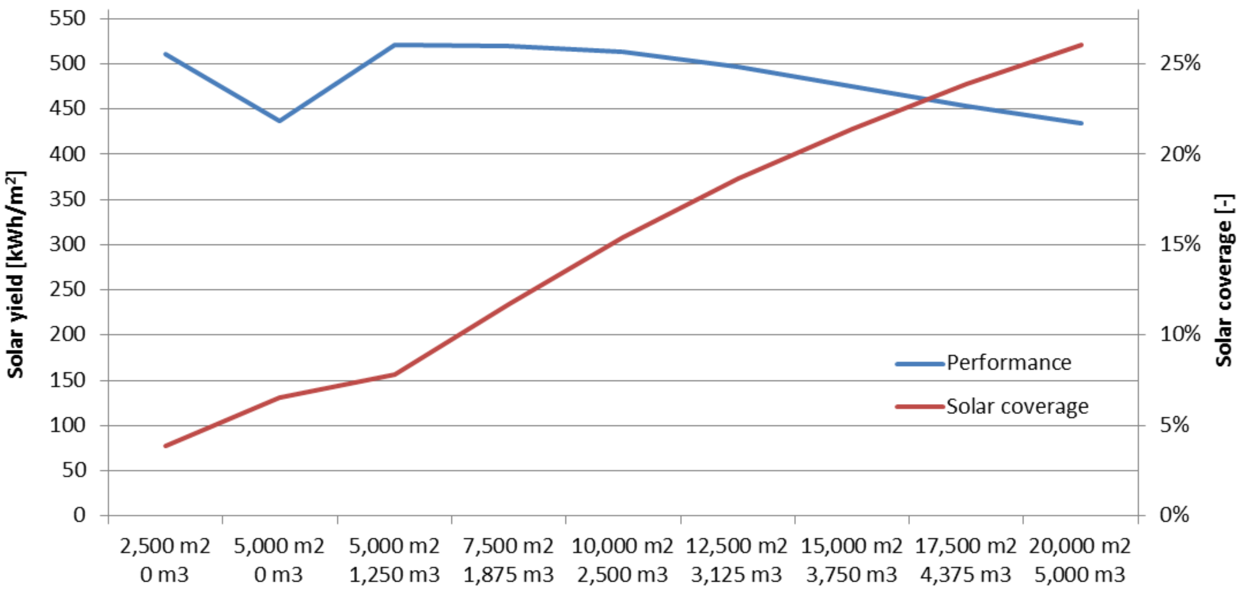

Figure 4: Solar collector performance.

From a very high production for solar collectors in the first scenarios with more than 500 kWh per m^2, the performance is reduced to around 430 kWh per m^2 for the highest solar coverage.

The monthly production from the solar collectors in each calculation compared to the monthly heat demand is shown in Figure 5.

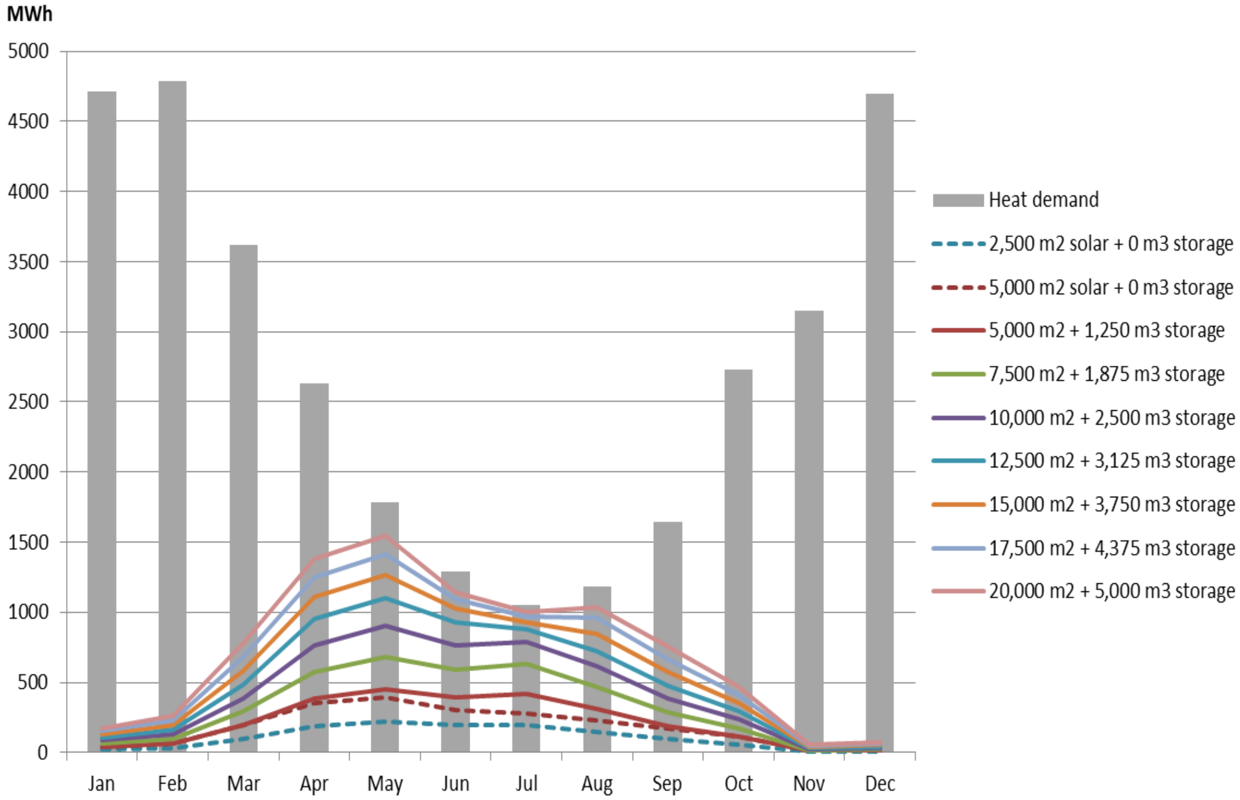

Figure 5: Monthly production from solar collectors.

6 Economic results

6.1 Budget

The estimated budget for all the calculations based on the investments from Section 2.5 is seen in Table 5.

2,500 m^2 solar panels	**0**	**m^3 tank**				
Investment solar panels	2,500	m^2 solar panels	300	€/m^2	750,000	€
Investment storage tank	0	m^3	0	€	0	€
Investment land	0.57	ha	5,100	€/ha	2,884	€
Total					1,455,768	€
5,000 m^2 solar panels	**0**	**m^3 tank**				
Investment solar panels	5,000	m^2 solar panels	280	€/m^2	1,400,000	€
Investment storage tank	0	m^3	0	€	0	€
Investment land	1.13	ha	5,100	€/ha	5,768	€
Total					1,405,768	€
5,000 m^2 solar panels	**1,250**	**m^3 tank**				
Investment solar panels	5,000	m^2 solar panels	280	€/m^2	1,400,000	€
Investment storage tank	1,250	m^3	296,000	€	296,000	€
Investment land	1.13	ha	5,100	€/ha	5,768	€
Total					1,701,768	€
7,500 m^2 solar panels	**1,875**	**m^3 tank**				
Investment solar panels	7,500	m^2 solar panels	255	€/m^2	1,912,500	€
Investment storage tank	1,875	m^3	353,500	€	353,500	€
Investment land	1.70	ha	5,100	€/ha	8,652	€
Total					2,274,652	€
10,000 m^2 solar panels	**2,500**	**m^3 tank**				
Investment solar panels	10,000	m^2 solar panels	235	€/m^2	2,350,000	€
Investment storage tank	2,500	m^3	411,000	€	411,000	€
Investment land	2.26	ha	5,100	€/ha	11,535	€
Total					2,772,535	€
12,500 m^2 solar panels	**3,125**	**m^3 tank**				
Investment solar panels	12,500	m^2 solar panels	230	€/m^2	2,875,000	€
Investment storage tank	3,125	m^3	468,500	€	468,500	€
Investment land	2.83	ha	5,100	€/ha	14,419	€
Total					3,357,919	€
15,000 m^2 solar panels	**3,750**	**m^3 tank**				
Investment solar panels	15,000	m^2 solar panels	225	€/m^2	3,375,000	€
Investment storage tank	3,750	m^3	526,000	€	526,000	€
Investment land	3.39	ha	5,100	€/ha	17,303	€
Total					3,918,303	€
17,500 m^2 solar panels	**4,375**	**m^3 tank**				
Investment solar panels	17,500	m^2 solar panels	215	€/m^2	3,762,500	€
Investment storage tank	4,375	m^3	583,500	€	583,500	€
Investment land	3.96	ha	5,100	€/ha	20,187	€
Total					4,366,187	€
20,000 m^2 solar panels	**5,000**	**m^3 tank**				
Investment solar panels	20,000	m^2 solar panels	210	€/m^2	4,200,000	€
Investment storage tank	5,000	m^3	641,000	€	641,000	€
Investment land	4.52	ha	5,100	€/ha	23,071	€
Total					4,864,071	€

Table 5: Investment budgets.

6.2 Average annual costs

Heat production from solar panels is seasonal dependent with high production during summer and no or very little production during winter months. Since the oil boilers do not produce heat in these calculations, the heat production from solar panels only replaces cheaper heat produced from biomass boilers. Calculations for the investment amortized with an interest rate of 3 % over 30 years are shown in Table 6:

		Reference	2,500 m^2 0 m^3	5,000 m^2 0 m^3	5,000 m^2 1,250 m^3	7,500 m^2 1,875 m^3	10,000 m^2 2,500 m^3
Operational costs	€/year	771,915	743,326	723,078	713,610	684,541	657,073
Operating savings	€/year		28,589	48,837	58,305	87,374	114,842
Investment	€		752,884	1,455,768	1,751,768	2,274,652	2,772,535
Capital costs	€/year		38,412	74,272	89,374	116,051	141,453
Simple pay back period	Years		26	30	30	26	24
Net savings	€/year		-9,823	-25,435	-31,069	-28,677	-26,611
Heat production cost	€/MWh	23.2	22.3	21.7	21.4	20.6	19.7
Heat production cost incl. capital costs	€/MWh	23.2	23.5	23.9	24.1	24.0	24.0

		Reference	12,500 m^2 3,125 m^3	15,000 m^2 3,750 m^3	17,500 m^2 4,375 m^3	20,000 m^2 5,000 m^3
Operational costs	€/year	771,915	633,052	612,434	594,024	577,639
Operating savings	€/year		138,863	159,481	177,891	194,276
Investment	€		3,357,919	3,918,303	4,366,187	4,864,071
Capital costs	€/year		171,319	199,909	222,760	248,161
Simple pay back period	Years		24	25	25	25
Net savings	€/year		- 32,456	-40,428	-44,869	-53,885
Heat production cost	€/MWh	23.2	19.0	18.4	17.8	17.3
Heat production cost incl. capital costs	€/MWh	23.2	24.2	24.4	24.5	24.8

Table 6: Average annual costs with an interest rate of 3 %.

The savings from heat production in the solar panels cannot finance the investment with the given assumptions – there is a negative net saving of between approx. 10,000 and almost 54,000 € annually. The payback period is calculated as a simple payback period, where the savings in operation are divided by the investment. In this context it should be noticed that the prices are fixed throughout the calculation period. While this is the case in practice for the solar heat, the price of biomass is expected to increase in the coming 30 years. This fact is addressed in the section below called "Sensitivity analysis".

The average heat production costs including capital costs for the investment is between 23.5 and 24.8 €/MWh, which is higher compared to 23.2 €/MWh in the reference situation.

The capital costs are here calculated for a period of 30 years, which corresponds to the technical lifetime is 30 years. A series of sensitive calculations are performed in the following.

6.3 Sensitivity analysis

The Danish Energy Agency expects that the price of biomass will increase by approximately 1 % on annual basis. This corresponds to an average price of biomass over the next 30 years which is of 16 % higher than the price today. In Table 7 the annual average costs are shown for each calculation, where the biomass price is 16 % higher than in the basic calculations. The biomass price is in these calculations 46.5 €/ton.

Since the lowest heat price when including a solar heating system is found at the smallest solar collector area, a calculation has been made for an extra scenario which includes half the area of the one in scenario 1, i.e. for 1,250 m^2 of solar collectors. (The cost per m^2 of collector is assumed to be the 300 €/m^2.)

		Reference	**1,250 m^2 0 m^3**	**2,500 m^2 0 m^3**	**5,000 m^2 0 m^3**	**5,000 m^2 1,250 m^3**	**7,500 m^2 1,875 m^3**
Operational costs	€/year	865,641	849,232	833,457	810,662	800,004	767,280
Operating savings	€/year		16,409	32,184	54,979	65,637	98,361
Investment	€		376,442	752,884	1,455,768	1,751,768	2,274,652
Capital costs	€/year		19,206	38,412	74,272	89,374	116,051
Simple pay back period	Years		23	23	26	27	23
Net savings	€/year		-2,797	-6,228	-19,293	-23,737	-17,690
Heat production cost	€/MWh	26.0	25.5	25.0	24.3	24.0	23.0
Heat production cost incl. capital costs	€/MWh	26.0	26.1	26.2	26.6	26.7	26.5

		Reference	**10,000 m^2 2,500 m^3**	**12,500 m^2 3,125 m^3**	**15,000 m^2 3,750 m^3**	**17,500 m^2 4,375 m^3**	**20,000 m^2 5,000 m^3**
Operational costs	€/year	865,641	736,358	709,315	686,104	665,379	646,933
Operating savings	€/year		129,283	156,326	179,537	200,262	218,708
Investment	€		2,772,535	3,357,919	3,918,303	4,366,187	4,864,071
Capital costs	€/year		141,453	171,319	199,909	222,760	248,161
Simple pay back period	Years		21	21	22	22	22
Net savings	€/year		-12,170	-14,993	-20,372	-22,498	-29,453
Heat production cost	€/MWh	26.0	22.1	21.3	20.6	20.0	19.4
Heat production cost incl. capital costs	€/MWh	26.0	26.4	26.4	26.6	26.7	26.9

Table 7: Sensitivity analysis: increase in biomass price of 16 %.

With a higher biomass price, the simple payback period decreases and is in this case between 21 and 27 years. Figure 6 shows the average heat price compared to the reference case when the increase in biomass price is taken into account. The smallest solar heating system reaches almost the same average heat price as the reference.

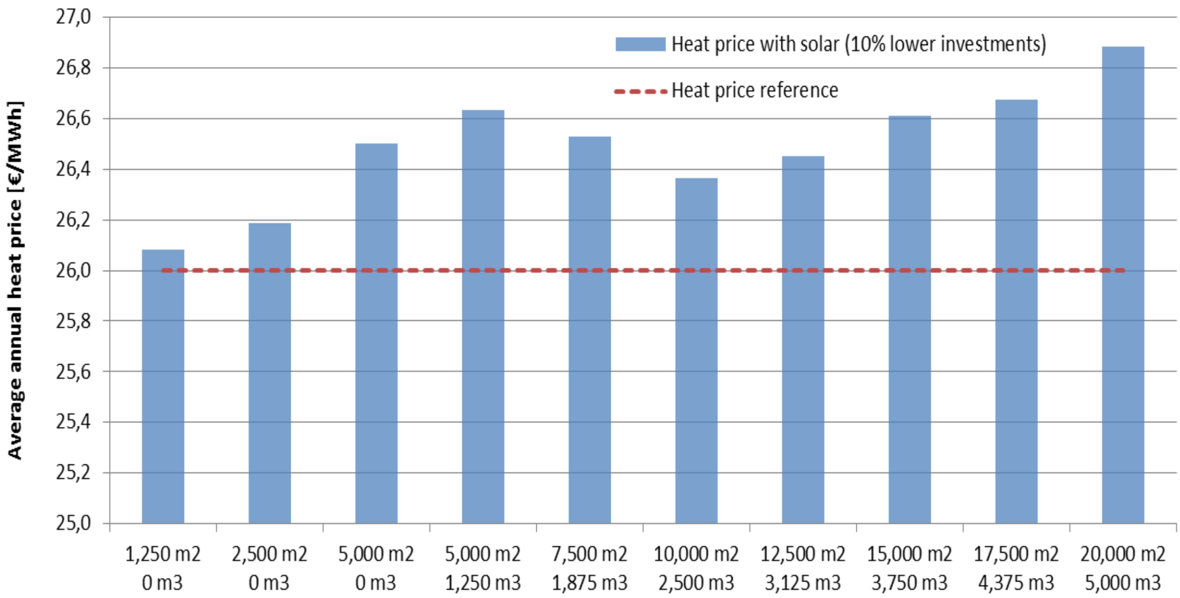

Figure 6: Average heat price for the calculations with increased biomass costs.

For the heat price for a solar heating system of the smallest scale to balance with the reference heat price, the biomass cost should be 25% higher corresponding to the average biomass price over the calculation period if the price increases 1.5 % per year.

As an alternative sensitivity analysis the following calculations investigates a situation where the investment shows to be 10 % cheaper. Hence all investments in these calculations are reduced by 10 %. A reduction in the investment amortized with a real interest rate of 3 % over 30 years gives the following result:

		Reference	**1,250 m^2 0 m^3**	**2,500 m^2 0 m^3**	**5,000 m^2 0 m^3**	**5,000 m^2 1,250 m^3**	**7,500 m^2 1,875 m^3**
Operational costs	€/year	771,915	757,338	743,326	723,078	713,610	684,541
Operating savings	€/year		14,577	28,589	48,837	58,305	87,374
Investment	€		376,442	677,595	1,310,191	1,576,591	2,047,186
Capital costs	€/year		19,206	34,570	66,845	80,437	104,446
Simple pay back period	Years		26	24	27	27	23
Net savings	€/year		-4,629	-5,981	-18,008	-22,132	-17,072
Heat production cost	€/MWh	23.2	22.7	22.3	21.7	21.4	20.6
Heat production cost incl. capital costs	€/MWh	23.2	23.3	23.4	23.7	23.8	23.7

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		Reference	10,000 m^2 2,500 m^3	12,500 m^2 3,125 m^3	15,000 m^2 3,750 m^3	17,500 m^2 4,375 m^3	20,000 m^2 5,000 m^3
Operational costs	€/year	771,915	657,073	633,052	612,434	594,024	577,639
Operating savings	€/year		114,842	138,863	159,481	177,891	194,276
Investment	€		2,495,282	3,022,127	3,526,473	3,929,568	4,377,664
Capital costs	€/year		127,307	154,187	179,918	200,484	223,345
Simple pay back period	Years		22	22	22	22	23
Net savings	€/year		-12,465	-15,324	-20,437	-22,593	-29,069
Heat production cost	€/MWh	23.2	19.7	19.0	18.4	17.8	17.3
Heat production cost incl. capital costs	€/MWh	23.2	23.6	23.6	23.8	23.9	24.1

Table 8: Sensitivity analysis: Reduction in investment of 10 %.

A smaller investment reduces the negative net savings on the solar heating system. This results in heat production costs between 23.3 and 24.1 €/MWh which in the lower end is almost as low as in the reference situation.

7 Conclusions

From the calculations with various coverage of solar panels with the given investments, amortized with an interest rate of 3 % over 30 years, it can be concluded that the investment is not economical beneficial to Raseiniai district heating plant with the given prerequisites. However if the biomass price is assumed to increase in the future, the solar heating system could prove to be a feasible solution after all. The future global demand for biomass may force the biomass prices upwards thus making it feasible to replace some of the biomass with solar heat and ship some of the biomass to other countries.

The average heat production price for a smallest solar heating system decreases to the reference level if the biomass price is assumed to increase corresponding to an annual increase of 1.5 %.

It can be concluded that though a solar heating system for the given assumptions is not economically feasible for the district heating plant in question, solar district heat production in Raseiniai may be possible at competitive costs if biomass prices increases in the future.