Solar Thermal Systems vs. Photovoltaic Systems. Case study: Single Family Building in Lithuania

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Abstract

Solar thermal systems have been installed in Lithuania for over 20 years, and the main trend is to use them on a small scale. Large-scale solar photovoltaic systems only blossomed in 2013 due to a very good feed-in tariff. Small-scale (up to 10 kW) solar photovoltaic systems became more attractive after the national energy distribution operator offered the possibility of electrical energy ‘storage’ in the grid after 2015. Only in recent years have photovoltaic system prices dropped significantly, and a subsidy system been started for renewable energy sources in single-family buildings. This has increased interest in these renewable energy sources.

The popularity of renewable sources is growing because of increasing traditional energy prices and the support of government policies. In certain cases, however, the renewable energy systems are competing with each other. This is noticeable in the single-family building sector, where solar thermal systems are often in competition with photovoltaic systems. There is no unambiguous answer to which system is more profitable for the owner of the building, as this depends on many aspects, which are discussed below. Herein, also, an analysis of the annual balance of various forms of energy used in building engineering systems is presented, which allows us to make an economic comparison between the systems, and to determine the ecological effects of produced green energy.

The aim of this study was to compare solar thermal and photovoltaic systems in technical, energy production, environmental and payback time aspects for the single-family building case in Lithuania.

Keywords: single-family building, renewable energy, solar thermal systems, photovoltaic systems, energy prices

1. Introduction

The renewable energy share has continued to grow worldwide in recent years, alongside increasing global energy consumption, decreasing investment in many renewable energy sources and declining global fossil fuel prices. Furthermore, in a lot of countries the fluctuating price of fossil fuels has had a serious impact on energy security. There are several alternative resources that can provide clean, continuous and renewable energy, such as solar, wind, biomass, hydro and geothermal.

Solar systems are one part of the environmentally-friendly technologies that produce renewable energy. Solar thermal (ST) systems first started being installed in Lithuania over 20 years ago. The solar photovoltaic (PV) market only blossomed in 2013 due to a very good feed-in tariff (0.472 €/kWh). Only in recent years have PV systems prices dropped significantly, and a subsidy system been started for renewable energy sources in single-family buildings, which has increased their popularity.

The cost of PV systems has dropped by more than 50% in the last few years, and is expected to continue dropping (Chung et al. 2015). From 2009 to 2015, there was a 56% reduction in the total cost, 77% in PV modules, 45% in inverter costs, and 44% in installation-related costs (Malinowski et al. 2017). In 2018, the price of small (up to 10 kWp) domestic rooftop PV systems in Lithuania has dropped below 1100 €/kWp (ESO 2018; TERMA 2018). On the other hand, the price of ST systems has not change much in the last decade. Analysis in 2016 showed that the average price of a medium-sized (25-166 m^2) ST system, with a flat plate solar collector, was 527 €/m², 657 €/m² with evacuated tube solar collectors (Valancius et al. 2016).

Studies on PVs currently concentrate on their improvement, presenting solutions for a higher efficiency and lower price of the panels and systems, and extracting the maximum possible amount of energy from the PV panels. The best-performing monocrystalline silicon models have about 26.7% efficiency (Photovoltaics Report, 2018). High-concentration multijunction solar cells have achieved up to 46% efficiency in the laboratory, and there is still much research and development needed in this direction (Photovoltaics Report 2018). On the other hand, ST systems have well-developed collectors, and the efficiency of these collectors has not changed much in the last decade.

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The Lithuanian energy market is quite unique. The district heating network in Lithuania occupies more than 55% of the total thermal market, and the average price in Lithuanian cities is 0.057 €/kWh (LSTA 2018). Quite frequently, natural gas (11.9%), biofuels (25%), coal (5.2%) or, in some cases, electricity (0.22%) are used for building heating systems (EHPA 2018). In 2017, the prices of natural gas varied from 0.38 to 0.59 €/m^3 for citizens in Lithuania, depending on the total consumption per calendar year. Electricity prices currently vary from 0.078 to 0.122 €/kWh, depending on the selected tariff (ESO 2018a). Despite small fluctuations in recent years, it is noticeable that traditional energy prices are slowly growing.

The cost of energy for heating and electricity needed for buildings is the most important factor that influences the renewable energy market. In Lithuania, some limited subsidy systems and funds for renewable energy installations have existed since 2005.

Depending on the project, subsidies covering from 30 to 100% of the initial costs are available. For example, it is possible to get a subsidy of up to 30% for a single-family building. On the other hand, if you want to get a subsidy for an ST system, heat pump or other renewable energy source for heating, your house must be older than five years. The maximum subsidy cannot exceed 14,500 €. Subsidies available in 2018 for different renewable energy sources in single-family buildings are presented in Table 1. In 2018, the subsidy system for single-family buildings was so popular that 3.3 million € was distributed in under five working days. Based on information from the Ministry of the Environment, Lithuanian subsidies for renewable energy sources in single-family buildings should stay the same for the next two years.

Table 1. Subsidies for renewable energy sources in single family buildings (APVA, 2018)

Technology and/or equipment	Unit	Fixed subsidy EUR/m^2 or EUR/kW
ST system with flat plate collectors	m^2 total area	160
ST system with evacuated tube collectors	m^2 total area	128
PV system without batteries	kW (peak power)	336
Vertical axis wind turbine without batteries	kW (peak power)	683
Horizontal axis wind turbine without batteries	kW (peak power)	557
Heat pump “soil to water”	kW (nominal power)	343
Heat pump “air to water”	kW (nominal power)	193
Heat pump “air to air”	kW (nominal power)	121
Biofuel boiler, rate of class 5 (EN 303-5)	kW (nominal power)	41

It is noticeable that, in Lithuania, increasingly more users in the single-family building sector are choosing PV systems over ST systems. This is because of their shorter payback time, easier maintenance, and better combination with heat pumps and other systems. In fact, customers who had installed ST systems in the past have, in recent years, also been installing PV systems (see Fig. 1.). There is evidence that ST and PV systems are competing in the market not only with traditional energy sources, but also with each other and other renewable energy sources.

Fig. 1: Single family house with ST (5m^2) and PV (5kWp) systems.

The aim of this study was to compare ST and PV systems in terms of technical, energy production, environmental and payback time aspects for in the case of single-family buildings in Lithuania.

2. Methods

The average global solar irradiation in Lithuania is similar to that in such countries as Germany, Austria, Denmark and Poland, with average annual solar irradiation of 1000 kWh/m², but with almost all the irradiated solar energy being collected between April and the end of October (Valancius et al. 2015).

Analysis of the Lithuanian market at the end of 2017 showed that the size of ST systems in single-family buildings vary between 2 and 20 m² in total area, and that the power of PV systems is from 1.2 to 10 kWp (ESO 2018; TERMA 2018). It is difficult to install a larger than 5 kWp grid-connected PV system in a single-family building in the Lithuanian market because of strict regulations. The maximum allowed PV system power for a single-family building cannot exceed 10 kWp. It is also not allowed to produce more electrical energy than a single-family building consumes per year. The use of network services ('upkeep') in low-voltage distribution networks is 0.0389 €/kWh for each kWh retrieved.

The most popular solar systems for three to five-person single-family buildings are:

- An ST system with flat plate collectors of 5 m² in total area, a domestic hot-water boiler with a 300-litre volume, and additional equipment. Average investment in such systems is 3360 €;
- A grid-connected 5 kWp (three-phase) PV system with polycrystalline modules. Most single-family electricity energy needs are up to 5000 kWh/year, with power consumption of up to 40%. Average investment in such systems is 6720 €.

These two systems where selected for detailed analysis. The simulation software T*SOL and PV*SOL and data from exiting systems were used to compare the systems in terms of their energy production, environmental and payback time aspects.

It was also assumed that the entire cost of the system was covered during the installation. The lifespan of both systems was considered to be 25 years. The parameters used for financial assessment of the systems are presented in Tables 1 and 2.

Table 2. Energy prices and other parameters used for economic calculations.

The lifespan of the system, years	25
Specific energy from district heating (average), €/kWh	0.056
Specific energy from natural gas price (consumption from 501 m³ to 20000 m³), €/m³	0.390
Specific energy from solid fuel or wood pellets (average), €/kWh	0.040
Specific electricity costs (standard), €/kWh	0.113
Index for energy prices, % per year	2.0
Running costs, %	0.5

3. Results of systems analysis

The results of the analysis showed that a typical 5 m² ST system for a single-family building can cover approximately 50% of the domestic hot-water (160 litres/day) needs. A 5 kWp PV system can produce electrical energy of up to 4700 kWh/year. In most cases, the payback time of a PV system is shorter than that of a ST system (see Table 3).

Table 3. Results of analysis of ST systems.

Main energy source	Cost of ST energy production (without subsidy), €/kWh	Savings in first year, €	CO_2 emissions avoided, kg	Amortization period, years	Amortization period with subsidy, years
District heating	0.091	93	360	>25	22.6
Natural gas		82	447		25.0
Solid fuel or wood pellets		66	929		25.0
Electricity		93	1098	14.8	11.9

The amortisation period of the analysed PV systems was 13.9 years (see Table 4), whereas the ST systems' amortization period, in most cases, was over 14 years (see Table 4) when potential subsidies (see Table 1) were not included. The payback period with possible subsidies in Lithuania (see Table 1) averaged three years less, although that is too long to ensure the stable growth of solar applications.

The analysed ST system can produce approximately 350 kWh/m² of thermal energy, and reduce greenhouse gas emissions from 360 to 1098 kg CO_2/year. A 5 kWp PV system can produce approximately 156 kWh/m², or 940 kWh with a 1 kWp system, and can reduce greenhouse gas emissions by approximately 2790 kg/year (see Tables 3 and 4). Calculations of energy related CO_2 emissions was done with T*SOL and PV*SOL software.

Table 4. Results of analysis of solar PV system.

PV system	Cost of PV electricity production (without subsidy), €/kWh	Savings in first year, €	CO_2 emissions avoided, kg	Amortization period, years	Amortization period with subsidy, years
Grid connected 5 kWp PV System	0.08	512	2790	13.9	10.5

4. The influence of the solar thermal systems and photovoltaic systems to the energy efficiency of the building

In Lithuania, the energy performance class of buildings that had a building permit issued after 1st January 2016 should not be lower than A, after 1st January 2018, not lower than A+, and after 1st January 2021, the energy performance class must be in the A++ class (STR 2.01.02:2016).

In buildings rated as energy efficiency class A++, the biggest share of energy consumed should be generated from renewable sources, therefore the implementation of renewable energy sources in such buildings will be mandatory. The renewable energy sources for A and A+ buildings are not formally obligatory, but their implementation improves complex building energy efficiency indicators, and gives more freedom in implementing different architectural solutions. For buildings with a certain architecture (mostly with big areas of glass partitions), renewable energy sources must also be integrated in order to meet the requirements of energy efficiency classes A or A+.

According to Lithuanian legislation (STR 2.01.02:2016), when evaluating the energy efficiency of a building, the use of solar energy will influence the value of the energy efficiency indicator, C_1, which describes the efficiency of primary, non-renewable energy used for heating, ventilation, cooling and lighting, and the value of the energy efficiency indicator, C_2, describing the efficiency of primary, non-renewable energy consumption for the preparation of domestic hot water. The C_1 and C_2 indicators are two of seven (for classes A and A+) or eight (for A++) that must be met by a building of a certain energy efficiency class. Other criteria influencing the building energy efficiency class are:

- The specific heat loss of the building, W/K;
- If the building is equipped with mechanical ventilation with a recuperator, the efficiency of the recuperator and the amount of energy used by the recuperator in Wh/m³;
- The thermal properties of the inner walls and overlays between the parts of the building having independent autonomic heating;
- The tightness of the building; and
- The annual consumption of thermal energy for building heating in kWh/m².

The values of C_1 and C_2 for different energy performance classes are given in Table 5.

Table 5. Values of C_1 and C_2 indicator for buildings with different energy performance classes

Energy performance class	Indicator value	
A++	$C_1 < 0,25$	$C_2 \leq 0,70$
A+	$0,25 \leq C_1 < 0,375$	$C_2 \leq 0,80$
A	$0,375 \leq C_1 < 0,5$	$C_2 \leq 0,85$
B	$0,5 \leq C_1 < 1$	$C_2 \leq 0,99$

As an example, in a randomly-chosen 120 m^2 single-apartment residential building, with partitions that meet the requirements of energy efficiency class A, by installing a PV system of 5 kWp power (with a modules area of approximately 30 m^2), as described above, with 45°south-facing, effectively-ventilated polycrystalline modules, the energy efficiency indicators of the building would be C_1=0.1314, C_2=0.1314; i.e., both would meet the A++ requirements. This system should be used for building heating, hot water and electrical appliances, and should be able to store excess electricity in distribution networks.

In order to simply improve energy efficiency indicators C_1 and C_2 for the same building, in order to reach energy efficiency class A++ (C_1<0.25, C_2≤0.70), a PV system power of 1.32 kWp (with modules area of 8.6 m^2) would be sufficient.

If a ST system with a 5 m^2 area of flat panels and an accumulation tank of 300 litres was to be installed in the same building, using this system for general heating and preparing domestic hot water, the building's energy efficiency indicators would be C_1=0.3145, C_2=0.4096; i.e., the heating performance indicator C_1 would meet the requirements of A+, and the domestic hot water indicator, C_2, would meet the requirements of A++. In order to meet the requirements of the A++ class with both indicators, it would be necessary to install a ST system of 28 m^2, where C_1=0.249, C_2=0.4294.

5. Discussions and conclusions

The main factor hindering market growth is still the high initial cost of solar systems. In the last few years, the cost of PV systems has dropped by more than 50%, and is expected to continue to drop in the near future. The national energy distribution operator in Lithuania has offered the possibility for electrical energy ‘storage’ in the grid, which has helped in promoting this technology. On the other hand, the cost of ST systems has not changed much over the last decade, and it is difficult to see the price reducing in the next few years.

The implementation of PV systems is also increasing with the growing popularity of heat pumps. The implementation of heat pumps as a heat source that can significantly improve the overall efficiency of the energy sector is encouraged by the EU.

Despite the long payback period and decreasing popularity of ST systems in single-family buildings, the market is slowly growing, and the trend continues towards larger systems in multifamily buildings, hospitals, hotels and other large complexes, due to support from the Lithuanian government, the EU and other sources of funding.

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