ASSOCIAÇÃO DE POLITÉCNICOS DO NORTE **(APNOR)**

INSTITUTO POLITÉCNICO DE BRAGANÇA

Economic viability of solar thermal systems: comparison between Ukraine and Portugal

Yuliia Semenchenko

Final Dissertation presented to *Instituto Politécnico de Bragança*

To obtain the Master Degree in Management, Specialisation in Business Management

Supervisors:

Ana Paula Monte

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***Bragança*, July, 2020.**

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Abstract

The challenges for energy resources and the concerns regarding environmental protection are significant and will require several changes, not only on how the energy is consumed but also how it is supplied. Solar thermal technologies can take the lead in meeting the decarbonisation targets in Europe. Solar thermal systems are used to convert solar radiation into heat to supply domestic hot water and space heating in residential buildings.

The current study analyses the initial theoretical research on the solar energy use, solar technologies, influencing factors, trend predictions and prospects for the development. The main objective of the current research work is to define a costing methodology that allows determining the total investment cost of solar thermal systems according to the system size and specification. Therefore, there is a need to analyse the solar thermal systems from the perspective of economic benefits as well as performing the financial analyses for such systems in Portugal and in Ukraine. To achieve this goal it was measured the technical and economic aspects of solar thermal systems to estimate the average production cost. Financial analysis was performed in order to define viability of such project and included Net Present Value (NPV), Profitability Index (PI), Internal Rate of Return (IRR) and Economic Life calculation. Moreover, sensitivity analysis was carried out in order to determine how some crucial values such as discount rate and energy price changes affect the viability of solar thermal system in both countries. With the purpose of accomplishing such goal the real market data provided by “Termozona”, “Solius.Energias Renovaveis”, The International Renewable Energy Agency, Institute of Renewable Energy NANU for Ukraine and tariffs from EDP and World Bank of Sustainable energy were taken into account. The results of the analysis showed that from the economical perspective, in Portugal, there is a considerable market opportunity for solar thermal systems though the government support and subsidy schemes from European Union are still required. In Ukraine the thermal energy produced by solar thermal systems is still not competitive with conventional energy sources but have big perspectives in case the government will provide the necessary support in terms of subsidies, grants or mandates. Therefore, created economical model is a helpful instrument as a high correlation between the cost results and the market data were achieved. The empirical results provided necessary information to fulfil the purpose of study, which is to understand cost efficiency and economical viability of implementing solar thermal systems in Portugal and in Ukraine.

Keywords: Solar energy, solar thermal system, costing methodology, domestic hot water, economic viability.

Resumo

Os desafios para os recursos energéticos e as preocupações com a proteção ambiental são significativos e exigirão várias mudanças, não apenas sobre como a energia é consumida, mas também como é fornecida. As tecnologias solares térmicas podem desempenhar um papel de liderança no cumprimento das metas de descarbonização na Europa. Os sistemas solares térmicos são usados para converter a radiação solar em calor para fornecer água quente sanitária e aquecimento do ambiente em edifícios residenciais. O presente estudo analisa a pesquisa teórica inicial sobre o uso de energia solar, tecnologias solares, fatores de influência, previsões de tendências e perspetivas para o desenvolvimento. O principal objetivo do presente trabalho é definir uma metodologia de custeio que permita determinar o custo total do investimento em sistemas solares térmicos de acordo com o tamanho e a especificação do sistema. Portanto, é necessário analisar os sistemas solares térmicos da perspetiva dos benefícios econômicos, bem como realizar as análises financeiras para esses sistemas em Portugal e na Ucrânia. Para atingir esse objetivo, foram medidos os aspetos técnicos e económicos dos sistemas solares térmicos nos dois casos de referência para estimar o custo médio de produção. A análise financeira foi realizada para definir a viabilidade desse projeto e incluiu o cálculo do Valor Atual Líquido (VAL), Índice de Rentabilidade (IR), Taxa Interna de Retorno (TIR) e Vida Económica. Análise de sensibilidade foi realizada para determinar como alguns valores cruciais, como taxa de desconto e mudanças no preço da energia, afetam a viabilidade do sistema solar térmico nos dois países. Com o objetivo de atingir esse objetivo, os dados reais de mercado fornecidos por “Termozona”, “Solius. Energias Renováveis”, Agência Internacional de Energia Renovável, Instituto de Energia Renovável NANU para Ucrânia e tarifas da EDP e Banco Mundial de Energia Sustentável foram levadas em consideração. Os resultados da análise mostraram que, do ponto de vista económico, em Portugal, existe uma considerável oportunidade de mercado para sistemas solares térmicos, embora ainda sejam necessários esquemas de apoio e subsídios do governo da União Europeia. Na Ucrânia, a energia térmica produzida por sistemas solares térmicos ainda não é competitiva com as fontes de energia convencionais, mas possui grandes perspetivas, caso o governo forneça o apoio necessário em termos de subsídios, doações ou mandatos. Como consequência, o modelo económico criado é um instrumento útil, pois foi obtida uma alta correlação entre os resultados de custo e os dados de mercado. Os resultados empíricos forneceram as informações necessárias para cumprir o objetivo do estudo, que consiste em entender a eficiência de custos e a viabilidade económica da implementação de sistemas solares térmicos em Portugal e na Ucrânia.

Palavras-chave: Energia solar, sistema solar térmico, metodologia de custeio, água quente sanitária, viabilidade económica.

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I am grateful to my mom for infinite love and encouragement to work harder and despite being a long distance away she always found time and patience to support me and being an example for me. I dedicate my master thesis to her.

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All above-mentioned people have considerably contributed to my success of completing my master thesis, what I greatly appreciate.

Acronyms

ASIT - National Solar Energy Association

CPS - Current Policies Scenario

CSP - Concentrated solar power

DNI - Direct normal solar irradiation

EBHE - Greek Solar Industry Association

EREC - European Renewable Energy Council

ESTIF - European Solar Thermal Industry Federation

ETC - Evacuated tube solar collectors

ETSAP - The Energy Technology Systems Analysis Program

FEMP - Federal Energy Management Program

FPC - Flat-plate solar collectors

ICS - Integral collector storage

IEA - International Energy Agency

IRENA - International Renewable Energy Agency

NERCEP - National Commission for the State Regulation of Energy

NPV - Net Present Value

NREAP - National Renewable Energy Action Plan

OECD - Organization of economic co-operation and development

PV - Photovoltaic

REAG - Renewable Energy Advisory Group

REC - Renewable energy consumption

REN21 - Renewable Energy Policy Network for the 21st Century

SDHW - Solar domestic hot water systems

SHIP - Solar heat for industrial processes

SPIUG - Association of Manufacturers and Importers of Heating Appliances

STS - Solar thermal systems

Symbols

t_a - Ambient temperature (℃)

C_i - Cash flow (€)

℃ - Celsius

$C_{circulation\ system}$- Circulation system cost (€)

α - Collector absorptance (W/m^2)´

kWh/inhab - Consumption of electric energy by inhabitant

C_{tfluid}- Cost of the thermal fluid (€)

$C_{ref,pump}$ - Constant reference cost of the pump €(m^3/h)

m^3 - Cubic metre

m^3/h - Cubic meter per hour

ρ_{tfluid} - Density (kg/m^3)

r - Discount rate (%)

c - Efficiency exponent

$\eta_{collection}$- Efficiency of the collection

CF - Future cash flow (€)

GW – Gigawatt

C_o - Initial investment (€)

CF_0- Initial investment (€)

$C_{installation}$ - Installation costs (€)

F' - Irrigation factor

Jkg-^{1}K^{-1} - Joule per Kelvin and kilogram

Kg/m^3 - Kilogram per cubic metre

kg/s- Kilogram per second

kJ/kg-K - Kilojoule per kilogram per Kelvin

kWth - Kilowatt thermal

kWh× $year^{-1}$ - Kilowatt- hours per year

kWh/m^2 - Kilowatt-hour per square meter

$F'U_{L0}$- Linear losses coefficient (W/m^{2}K)

L – Litre

V_{pump} - Mass flow in the circulation pump (kg/s)

MW – Megawatt

$V_{storage}$- Optimal volume of the tank storage (L)

U_L - Overall heat losses coefficient (W/m^{2}K)

m^2/inhab - People per square metre

F_i - Physical variable value

C_{solar}- Purchase cost of the solar collector (€)

C_{pump} - Purchased cost of a pump (€)

$C_{storage}$- Purchased cost of a storage (€)

C_{ref} - Reference cost coefficient that corresponds to a cost per unit physical variable (€)

$C_{ref,storage}$- Reference cost coefficient for storage tank (€)

$V_{ref,storage}$- Reference storage volume (€/m$^{3)}$

F_{ref} - Reference variable value

b - Sizing exponent of a system component

τ - Solar collector aperture transmittance

A_{solar} - Solar collection area (m^2)

I_g- Solar irradiation level (kWh/m^2)

$Cons_{dhw}$ - Specific daily hot water consumption (L)

$c_{ptfluid}$- Specific heat capacity of thermal fluid (Jkg-^{1}K^{-1})

$V_{storage}$ - Storage volume (m^3)

m^2 - Square meter

t_f - Temperature variation between the mean temperature of the thermal fluid (℃)

T^* - Temperature for effective performance (℃)

ΔT - Temperature increase from the grid water temperature up to 60℃

Q_{dhw} - Thermal requirements for domestic hot water (kWh× $year^{-1}$)

T - Time period (years)

C_{inv} - Total investment cost (€)

P - Useful power (watt, W)

W – Watt

W/m^{2}K – Watt per square metre times Kelvin

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Introduction

"The Sun never repents of the good it does, nor does it ever demand recompense". - Benjamin Franklin

Solar energy is an attractive renewable energy source because is the most abundant and carbon free. It can be captured and used in several ways and, as a renewable energy source; it can help to decrease the fossil fuel dependency and is a main part of clean energy future. While the cost of solar energy has declined in the recent past, it still remains much higher than the cost of conventional energy technologies and still supplies only a small fraction of global market. Solar technologies surround a wide range of applications such as electricity production, water heating and space heating, cooling and air conditioning, water heating for hotels or swimming pools and industrial process heat.

Solar thermal system for domestic hot water heating represent one of the most promising technologies for enhancing the economic viability of a solar energy in a long-term perspective. Solar thermal systems are used to convert solar radiation into heat to supply domestic hot water and space heating in residential buildings as well as for industrial purposes. It is a mature technology that has been successfully implemented in a number of countries for more than thirty years. Solar thermal systems have been experiencing a fast development over the past years. In order to evaluate the performance of solar thermal systems it is vital to understand its principles and main components design as some of the basic components, such as solar collectors and storage tanks, remain the same for most types of solar thermal applications. This research will consider the performance of the most relevant component of solar thermal systems, concepts and methodologies to support the process of sizing and selection of solar thermal system components will be exposed.

Therefore, the main research objective of the study is to perform the cost analyses for solar thermal systems and define a costing methodology that allows determining the average production cost of such systems according to the system size and specification. The costing methodology is based on the research developed by Ferreira et al. (2019) and will be comprised on the derivation of a cost expression for each component of solar thermal systems by combining thermodynamic and cost coefficients, and also taking into account real market data in Portugal and Ukraine. In order to achieve this goal it will be analyzed the technical and economic aspects of solar thermal systems to estimate the average investment cost. The cost of solar thermal systems varies and strongly depends on the quality of the solar collector, costs of workforce and ambient climate conditions. This research work will focus specifically on residential applications of solar thermal systems for domestic hot water. Theoretical literature review of the study provides a background for developing an analysis of solar thermal systems in Ukraine and Portugal and evaluating the viability of these applications.

The purpose of the current research is to analyse the solar thermal systems from the perspective of thermal energy production and economic benefits. To complete this purpose, the research questions will be answered: Is it profitable to use solar thermal systems for domestic hot water heating in Portugal? Is it economically viable to install solar thermal systems for domestic hot water in Ukraine?

During the present research work, it will be quantified the economic model for solar thermal system that will be validated for reference scenarios in Portugal and in Ukraine. By applying, simultaneously, this economic model to reference scenarios in both countries, the research work will try to establish an average investment cost of solar thermal systems for both markets. Both reference scenarios have application sector in a single family dwelling, it contains concepts and principles which are general: (i) knowing the main concepts and understand their meaning; (ii) using a new legislative framework; (iii) knowing the main characteristics of the solar thermal system components and understand their importance in the installation; (iv) knowing the limitations of each solution; (v) develop a process to support dimensioning; (vi) evaluating the economic viability of the solutions; (vii) understanding the importance of the factors involved.

With the purpose of establish an average investment cost of solar thermal system implementation in Portugal and Ukraine, in the cost analysis, it will be used a data provided by The International Renewable Energy Agency, Institute of Renewable Energy NANU for Ukraine and tariffs from EDP in Portugal will also be considered. These provided data will be consistent with the commercial data for solar thermal systems in Portugal and Ukraine. Information about prices for solar thermal systems facilities will be given by one of the largest suppliers of solar thermal systems in Portugal "Solius. Energias Renováveis" and "Termozona" in Ukraine. The Financial analysis of solar thermal systems includes additional values of economic performance measurement to determine the viability of a project such as Economic Life of a project, Net Present Value (NPV), Internal Rate of Return (IRR) and Profitability Index (PI). The calculation of the main financial parameters to measure the life cycle of solar thermal systems follows the criteria established by the Federal Energy Management Program (FEMP) used for the economic evaluation of renewable energy projects. Moreover, sensitivity analysis is performed in order to determine how some crucial values such as discount rate or energy price changes affect the viability of solar thermal system in both countries.

The research study comprises the three sections apart the introduction and conclusions. The first section is the theoretical part that includes the literature on the topic under study. It involves acquaintance with the renewable energy general overview, main features of solar thermal technologies and solar technologies to generate electricity, benefits and limitations of solar energy, influencing factors and trend predictions, solar energy development in European Union and particularly in Portugal and Ukraine, solar heat markets in European Union and also literature review concerning viability of solar technologies. Follows the section of methodology, in particular, description of the research methodology as well as economical model. The following section is the main part of this research work – the empirical part that will add some knowledge to the one reviewed in the previous section. The empirical part aimed at reaching the final outcome of the research, by creating and validating the economic model and applying financial analysis and sensitivity analysis to define the viability of solar thermal systems in both reference cases as described before. Finally, conclusions, limitations and further research work will finish the research. It sums up the findings of the study as well as establish the future research lines. The possibility of implementation expansion of solar thermal technologies for domestic hot water heating in Ukraine will also be discussed in this part of the work. As a consequence, created economical model is a helpful instrument, especially if it will be possible to obtain a high correlation between the cost results and the market data. Current work is considered being valuable as it contributes to the expansion of knowledge in the area of viability of solar thermal systems in Ukraine and Portugal.

1. Literature review

This literature review is conducted on solar thermal systems; it slightly touches upon the overview of the factors that affect the development of solar energy in Portugal and Ukraine as well as future prospects, benefits and limitations. The main part of the literature review is dedicated to the economic benefits of solar thermal systems. The range of introduced issues is supported by the literature review.

1.1. Renewable energy: general overview

Energy is one of the requirements as an instrument of refining human development as well as economic growth. During the recent years, there has been a significant increase in energy demand due to growth in economies as well as changes in the lifestyle. According to the World Energy Outlook (2019) global demand for energy is predicted to increase in the coming decades. The Current Policies Scenario (CPS) explains what happens if the world continues along, without any changes in policy. As stated by CPS energy demand rises by 1,3% each year to 2040, with increasing demand for energy services unconstrained by further attempts to improve efficiency. There is discussion about the positive correlation between efficiency and levels of resource consumption, it is called Jevons paradox. According to York and McGee (2015), efficiency is often related with rising resource consumption and the state that efficiency leads to greater resource use. Resource consumption may increase notwithstanding with rising efficiency, rather than because of it. While this is well below the remarkable 2,3% growth seen in 2018, it would result in a persistent upward march in energy-related emissions, as well as in all aspects of energy security.

The growing energy demand led to the continual use of fossil fuel-based energy sources such as coal, oil and gas, which became difficult by creating several challenges such as: exhaustion of fossil fuel reserves, greenhouse gas emissions, as well as geopolitical and military conflicts and the continual fuel price swings. These issues will create unsustainable situations that in a future can cause potentially irreversible threat to human societies (UNFCC, 2015). Currently, almost all countries cover their energy needs from fossil fuels and as the energy consumption of countries increases, pollution is increasing as well (Elum & Momodu, 2017). Tiwari and Mishra (2011) concluded that renewable energy sources are the most outstanding alternative and the only solution to the growing challenges. The main renewable energy forms, their uses and characteristics are presented in 0.

Table 1. Renewable energy sources and their use

Energy source	Energy conversion	Characteristics	Services
Solar	Solar energy converted directly into electricity or used as thermal energy. Types: Solar thermal, Concentrated Solar Power (CSP), Solar photovoltaic.	Solar thermal: Active heating, wide variety of devices. CSP: various designs, heat can be stored, large-scale can produce both electricity and heat, growing in countries with high solar radiation. Solar photovoltaic: light converted directly into electricity, rapidly declining prices, variable resource, operating silently.	Solar thermal: water, space heating and cooling, heating swimming pools, can be connected with a district heating. CPS, Solar PV: electricity production.
Wind	Wind drives turbines Types: Onshore, Offshore.	Low cost (onshore), availability of resource, environmental issues, scalable, high potential.	Electricity production.
Biomass	Energy derived from non-fossil materials of biological origin. Types: Solid biofuels Biogas Liquid biofuels.	Liquid biofuels: made using thermal, chemical and biological processes, competition for feedstock, high energy efficiency, mostly made from food crops. Biogas: relatively cheap. Solid biofuels and renewable waste:, most common renewable energy.	Heat, electricity, transport etc.
Geothermal	Steam or hot water taken from wells.	Large-scale, cost-effective, resources are quite limited in space.	Electricity, heating and cooling.
Hydro	Water drives turbines.	High investment, low cost, easy to control, environmental issues, storage.	Electricity.
Ocean	Mechanical, thermal, chemical energy. Types: Tidal energy; Ocean energy; Wave energy; Ocean Thermal Energy Conversion (OTEC); Salinity gradient power.	Still at development stage. Tidal energy: used in locations with large tidal range. Ocean energy: base load power. Wave energy:, variability of resources. Ocean Thermal Energy Conversion (OTEC): power generation from temperature difference between surface and deep ocean. Salinity gradient power: power generation from difference in salinity.	Mechanical power used for electricity generation.

Source: Author's own elaboration, based on the data of IRENA (2020)

Typically, renewable resources include six different types of energy: solar, wind, hydro, ocean, geothermal and biomass. The term “renewable energy” can be defined in several ways: for example, in the past, Twidel and Weir (1986) mentioned that for practical purposes energy supplies can be divided into two main types. According to their work, renewable energy can be described as energy obtained from the continuous or repetitive currents of energy recurring in the natural environment and obvious example of this is solar energy, where ‘repetitive’ calls to the 24-hour major period. In their opinion such energy may also be named Green Energy or Sustainable Energy. Non-renewable energy was clarified as energy that persists underground unless it gets released by human interaction. For instance, they brought nuclear fuels and fossil fuels of coal, oil and natural gas. To avoid operating the word ‘non-renewable’, such energy was offered to call finite supplies or Brown Energy. Before Sorenson (1979) explains renewable energy as “energy flows which are replenished at the same rate as they are used”. Moreover, in his work he concluded that the expression of a renewable energy may be taken to include the usage of any energy storage which is being refilled at rates comparable to that of extraction.

Regarding the Energy Statistics (2004) the term renewable energy can be defined as “energy that is derived from natural processes that are replenished constantly”. The renewable energy sources are also covered by Europe’s climate change and energy policy.

Armstrong and Hamrin (2000) offers the idea that the term “renewable” can be applied to those energy resources and technologies whose common characteristic is that they are non-depletable or naturally replaceable. According to authors renewable resources include solar energy, wind, falling water, the heat of the earth (geothermal), plant materials (biomass), waves, ocean currents, temperature differences in the oceans and the energy of the tides. Renewable energy technologies produce power, heat or mechanical energy by converting those resources either to electricity or to motive power. To Apergis and Danuletiu (2014) the term of renewable energy is clarified as energy generated from solar, wind, geothermal, tide and wave, wood, waste, and biomass. With this aspect, these energy sources are clear, safe and inexhaustible contrarily to conventional energy. At the same time, Kalogirou (2014) came to the conclusion that all the renewable energy technologies produce energy by converting natural resources into several forms of energy by using solar energy and its direct and indirect effects (solar radiation, wind, falling water, and biomass), gravitational forces (tides), and the heat of the earth’s core (geothermal). Despite renewable resources have high potential, in general they are diffused and not fully approachable, and majority is irregular and have distinct variability.

Essentially, all the definitions have similarities and one can conclude that the term renewable resource can be clarified by two different meanings. Either it means a never-ending resource that is long-term available and self replaceable, or it can mention the resources that were harvested in a sustainable way.

Renewable energy has grown rapidly in recent years. As stated by Eurostat Statistics (2018); EU countries agreed in 2014 on a new renewable energy target which is aspire to increase the renewable energy consumption (REC) share in total consumption at least 27% by 2030. According to The International Renewable Energy Agency (IRENA) renewable energy statistics annual reports worldwide renewable power capacity has increased from 1,225 gigawatts (GW) in 2010 to 2,351 GW in the end of 2018. IRENA provides a definition of renewable power generation capacity as the maximum net generating capacity of power plants and other installations that use renewable energy sources to produce electricity. For most countries and technologies, the data reflects the capacity installed and connected at the end of the calendar year.

In 2018 hydro constitutes the largest part of the global total, with an installed capacity of 1,172 GW. Wind and solar energy accounted for large proportions, with capacities of 564 GW and 486 GW respectively. Other renewable sources included 115 GW of bioenergy, 13 GW of geothermal energy and 500 MW of marine energy (tide, wave and ocean energy).

In general, renewable generation capacity increased by 7,9 % (171 GW) from the 2017. Renewable capacity expansion continues to be determined mostly by new installations of solar and wind energy. These accounted for 84% of all new capacity installed in 2018, while the overall share of hydro continued to reduce to 44%, with only China adding a significant amount of new capacity in 2018 (+8,5 GW). Solar energy continued to dominate, with a capacity increase of 94 GW (+24%), followed by wind energy with an increase of 49 GW (+10%). Hydropower capacity increased by 21 GW (+2%) and bio energy by 6 GW (+5%). Geothermal energy raised by just over 500 MW (Renewable Capacity Statistics, 2019).

As the costs of renewable energy sources have historically been higher than conventional energy sources, support policies were essential for the promotion of renewable energy. In this vein, the number and the variety of renewable energy policies have sharply increased around the world. For instance, as of early 2015, 145 countries have adopted renewable energy support policies—more than 9 times of that in 2005, which were only 15 countries. Since, the production of fossil fuels is usually more intense in countries with unstable political situation; the rising energy demand is creating unbalance between producing and consuming countries. Renewable energy sources can help to reduce dependence of fossil fuels import (Kaygusuz, 2001). Moreover, one of the most important reasons for renewable energy development is related with economic. Piebalgs (2007) believed that the renewable energy technologies will support the development of new technologies and help to create a need for expert system, increase the industrial competitiveness of the country, improve innovation framework and will also develop the conditions to create new jobs opportunities and innovative businesses.

1.2. Solar thermal technology: main features

As an important part of a solar energy market development, solar thermal technologies are highly rated by all the countries in Europe. In this chapter will be introduced the working principles, applications, advantages and disadvantages of common solar technologies such as solar thermal systems.

Solar thermal systems (STS) are used to convert solar radiation into heat. The generated heat can also be stored in a storage tank for use at night. Solar heating systems are a mature technology that are successfully deployed in a number of countries and have been commercially available for more than 30 years. In some countries like Cyprus and Israel it have achieved penetration levels of up to 90% since it is mandatory to install solar collectors for hot water production in new households. Nevertheless, average only 1.2% of water and space heating in the worldwide buildings sector is covered by STS. Generally, implementation of solar thermal systems make sense for countries that rely on gas or oil imports, countries with growing economies and countries with high cooling demand during solar hours (IEA-ETSAP & IRENA, 2015). In either way, solar thermal systems used for water and space heating in buildings as well as in applications to supply district heating systems, are becoming more and more popular in the market. Nowadays, solar thermal systems are widely used to supply domestic hot water and district heating in many European countries which in fact corresponds to the largest share of heat consumption. Moreover, it can be used in the industry sector, to heat swimming pools, in services sector or even at agriculture. Lately, new areas of application are being developed, especially space cooling facilitated by solar energy (ESTIF, 2019).

Kalogirou (2014) put into order that in solar thermal systems, the solar radiation is converted directly into thermal energy through solar collector which is a major component of any solar system, it absorbs the incoming solar radiation, then converts it into heat, and bring the heat to a special fluid (water with glycol) flowing through the collector. Collected solar energy is carried from the working fluid directly to the hot water or space conditioning amenities or to a thermal energy storage tank, from which it can be saved for utilization at night or on days with low level of solar radiation. At present, two dominant designs of solar collectors exist: flat-plate solar collectors (FPC) and evacuated tube solar collectors (ETC) which are mature and vary depending on the meteorological circumstances, operation temperature, heating and cooling demands, load profiles, efficiency and costs. A third type of collector is the integral collector storage (ICS) system, which uses both the collector and the storage tank, but this system is vulnerable to heat loss during night and suitable mostly in some tropical locations. (IEA-ETSAP & IRENA, 2015) Furthermore, several new designs are available: collectors with single or multiple glass covers or without any cover, unglazed with a vacuum, glazed or evacuated. Worth to mention, that the presence of a glass layer or vacuum allows the operation of collector with higher efficiencies at higher temperatures. Solar thermal systems also include a pump, a controller, a storage tank to accumulate heat from the circulating fluid and the circuit of pipes (Ferreira & Silva, 2019).

Solar domestic hot water systems (SDHW) are the most widespread application and mostly used in markets with a low demand for space heating. SDHW are specifically build to satisfy the majority of the hot water needs in summer and partly in the winter, depending on the weather conditions and the efficiency of the installed equipments. In that case, a supplementary heater can be also included (integrated electric or gas heater), or they can operate as pre-heaters. Solar collectors normally supply from 60% to 80% of the domestic hot water requests, whereas the remaining 20-40% is provided by another heat source, typically electricity or gas (Evarts & Swan, 2013).

In accordance with Psomopoulos (2013) solar thermal heating systems for domestic hot water can be divided into two main classes depending on the fluid circulation type, into natural circulation type (thermosiphon systems) and into forced circulation type in which the fluid is driven by a pump (forced circulation systems). Furthermore, there is a new not fully widespread technology named combi-system that can supply both domestic hot water and space heating. These systems have a high potential in markets with cold climate for the reason of their sufficient capacity to supply space heating in winter, air-conditioning in summer and domestic hot water throughout the year. Combi-systems are more complex than regular SDHW systems and have a bigger collector area size (ESTIF, 2019).

Noteworthy that thermosiphon systems use gravity to circulate the heat, on these terms, domestic hot water can be taken directly from the tank, or indirectly through a heat exchanger in the tank. The main advantage of a thermosiphon system is such plants are very simple and don’t require a pump and controller and have self-controlling capability. On the other hand, thermosiphon system is entailing architectural impacts and demand specific technical requirements as the tank must be located above or beside the collector and that stand the need for the availability of extra space. Typically, one house thermosiphon system for domestic hot water has a 2-5m^2 of collector area and a 100-200 liter tank (ESTIF, 2019). Moreover, such systems are less acceptable for cold climates because of the possible heat loss from external hot water stores and the danger of freezing during winter. If thermosiphon systems are used in low temperatures, the collector fluid must be antifreeze to prevent the possibility of freezing and must contain an additional (electric) heater, in that way it affect the price of system (Streicher, 2016). Nowadays, thermosiphon systems are the most frequently installed solar systems worldwide and account for almost 75% of installed capacity, even if they are most beneficial in areas with a mean annual sum of global radiation above 1800 kWh (IEA-SHC, 2014). The Figure 1 shows a simplified scheme of a thermosiphon system.

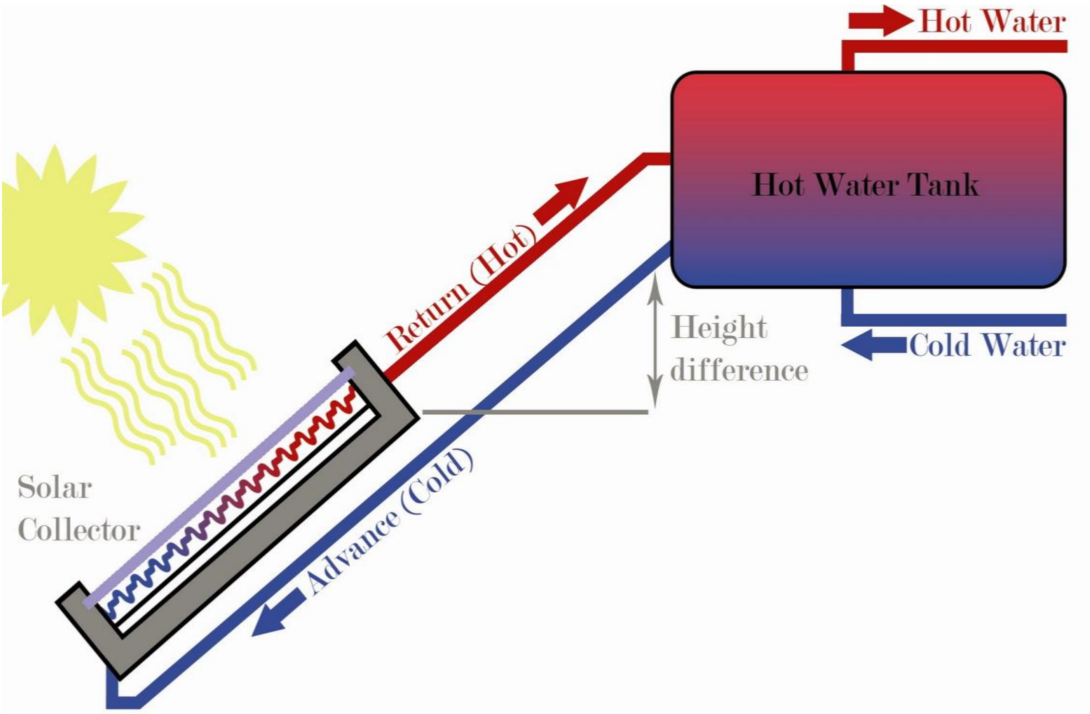

Figure 1. Thermosiphon solar thermal system

Source: dawtec.com (2020)

As maintained by European Solar Thermal Industry Federation (ESTIF), in the forced circulation systems the heat transfer fluid is circulated by a pump, so the location of the tank can be arbitrary. This type of system is the most common in Central and Northern Europe as they easily integrate with other heating systems. A typical forced circulation system for domestic hot water has 3-6m^2 of collector area and a 150-400 liters tank. Forced-circulation DHW systems have several advantages. As they have high flexibility in the positioning of components, it makes these types of systems suitable for hotels, swimming pools, and other commercial applications. Its aesthetic and functional impact is lower as they allow using pipe with a smaller size. Forced circulation systems usually used in larger installations, but with the development of a circulation pump of moderate cost, they are becoming more popular in small installations. Besides, these systems are more complex than the systems with natural circulation and also include sensors, a controller and a pump. A well-functional forced circulation system shows the same level of performance and reliability as a thermosiphon system (ESTIF, 2020). The next figure 2 shows a scheme of Forced Circulation system.

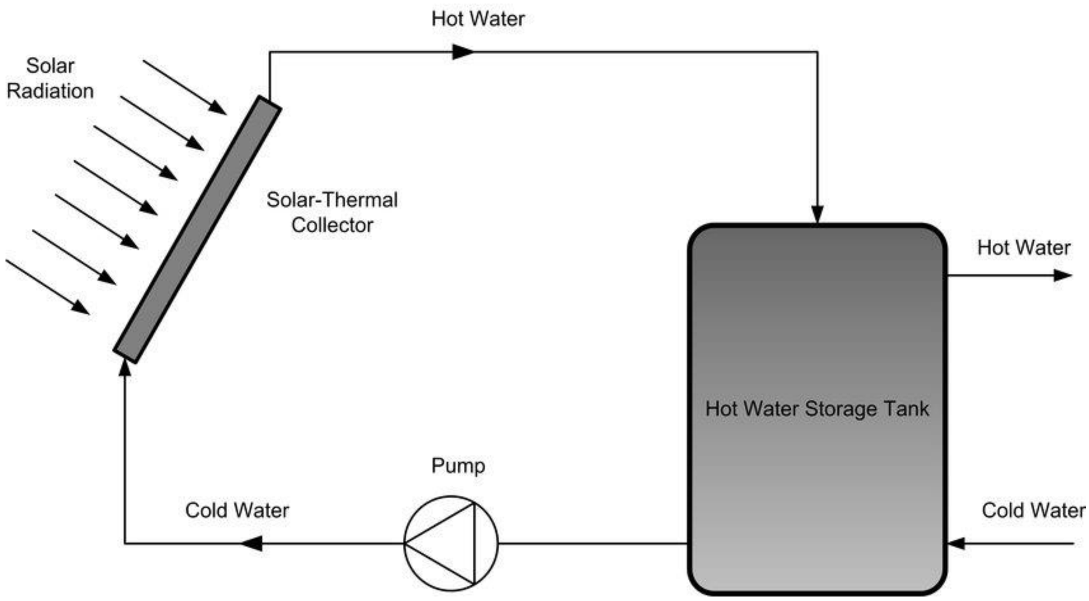

Figure 2. Forced Circulation solar thermal system

Source: Milani (2012, p.132)

Another option for increased penetration of solar heating systems is through district heating (DH). Letcher (2016) cleared up that solar district heating systems are becoming more common in Europe and some regions can even become cost competitive with traditional heating sources. Author mentioned that solar district heating is the heating of a central thermal storage system, with the collected heat being dispensed according to the needs of community. Solar collectors can be centrally based, or spread throughout region, but they all should provide heat to the central heating system. Such systems usually require immersed heat exchanger integrated in the storage tank, for larger application should be also used external heat exchange and a second pump. As yet, the commercial market for solar district heating is restricted to small towns (up to 10,000 inhabitants) with an already available district heating network in use. Despite, large solar district heating systems still seem to be expensive and require extensive support measures, they have confirmed to be cost effective in cases of combining a large solar thermal system with a seasonal heat storage (Kveselis, Lisauskas & Dzenajavičienė, 2014). Notable, that without heat storage solar district heating can provide just 10–30% of the annual demand and with seasonal storage; it can grant up to 100% depending on the distribution of the solar radiation and the load (Nielsen & Sørensen, 2016). Figure 3 shows a district heating system with a centrally based collector. As the majority of solar irradiation is coming during the warm season when there is no need of heating, summer time is operation is crucial for economics of a solar thermal system (Kveselis et al., 2014).

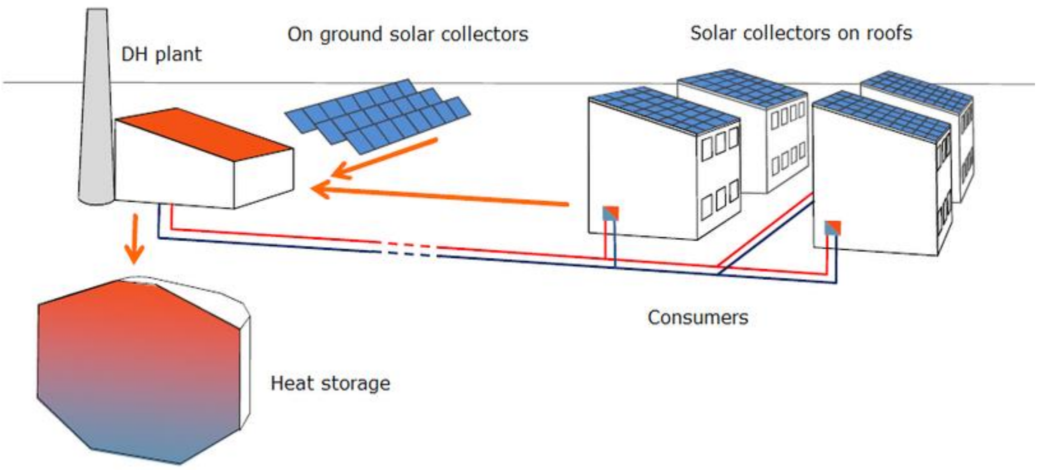

Figure 3. Central solar district heating system

Source: solar-district-heating.eu (2020)

According to IRENA and IEA-ETSAP, the cost competitiveness of solar thermal heating and cooling technology depends on the initial cost of the solar thermal system, proper maintenance and the price of alternative sources. The cost of STS varies across countries and strongly based on the quality of the solar collector, labor costs and local ambient climate conditions. In many emerging-market countries, solar thermal systems provide an economic profitable alternative to the increasing demand for electric boilers. In Portugal, the distribution of installed systems is divided between the thermosiphon, forced convection systems, and individual collectors.

1.3. Solar technologies to generate electricity

Based on a work of Ahmadi, Ghazvini, Sadeghzadeh (2018), it has not escaped from this research that using solar energy to generate electricity can be done by two methods either directly and indirectly. Authors claim that in the direct method, photovoltaic modules are utilized to convert solar radiation into electricity and in the indirect method; thermal energy is harnessed employing concentrated solar power. In consonance with Bravo and Friedrich (2018) there are mainly two technologies related with solar energy utilization for generating electricity: solar photovoltaic (PV) and concentrated solar power (CSP). Besides, both technologies have principal differences: in PV technology, photovoltaic cells directly convert solar radiation into electrical energy while in CSP technology solar radiation is being concentrated and converted into heat, and then generator can be used to produce energy from the previously produced heat.

Acording to Ma, Pan and Yang (2019), PV power generation is mainly composed of three main components: solar panel, controller and inverter. They point out that this is the most common and largest photovoltaic technology on the market today. Touching on the working principle of PV technology it is important to mention that the main principle is to convert light energy into solar energy, and then store the electricity generated by solar cells through the battery pack or use it directly in electrical application (Alaa, Zuha & Suhaidi, 2018). Li and He (2017) indicate that the CSP technology is realized by the conversion of radiant energy, thermal energy and electric energy. CSP technologies use mirrors to reflect sunlight into receivers, concentrate the sun's rays to a high temperature and transform it into heat. That heat is, in order, used to produce electricity using a gas turbine or an engine. One significant characteristic of CPS is that they allow storing the heat captured during the day and transform it into electricity during the night and has growing tendencies mostly in countries with a high solar radiation. As stated by Reddy and Kaushik (2013) research that was made on solar power, CPS technology is now behind the PV, but it will become the new trend direction of the future development of solar energy.

1.4. Solar energy: Benefits and limitations

Consequently, it is obligatory to explore appropriate alternatives sources of energy which will be environmentally sustainable as well as profitable. Nowadays, solar energy related research continues in order to decrease the constraints (mostly technical) and cost of solar thermal systems. There exist a considerable number of studies which hint at the importance of solar energy technologies utilization as well as future development, risks and limitations in addition to advantages and benefits of common solar power technologies.

Recently, Sampaioy and González (2017) analyzed renewable energy current status and research trends and concluded that among three renewable energy sources (biomass, geothermal, and solar) which can be used to yield sufficient heat energy, solar energy has the highest global potential since geothermal sources are limited on space and the supply of biomass is not ubiquitous in nature. A study by Cai (2018) analyzed the research status and development prospect of solar energy use. He point out that solar energy reserves are a kind of environmental protection and clean renewable energy with rich resources and wide distribution. Recent advances in solar energy research and development have helped make solar power systems more affordable for commercial utilization (Reddy, Kaushik & Ranjan, 2013). It is important to mention that solar energy is considered to be a non-polluting, reliable, and clean source of energy. Burning coal is accompanied by an ejection of specific pollutants that cause a negative effect on the respiratory system, for instance, articulate matter, sulfur dioxide (SO_2), oxides of nitrogen (NO_2) and specific particles (soot, carbon black, metals). The mechanism injury lungs across damage to cells originated by oxidizing molecules in pollutants, this can lead to inflammation and cell death and can be a reason of neurological damage, heart attacks, breathing problems or cancer (Burt, Peter & Susan, 2013). Furthermore, Machol (2013) believe that the replacement of fossil fuels with renewable energy sources like solar energy could minimize premature mortality rates and reduce the overall costs for healthcare in general.

Concerning solar heating and cooling technologies, solar thermal systems for residential applications can reduce the fuel consumption by 50%-70% for hot water and by 30%-60% for space heating. Taking into account that about 55% of energy consumption in the building sector is for space and water heating needs, solar thermal have a large market potential (Faninger, 2010). To Kumar, Hasanuzzaman and Rahim (2019) is clarified that solar thermal system is a good substitute for fossil fuels in the industrial sector for heat producing due to energy security, economic feasibility and environmental profit. Authors pointed some benefits of harvesting solar energy as thermal energy for industrial process heat for instance reduction the dependence on fossil fuels and depletion of greenhouse gases emissions. However, they mentioned a big challenge for integrating solar heat into the industrial processes such as proper selection of solar thermal technology compatible for integration determined by the type of solar thermal collector and temperature ranges. Furthermore, installation of solar heating and cooling technologies involved with some limitations. One of the main disadvantages is high installation costs as well as lack of appropriate regulatory frameworks to make sure that solar thermals meet the technical conditions and to provide appropriate and reliable operation of the system. Among the others barriers related with STS are the undesirability of the majority of residential users to switch from conventional heating that provides reliable supply and the lack of knowledge of solar thermal capabilities among architects and within the construction and energy industries (IEA-ETSAP & IRENA, 2015).

In work of Kabir, Kumar, Adelodun and Kim (2018) the authors stress that there are a number of limitations associated with solar energy use particularly for PV technologies. Among the most significant are high initial installation cost, require of an extra space and the performance limitations of some components such as inverters or batteries (short battery lifetime, safe disposal of spend batteries). Authors also take notice that deficit of skilled manpower for installation, maintenance, inspection and repair as well as lack of basic technical skills of the users can result irregular usage, overcharging the battery, polarity reversal, by-passing the charge controller which can lead to system damage. Moreover, as solar collectors are usually made from rare or precious metals such as silver, tellurium, or indium there are some restrictions of recycling exist. Despite, solar power technologies require high investment for their installation; they operate at very low costs.

Authors indicate that traditional energy sources like fossil fuels require big amounts of water for their operation, influencing the current water shortage issue. On the other hand, produced heat or electricity generated from solar installations does not require water; additionally, the requirement for radioactive waste storage is nonexistent (Kabir et al., 2018).

Radivojevi, Pavlovi, Milosavljević and Djordjević (2015) believed that air pollution levels at the installation area of solar PV systems can also influence the effectiveness of them. According to the empirical study of Lakatos, Hevessy and Kovács (2011) only a certain part of solar energy can be used as the angle of incidence of solar rays as well as the distance between the site of installation and Equator (latitude), the angle of adjustment of the solar cell to solar rays' influence the measure and efficiency of system utilization. Moreover, solar radiation also changes depending on season and weather conditions.

Ahmadi, Ghazvini and Sadeghzadeh (2018) believe that solar energy is one of the most attractive sources of energy. Despite that some complications exist, for instance, solar energy can only be harnessed during the day and needs to be stored with a purpose of utilization in the night. Besides, using energy storage units typically require increased investment and maintenance costs and hence an increase in the cost of generated electricity (for PV systems). Furthermore, solar energy is not the most reliable source of energy in regions with unsustainable weather or climate conditions. According to their work, the potential of solar energy makes it beneficial in several ways: (1) solar energy is very suitable to generate electricity in the tropical and subtropical regions because they receive huge amounts of solar irradiation, (2) social acceptance of solar energy increased in recent years, (3) electricity generation using solar energy is relatively affordable and it is appropriate for rural and urban regions.

The Solar Foundation indicates that solar technologies are regarded as being more labor-intensive "more jobs can be created per unit of electricity production with solar energy as opposed to fossil fuels". The 2018 Census reported that USA has 242,343 workers that are employed in solar energy industry. Even though, solar employment declined by nearly 8,000 jobs (3.2 percent), since 2017, in general, the solar workforce has grown 159 percent since 2010, adding nearly 150,000 working places.

From an economic outlook, generally, solar energy is advantageous in a variety of ways due to tax incentives, reducing of electricity bills, increased property values, and high endurance, financial demand for solar power is relatively stable over long periods. On top of that, as solar energy projects are mostly local that would keep money circulating within the local economy, allowing to save a significant amount of money presently being spend for the importation of fossil fuels. For that reason, the "adoption of solar technologies would significantly mitigate and alleviate issues associated with energy security, climate change, unemployment" (Kabir et al., 2018, p.894).

1.5. Solar energy development in European Union

In order to obtain a more comprehensive overview of solar energy, it is significant to determine which influencing factors are affecting solar energy development in European Union. Accurately, the question should be next one. Which of the influencing factors promote or hamper the solar energy utilization in EU?

Regarding Owusu and Asumudu-Sarcodie (2016) the development of solar energy is unique as the harmful environmental impacts and associated costs could be avoided with choosing the appropriate location and correct decision-making and the first step to achieve sustainability in solar energy entrepreneurship is to understand this establishments. Abbasi, Premalatha and Abbasi (2011) concluded that the development of solar energy started to gain momentum dated back in the late 90s in the twenty century when have began the price growth of oil production. As was mentioned before solar energy in the European Union consists of solar thermal energy (STE) and photovoltaic (PV). Demand for solar thermal energy varies mostly based on climate, the efficiency of the building envelope, occupancy, behaviour and many other factors. Important factors that affect the solar heat market in Europe are the costs of the solar thermal stations components, local conditions in terms of solar irradiation, as well as, the characteristics of the infrastructures (Ferreira & Silva, 2019).

The development of solar energy across Europe varies between countries and also within countries. Relying on assessment over five regions in Europe made by Krozer (2012) it is worth to mention that the development of renewable energy comes out from social innovations intended at regional development, which can collaborate together with national and regional policies for project implementation. Earlier, Tabellini (2005) mentioned that the culture and the current economic are also important issues that affect the development.

In general, the literature approaches the concept of renewable energy development from institutional, economic and technical outlook. The causes behind the developments of solar energy in European Union are multiple. It is triggered mostly by environmental or ecosystem problems (pollution from conventional sources of energy), political and economic factors, such as the dependence on finite sources that can be the reason of political conflicts. It can be driven by the rise in energy prices or energetic shortages and liberalization of the energy market. The earlier studies of solar energy have made the conclusion that the dominant driving factor of the development process is a market demand (Rescoop, 2020).

With regards to institutional factors it was found by Bomberg and McEwen (2012) that the development of solar energy projects depends on the political environment in which they are implementing. The role of governmental policies and support should not be underestimated while considering renewable energy. The institutional structure influences access to resources, availability of markets in addition to legitimacy of new technologies. Another aspect of this is the scientific evidence of Rooijen and Wees (2006) who believe that governments can help in development by providing technologies, encouraging related research and creating an environment that enables investment. Through the policies, investment, and supports (such as research funding from various organizations) government is regulating and helping to build up a strong foundation for the exploitation of solar energy.

When mentioning the technological factors Müller, Brown and Ölz (2011) refer to factors that are related to the technical side of the projects such as the renewable energy equipment and its operation. Technological innovations, among other things, can promote investment in renewable energy and accelerate the development of solar energy (Popp, Hascic & Medhi, 2011). On the report of IEA-ETSAP and IRENA (2015) authors concluded that heating demand is highly dependent on technical factors such as the architectural layout of buildings, energy efficiency, insulation and building materials used as well as demographic factors that affect the development, for example, income, age, urbanisation, and population growth. What's more, development also depends on other renewable energy alternatives such as heat pumps and solar PV systems.

In terms of economic features, is necessary to find factors that affect the development from a financial perspective, such as investment costs or subsidy availability. Discussing more obstacles Faiers and Neame (2006) mentioned the availability of grants, since solar power technologies require high investment for installation and have a long payback period. In the European Union countries, the deployment of solar heating technologies has mainly been driven by subsidy schemes and mandates. Eggert, Hecl, Jenkins, Marín, Mayer, Schweizer and Zervos (2005) emphasize the fact that exist three types of financial mechanisms that stimulate the deployment of renewable and especially solar energy for electricity generation (PV technologies): the feed in tariffs, green certificates and tenders. Moreover, development of green initiatives can be fostered by tax incentives, grants and subsidy programs, as the new projects will not be implemented without the external funding. International standards and regional certification schemes for quality assurance will be a stimulating factor for continued development as an international market for solar thermal systems is slowly emerging.

In the report of IEA-ETSAP and IRENA (2015) authors mentioned that for countries with a growing housing stock, mandates for solar thermal systems could be main factor. A relatively new development is government support for small domestic solar water heating systems in low-income families or social housing projects which help to reduce energy waste and increase job opportunities. Other options, such as low interest loans or the implementing of solar-based district heating, are also effective approaches to foster solar technologies development.

As reported by Global Market Outlook 2019 – 2023, exist numerous business opportunities for solar power in all market segments such as energy, heat and transport. Moreover, solar thermal cooling is a growing market in countries and regions with high cooling demands and has a high potential. The main drivers for development of this technology are price competitiveness and government support, especially in newly constructed households. Generally, innovations aim to make solar thermal systems thinner, cheaper and more durable and make easier the integration of them into rooftops (IEA-ETSAP & IRENA, 2015). As stated in IEA SHC Solar Heat Worldwide 2019 report the solar heat for industrial processes (SHIP) is the most actual trend in solar energy utilization. Lately, a lot of promising projects have been implemented in EU ranging from small-scale to very large systems. Traditionally in European Union, the distribution of solar thermal technologies for industrial implementation receives its main support in the form of capacity building. Moreover, it is also getting common to utilize building codes, mandates and binding targets for renewable heating to advance technological development. Besides, several relevant studies and progress have been conducted in this field, there is not yet a full understanding exists of the potential that could be achieved through the exploitation of solar energy.

1.6. Solar Heat Markets in European Union

Solar thermal technology, which harnesses the solar rays to convert it into heat and generate thermal energy, is finally getting bigger interest. Solar heating technologies play important role for many years in the European Union.

According to EurObserver annual statistic (2020) the European Union market for solar heating technologies more than tripled between 2002 and 2008. The growth rate for the next years was -10% in 2009 and -13% in 2010 and after this systematic decrease was visible until 2018 when the market finally started to gain growth and increased from 2 to 2,2 million m^2 (8,4% year-on-year growth). The European market data includes systems with flat plate collectors, vacuum collectors and unglazed collectors. Collectors provide a range of temperature depending of the technology (IEA, 2013). Mentioned technologies intend to produce domestic hot water and heating as well as heat and hot water for district heating networks and industry. Psomopulus (2013) noticed that domestic hot water for detached single-family houses, apartment buildings, for multifamily houses and for the hotels is the most widespread application.

In consonance with the latest IEA SHC Solar Heat Worldwide 2019 report, the European solar heating network is filling out with small-scale solar thermal heating systems($<$350 kWth; 500 m^2)and large-scale solar thermal heating systems($>$350 kWth; 500 m^2). The latest statistic shows that the collector surface that were connected in 2018 to European solar heating networks reached 83760 m^2 (58,6 MWth). Combi-systems for both hot water and space heating usually related to small-scale solar water heating systems and represent more than 90% of the world wide annual installations, in Europe are still in an increasing stage. While EU market growth is positive generally, it varies through the national markets. The installed solar thermal market is provided in a Table 2.

Table 2. Installed solar thermal market in EU

	Installed solar thermal market in EU in 2016		**Installed solar thermal market in EU in 2017**		**Installed solar thermal market in EU in 2018**	
Country	MWth	Area, m^2	MWth	Area, m^2	MWth	Area, m^2
Total EU	1823,2	2604627	1426,1	2037324	1546,1	2208681
Germany	536,2	766000	455,0	650000	401,5	573500
Greece	189,0	270000	221,2	316000	230,0	328500
Poland	80,8	115400	77,8	101100	217,0	310000
Spain	148,5	212190	141,1	201505	143,9	205530
France	82,9	118482	85,8	122576	109,3	156122
Italy	147,0	210000	105,7	151000	97,3	139000
Austria	78,3	111800	71,1	101460	71,0	101389
Denmark	350,0	500000	22,1	31500	42,7	61000
Portugal	38,5	55000	38,6	55105	38,5	55000
Cyprus	13,0	18600	37,6	53718	39,5	56404
Netherlands	19,6	27937	21,0	29933	25,3	36119
Belgium	32,6	46500	24,8	35400	20,9	29900
Czech Republic	21,7	31000	16,8	24000	16,8	24000
Slovakia	4,2	6000	16,8	24000	16,8	24000
Croatia	15,1	21500	15,9	22700	15,9	22700
Bulgaria	3,9	5600	16,8	24000	14,0	20000
Romania	12,5	17800	11,8	16800	11,8	16800
Hungary	13,2	18830	12,0	17180	11,2	16000
Ireland	13,8	19768	14,2	20303	9,1	13041
United Kingdom	8,1	11609	7,0	9938	4,9	7000
Finland	2,8	4000	3,5	5000	2,8	4000
Luxembourg	2,6	3759	2,5	3600	2,4	3418
Sweden	2,2	3174	2,2	3208	2,2	3100
Slovenia	2,0	2800	1,1	1550	1,1	1550
Malta	0,5	768	0,5	648	0,4	608
Lithuania	1,5	2200	1,4	2000	0	0
Estonia	1,4	2000	1,1	1500	0	0
Latvia	1,3	1910	1,1	1600	0	0

Source: Based on the data of EurObserv'ER (2020)

The table 2 shows the power capacity of the annual installed solar thermal surfaces across countries of the European Union in megawatt thermal (MWth) as well as installed area in square meters m^2. The installed solar thermal market in EU in 2018 was 1546,1 MWth (2208681 m^2) adding the significant part mostly from the flat plate collectors. The top countries in 2018 were Germany, Greece, Poland, Spain, France and Italy.

According to IEA SHC Solar Heat Worldwide (2019), in Sweden, Austria, Germany, Spain and Greece the most common are large-scale solar thermal systems that connected to local or district heating grids or situated on large residential, commercial and public buildings. By the end of a 2018 year, 339 large-scale solar thermal systems were in utilization, installation area of these systems was 1,747,200 m^2 (1,200MWth). In EU the report spots 14 new large-scale solar thermal collector fields that are connected to a heating network, 6 in Denmark (66800 m^2 including extensions of already existing networks), 6 in Germany (9380 m^2) and 2 in Austria (3010 m^2). The largest system was installed in Denmark, city of Aabybro with 26 195 m^2 (18,3 MWth), following systems by size were put in Germany 983 m^2 (0,7 MWth) Berlin-Köpenick system and in Austria, a 656 m^2 (0,46 MWth) collector field that was connected to Vienna's heating network. In France two industrial heat projects were connected – a food-processing plant at Melville (1772 m^2) and the Condat paper mill (4032 m^2). Despite, Germany still leads the European Union market rankings with 573500 m^2 installed; generally market is not stable and showed the decrease by 11,8% comparing with previous year.

On the report of AGEEstat (2019) become aware that it was caused mostly by lack of interest to market for combi-systems and increasing competition from new, more efficient gas-fired condensing boilers, which are getting benefits from a relatively low gas price.

Another situation was in Greece which showed the annual market growth by 4% with 230.0 MWth (328500 m^2). According to EBHE (Greek Solar Industry Association, 2019) this growth was described by the drop in system price due to a high competition in a field, the arrival of retailers such as Leroy Merlin, the entry of new private labels and the improvement in a Greek economy. EBHE also highlights that Greek solar thermal market is robust, stable, the equipment level is very high and industry increases export volumes, which boost the competitiveness of a country.

Based on last survey run by SPIUG (Association of Manufacturers and Importers of Heating Appliances, 2019) the biggest growth of heating technologies in the European Union solar heat market were in Poland, where the market expanded and increased from 111.100 m^2 to 310.000 m^2 and showed a 180% growth. SPIUG declared that this performance had been the award of implementation of municipal public tenders in the previous year. Authors of a survey among the association's members stated that 74% of collectors sold were intended for small solar hot water systems, 10% for combi-systems and 14% for large scale solar thermal systems to provide heating for hospitals, public buildings or projects related with solar district heating. Local tenders were funded by European Union and were set in motion to deal with the smog generated by coal-fired domestic heating devices.

Regarding with ASIT (National Solar Energy Association, 2019), the Spanish solar thermal market grew for the first time since 2014 up to 2 % and added 205,530 m^2 (144 MWth) of collector area. This return to growth can be ascribed due to better housing construction regulation, which has required the installation of solar water heaters in all new-build constructions according to new Technical Building Code. ASIT's annual report shows that 86% of the collector area added was due to this regulations and just 14 % was installed because of local incentives or was unsubsidised.

Worth to mention, that despite the competition from thermodynamic water heaters in France the sector grew to 109.3 MWth (156122 m^2). As for Italian market, it declined by 7,9% to 97.3 MWth (139000 m^2) caused mostly by high competition with photovoltaic systems. Generally, space heating demand is expected to remain stable in Europe or even decline in countries with firm economy due to houses isolation, building improvement and energy efficiency development. As for water heating demand, it is expected to increase in developing countries due to income growth, standard of living heightening and a desire for increased comfort (IEA SHC Solar Heat Worldwide, 2019).

IEA-ETSAP and IRENA (2015) indicated main challenges for wider development of solar thermal systems in European Union. Among the most important are high up-front installation costs compared to conventional technologies like natural gas or electric boilers, the more complex process of installation, higher associated costs of integrating solar thermal systems into already existing housing, the competition with heat pumps for heating and cooling services, and with solar photovoltaic panels for rooftops. Solar thermal systems have been very successful in countries where governments have mandated their deployment into new builds, by that effectively removing development limitation. Some governments heavily subsidize and donate conventional energy, thereby creating an intimidating economic barrier for deploying of solar thermal systems.

According to a report, by IRENA, IEA and the Renewable Energy Policy Network for the 21st Century (2017), European Union governments assert to support the development of renewable by providing grants, loans, tax incentives and implementing market instruments such as renewable energy certificates and guarantees of origin. Some countries are providing financial incentives for expansion of solar energy for combined heating and cooling. For instance, Germany in 2017 initiated a program Marktanreiz (market incentive) that offers grants of up to 60% of investment for innovative heating and cooling system (at least 50% from renewable sources), France have a similar program under the Heat Funds (Fonds Chaleur), Netherlands provides donations under the Sustainable Energy Investment Subsidy Scheme to support small renewable heating installations in homes and businesses (EUR 650 for solar thermal and EUR 1 500 for ground source heat pumps).

1.7. Solar energy development and prospects in Portugal and Ukraine

Conforming to The Organization of economic co-operation and development Portugal is strongly dependent on imported fossil fuels and that was a stimulating factor to arouse its energy supplies by encouraging the renewable energy sources (OECD, 2020). Portugal is a one of a few countries where renewable energy is the only form of energy produced, as any notable deposits of fossil fuels have not been discovered yet (Economic Surveys Portugal, 2019). One of the main renewable sources in Portugal is high solar radiation, especially when compared with the eastern countries, such as Ukraine. Besides, there are significant differences between two economies in the sector of solar energy. Comparison between Portugal and Ukraine aims not only to present an overview of the development of solar heat sector in both countries but also, in addition to analysis of the current situations to set strategic guidelines and examine future prospects.

Gill and Cabrita (2017) noticed that despite Portugal is one of the European countries with the highest solar radiation per year, is not taking all advantages of its wide availability. One of the most important natural resources is high solar radiation in a whole territory, the available potential is quite considerable, with Portugal being one of the countries with the best conditions for the development of solar energy, with an average annual number of solar hours varying between 2200 and 3000, on the continent, and between 1700 and 2200, for the Azores and Madeira. The seasonal distribution of global radiation in mainland Portugal is marked due to the country's latitude. Maximum radiation values are recorded in summer and the lowest in winter.

As Portugal is heavily dependent on external energy sources, the government is trying to foster the use of renewable energy. Exploring of renewable energies occurred mainly in the previous decades but for the last couple of years, the country has experienced a period of strong growth in solar energy development. The main reason for that was the influence of European Union energy policies as well as domestic government’s national plans for energy efficiency, specific legislation to encourage the renewable energies use and specific programs supporting solar energy exploration (DGEG, 2016).

Portugal presented its first National Renewable Energy Action Plan (NREAP) to the European Commission in 2007. Following the approval of this plan, Portugal introduced a number of actions to promote solar energy projects. Besides that, specific programs to increase the solar heat market growth were implemented: the "Renove - Solar Térmico" defines support to the renewal of the existent solar thermal collectors, the Solar Thermal 2009 Scheme, funding solar thermal systems with Solar Keymark certification for large, small and medium-sized enterprises while the financial incentive is reaching up to EUR 1600 that can also be combined with a 30% tax credit from the Portuguese government for investments in renewable energies. There are also programs aimed at specific segments such as condominiums, pools and social housing (ESTIF, 2019). Figure 4 displays the resource map of solar irradiation distribution in the territory of Portugal.

Figure 4. Direct normal distribution in Portugal

Source: World bank group, Solargis (2020)

In Portugal, the year 2010 marks the beginning of the market contraction for solar thermal systems, which caused a continuous decline in this market. That decline was caused by financial crisis in Portugal and that was a reason for a crisis in building industry. It was also found that the Portuguese solar thermal market seems to be more competitive for applications with bigger buildings (Figueiredo, 2015).

In 2018, an installed capacity of 55000 m^2 (38,5MWth) was registered and the accumulated capacity reached the value of 1286105 m^2, corresponding to 900 MWth. The installed capacity decreased by 70,7 % in 2018 when compared to 2010. The decline trend was maintained every year but in 2017 annual installed capacity slightly increased by 1 % (EuroObserver, 2020).

Table 3 shows the evolution of total and newly installed capacity of solar thermal systems in Portugal between 2010 and 2018. At the current moment Portugal is below the 2020 target for the solar thermal systems which is 2214282 m^2 of collectors installed (NREAP Portugal, 2020).

Table 3. Capacity of solar thermal systems in Portugal

Year	Annual installed surfaces		Cumulated capacity of thermal solar collectors		Solar thermal capacities in operation per capita	
	Total (m^2)	**Equivalent power (MWth)**	**m^2**	**MWth**	**m^2/inhab.**	**kWh/inhab.**
2018	55 000	38,5	1 286 105	900	0,125	0,087
2017	55 105	38,6	1 231 105	862	0,119	0,083
2016	55 000	38,5	1 176 000	823	0,114	0,080
2015	46 134	32,3	1 121 104	785	0,114	0,080
2014	50 967	35,7	1 133 965	794	0,109	0,076
2013	57 234	40,1	1 024 004	717	0,098	0,068
2012	90 896	63,3	96 6770	677	0,092	0,064
2011	128 142	89,7	87 6 818	614	0,082	0,057
2010	187 645	131,4	75 1711	526	0,071	0,049

Source: Author's own elaboration, based on the data of EurObserv'ER (2020)

In Portugal, the distribution of installed solar thermal systems is divided between the thermosiphon, forced convection systems, and individual collectors. Worth to mention, for the last four years the installed capacity was increasing just by flat-plate collectors. Generally, in Portugal the share of thermosiphon systems correspond to 22%, the forced convection systems 25% and the individual collectors correspond to 53%. Concerning individual collectors, majority of them are used in private residential habitats (83%) and only 17% is used in public services such as swimming pools and hotels (Gil et al., 2017).

Associação Portuguesa da Indústria Solar (APISOLAR, 2016) claimed that among the main challenges of solar energy development in Portugal is the competition from more technologically advanced countries or from countries with low production costs. Furthermore the main obstacles were presented such as: high initial investment costs, weak credibility in the solar industry, low awareness among investors and customers, low impact of financing schemes, limitations concerning building construction and lack of information.

Solar energy is a relatively new emerging industry field in Ukraine that have been examined mostly by the Institute of Renewable Energy NANU, Intersectoral Scientific and Technical Centre, Bioenergy Association of Ukraine and other research institutions. According to NANU report for the end of 2019 the solar energy share in the total energy generation of Ukraine was 1,65% (52% share of all renewable energy sources). Eliseeva and Khazan (2016) noticed that taking into account the experience of implementing solar plants in European countries with similar level of solar radiation, as well as global tendencies of permanent decrease in the cost of solar systems, solar energy has a high potential in Ukraine. The average annual amount of total solar radiation coming into the territory of Ukraine is in the range from 1070 kWh / m^2 in the northern part of Ukraine to 1400 kWh / m^2 and above in the south part of Ukraine and the Crimea peninsula and is being on the same level as in the countries that actively use solar collectors (Sweden, Germany, USA, etc.). The whole territory of Ukraine is suitable for the implementation both photovoltaic and solar thermal systems, the highest indicators of solar energy potential are observed in the following areas of Ukraine: Zaporizhye, Mykolayiv, Odesa and Kherson, all of mentioned regions are located in the South of Ukraine. Generally, renewable energy sources installed in Ukraine have a tendency to increase annually (the fall in 2014 was caused by loss of energy facilities in the Autonomous Republic of Crimea and in the ATO zone). Figure 5 displays the direct solar irradiation distribution in the territory of Ukraine.

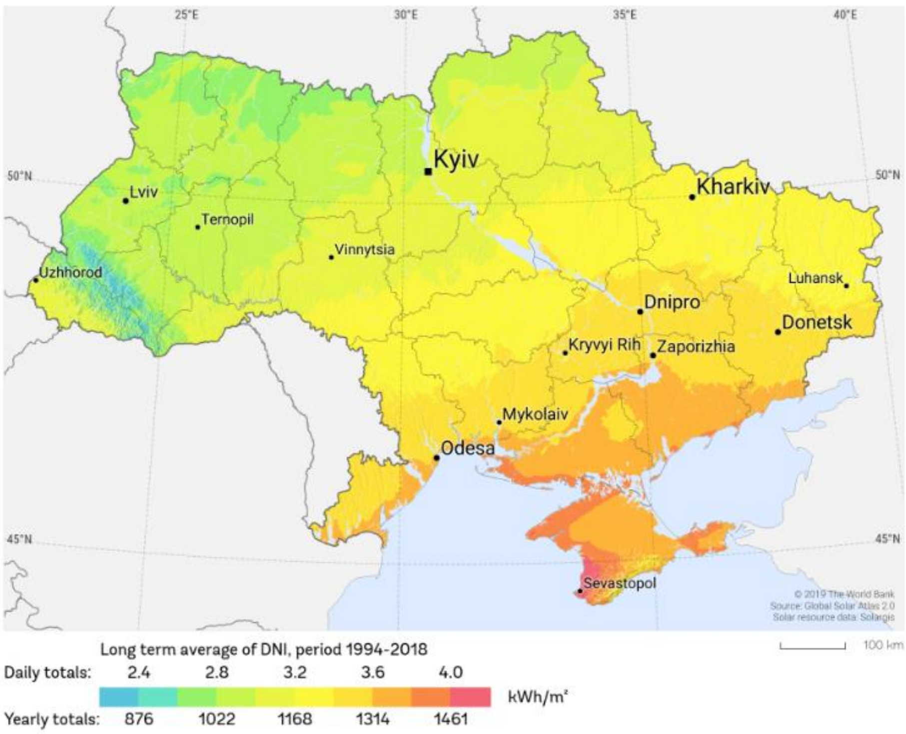

Figure 5. Direct normal irradiation in the territory of Ukraine

Source: World Bank group, Solargis (2020)

According to National Commission for the State Regulation of Energy, (NERCEP) till the end of 2016 the renewable energy sector of Ukraine accounted 260 companies of renewable energy facilities. During 2019 the largest increase was demonstrated by solar energy. As of the end of 2019, solar technologies has been installed with a total rated capacity of 4925 MW, excluding about 407.9 MW of capacity in the territory occupied by Russia, the difference with a previous year is 3537 MW, in general, in 2019 solar energy field showed the growth of 255%.

The main reasons for the rapid growth of solar energy in Ukraine are the high rate of "green" tariff, which were implemented in 2008 and is fixed until 2030, as well as lower prices for equipment. However, experience has shown that the development of an industry built on a single support mechanism is not sustainable. High green tariffs and unintended planned reductions can lead to increased imbalances in the market and concentration of profits in one sector (Malyarenko & Tymchenko, 2018).

As shown implemented in recent years, experimental projects, the techno-economic potential of solar thermal energy production in Ukraine reaches 500 - 600 kWh / m^2 and almost the whole irradiated solar energy is collected during the warm period of the year (from April till October). According to the rule of the thumb, potential of using solar collectors for developed countries that is 1 m^2 per person, as well as solar performance plants for the conditions of Ukraine, annual resources of solar hot water supply and heating can reach 28 billion kWh. Hugo and Zmeureanu (2012) cost analysis indicated that seasonal thermal storage systems for solar thermal systems in cold climates don't provide an acceptable payback period but with some financial support from the government, the initial costs could be recovered faster. Generally, solar systems have a big potential in Ukraine but is more profitable to install these systems for domestic hot water production in buildings with already existing district heating systems (Eliseeva & Khazan, 2016).

Eliseeva and Khazan (2016) mentioned the utilization of solar energy can be significantly increased due to the improvement of technology and government policies. Back in 1997, the Cabinet of Ministers of Ukraine approved "The program of state support for the development of renewable energy sources, hydro and heat power". It outlines the most promising areas of solar energy use: direct conversion to thermal energy for hot water and heat supply, as well as direct conversion to electricity. A comprehensive program for the use of unconventional and renewable energy sources have also been developed by the State Committee of Ukraine for Urban Development and Architecture, which recommends three types of solar thermal and electricity installations for common application: solar boilers for hot water; seasonal systems for private households and modular installations for solar water heating (Eliseeva & Khazan, 2016).

Malyarenko and Tymchenko (2018) observed that in Ukraine, there are numerous barriers to the growth of solar energy market. First of all, economic: quite high price for solar systems and payback period, lack of coordination in the field of solar technology development, absence of specific institutional mechanisms to stimulate production in the form of subsidies, tax exemptions, preferential tariff policies, etc.

Concerning solar energy, both countries have green tariffs for private households for electricity production, but they present major differences in terms of tariffs values, systems features and limitations and in a particular set of circumstances, the installation of solar thermal collectors in new buildings is currently mandatory in Portugal. This requirement is very important to improve the development of the solar energy sector; despite, it should not be seen as the only measure to promote this type of energy.

1.8. Literature framework concerning viability of solar technologies

Several researchers (for example, Ferreira & Silva, 2019; Tarigan, 2018; Guédez, Topel, Spelling & Laumert, 2015; Rahaman & Iqbal, 2019; Herbut, Rzepczyński & Angrecka, 2018; Valančiu, Jurelionis, Jonynas, Katinas & Perednis, 2019) presented their case studies analyzing the profitability for solar power technologies in order to evaluate the financial performance, economic viability and estimate the costing analysis of such systems.

Table 4 was elaborated for a quick guide regarding techniques researchers applied for profitability analysis. This table presents the literature framework for the concerned methodologies which contains literature support for each of case.

According to the research of Ferreira and Silva (2019), authors took a look into profitability of solar thermal systems in implementation to Portuguese scenario. The purpose of their work was to determine a costing methodology allowed to calculate the capital cost of solar-thermal systems in accordance to the system size and construction. Their model was demonstrated for a residential house located in Lisbon, with a quantity of 4 people with an evaluated domestic hot water need of 2377 kWh/year. Achieved results of their scenario indicated that for solar-thermal system with a 4 m^2 collector, located at Lisbon, the system cost ranges from 631€ to 707€ per m2 of the solar collector. Considering all technological components solar collector design, building characteristics as well as a level of solar irradiation, the cost of STS may differ by up to 20%, was also stated by the researches. Regarding their work it should be taken into account that exist a limitation in STS profitability determination, like complication of evaluating the effective savings that allow the return of the invested costs in the purchase of solar thermal systems.

The study conducted by Herbut, Rzepczyński and Angrecka (2018) analyses the efficiency, potential financial savings and investment potential of solar domestic water heating system. Several types of analysis were performed by researchers to compute the economic viability. Authors calculated the efficiency by comparing the amount of energy from absorbent solar radiation to the amount of produced energy and applied it to the already existing DHW system. Based on the results of the first analysis as well as general data about the efficiency, the second analysis was performed to determine the installation and operation costs and the depreciation period of the inspected system. The analysis concerning savings on the gas consumption for solar thermal system included the data about the bills paid by the housing association. The current study was performed in the multi-family building, located in Cracow (Poland) and included data for two years from 2010 to 2012. After two-year analysis for the domestic hot water system, authors concluded that the best period for operating such system was from April to September which allowed generating 78% of thermal energy, the consumption of gas went down by 25%, the time for the return on investment in the system, was 13,4 years.

Table 4. Literature framework concerning methodology

Bibliographic reference	Applied methodology
Tarigan (2018)	Economic analysis based on economic indicators (investment costs, net-present value, annuity, and renewable energy fraction) and the CO_2 emission. The cooling load was calculated based on the rule of thumb applicable to this building type in Indonesia. Tool: The profitability tool embedded in the Polysun software, excel-calculator.
Herbut, Rzepczyński and Angrecka (2018)	The methodology explores technical design characteristics, meteorological and market price data and user-specified cost functions for estimating the economic performance. Several types of analysis were performed by researchers to compute profitability: analysis of generated energy amount, analysis of the installation costs, operation costs and the depreciation period, analysis of savings on the gas consumption for DHW.
Guédez, Topel, Spelling and Laumert (2015)	Thermoeconomic analyses based on multi-objective optimization of capital investment cost, two main indicators were examined, the levelized cost of electricity and the internal rate of return.
Ferreira and Silva (2019)	The implemented methodology included the derivation of a cost for each component by combining thermodynamic and cost coefficients, and also estimating the real market data.
Valančiu, Jurelionis, Jonynas, Katinas and Perednis (2015),	Financial analysis. The calculated economical values include Net Present Value (NPV) and Internal Rate of Return (IRR). Tool: simulation with “T*SOL 5.0 Pro” software.
Rahaman and Iqbal (2019)	The simulation was done for every month during a year. In their work authors compared the design, sizing, cost analysis, output power and rate of return for both systems. Then house again was examined by using the BEopt Software, input parameters have been chosen analogously to the existing house materials. Tool: PolySun software, the BEopt Software.

Source: Author’s own elaboration

A recent study by Valančiu, Jurelionis, Jonynas, Katinas and Perednis (2015), had on aim to analyse already existing solar hot water systems from the outlook of energy production and economic benefits, in addition to define the variation of their actual performance with the numerical simulation results. Authors choose three medium-scale solar thermal systems in Lithuania for the analysis, differ in equipment used (flat type solar collectors, evacuated tube collectors) and application (swimming pool building, domestic hot water heating, district heating). From the economical perspective, authors demonstrated that the system with flat type solar collectors used for domestic hot water production was the most efficient solution. Moreover, researchers made a conclusion that the payback time for such systems is too long to guaranty stable growth without government support.

A study carried out by Tarigan (2018) discussed two different possibilities of solar cooling technologies: photovoltaic powered cooling system and solar thermal absorption cooling system. The aim of his study was to find the most profitable and economically effective solar cooling technology for a residential houses or office buildings in a tropical climate. For the economic calculations of profitability for both technologies, the simulation software Polysun in addition to excel calculations was used. Based on the comparative analysis and estimating the level of daily average solar radiation, the number of solar hours in Indonesia and cooling demand, the following results were achieved by researcher. From economic aspect, solar thermal absorption cooling system was recognized as more profitable in comparison with PV powered cooling system since the investment cost for PV system were almost twice higher than STS costs. Furthermore, it was mentioned that solar thermal absorption cooling system allows the maximum CO_2 emissions savings as it operates just on the solar thermal energy. Despite, author noticed that for such technologies to become more competitive, the prices for solar collectors and absorption chillers should be reduced.

The research of Guédez, Topel, Spelling and Laumert (2015) was observing the profitability of solar tower power station with integrated thermal energy storage. The aim of their study is to find the optimum configuration of solar tower power system elements in terms of sizing and operating strategy in addition to profitability review. This research contains a comprehensive methodology which is based on thermoeconomic analyses that takes into account the curves between cost, profitability and investment. Authors measured the profitability through thermoeconomic analysis which, in sequence, was based on multi-objective optimization of capital investment cost which is the sum of all direct (equipment related costs) and indirect (land purchase, taxes and labor) costs. The methodology was conducted by examining the design of a solar power station in the region of Seville, and considered the Spanish market.

Recently, Rahaman and Iqbal (2019) provided a research in which they compared viability of solar thermal collector with solar photovoltaic for water and space heating use in residential house. The adapted single-family house, located in Canada has been modelled and simulated in professional PolySun software. According to all calculations, authors made the conclusion that solar thermal collector system is requiring higher investment cost even thought the output power of such system is much lower than the PV based system. Researchers generalized that the solar PV based system is a more suitable, profitable, cost-effective, and reliable solution for residential house applications, water heating, and space heating in a considered location.

2. Research methodology

2.1. Objective of the study

The research objective of the current work is to define the economic viability of solar thermal systems implementation projects in Portugal and Ukraine. In order to meet the research objective it is important to establish a costing methodology that will help to estimate the average cost of such systems and evaluate the cost of each component. In the present research, it will be identified the economic model for solar thermal system which will be applied, simultaneously to defined reference scenarios in Portugal and Ukraine. It will be presented an economic model that includes a set of equations able to describe solar thermal system, as well as a set of equations that describe the cost of each component. In order to validate the created economic model, real market data for both countries will be considered in addition to yearly sum of global irradiation. Domestic hot water consumption will be computed by taking into account the water needs per person per day and the occupancy of the buildings. Furthermore, solar collector orientation and tilt angle are also important aspects, so for both reference scenarios a solar collector orientation (azimuth) towards south 45° will be chosen to receive most irradiation on a yearly basis and take the most advantages of it (applicable just for the northern hemisphere).

The Financial analysis of solar thermal systems in both reference cases to analyse economic benefits of these projects will include additional values of economic performance measurement such as Economic Life, Net Present Value (NPV), Internal Rate of Return (IRR) and Profitability Index (PI). These values are common financial indicators to determine the viability of small projects. Moreover, sensitivity analysis will be performed in order to determine how different values of an independent variable such as discount rate or energy price affect the economic viability of solar thermal system in both countries.

With the purpose of establish an average cost of solar thermal system implementation and make the economic viability analyses of solar thermal systems, it will be used a data provided by The International Renewable Energy Agency, Institute of Renewable Energy NANU for Ukraine and tariffs from EDP in Portugal will also be taken into account. These results will be consistent with the commercial data for solar thermal systems in Portugal and Ukraine. As solar thermal system is a relatively simple technology and most countries including Portugal and Ukraine produce, install and maintain the equipment themselves, information about prices for solar thermal systems facilities will be given by one of the largest suppliers of solar thermal systems in Portugal “Solius. Energias Renovaveis” and “Termozona” in Ukraine.

There are several types of costs associated with purchasing, operating and maintaining a solar thermal system, choosing the costs for analysis is one of the first decisions to be made as it is necessary to evaluate the economic effects that will result from each alternative. It is not necessary to consider all costs related to the project, costs that do not have a significant implication can be neglected. For this research, the operation and maintenance costs are disregarded. The focus will be just on the total investment cost. Investment costs include costs related to planning, design, purchase and installation.

2.2. Costing methodology and economical modelling

There are several common costing methodologies, and they all have their usefulness in specific situations. The costing methodology that will be used in this research is based on the approach developed by Ferreira et al. (2019); it is a bottom up costing, or the engineering approach. The bottom-up approach is based on detailed engineering analysis and calculation to determine estimate costs, which is a summation of all the costs involved. Specific design details must be observed to involve the current method correctly. To apply this approach, we would need the detailed design and configuration information for various components of solar thermal systems in addition to accounting information for all materials. The current methodology will contain the derivation of a cost expression for each component of solar thermal systems and will combine thermodynamic and cost coefficients. One of the advantages of this approach is that each component of solar thermal system is getting analyzed separately, and the value of each component can be well understood, it gives good insight into major cost contributors. For instance, we could affect the cost by choosing an alternative material, or changing the size of a component. However, the current methodology has some drawbacks. The analysis process is time consuming, the system should be well defined, specification of a product must be well known and stable and all the process changes must be reflected. Although, the proper sizing of solar thermal system components is a complex task, as predictable (solar irradiation level) characteristics in addition to unpredictable (solar thermal system components prices) need to be analyzed.

By using this costing method, it will be identified the economic model for solar thermal system which will be applied, simultaneously to reference scenarios in Portugal and Ukraine. According to a research of Estrada (2015) economic modeling can be interpreted as an academic research process that is followed by the use of theories, quantitative or qualitative models and techniques, to analytically evaluate what might happen in different scenarios. Following the study of Estrada (2015), economic models have the next classification: (i) domestic and international trade models; (ii) energy, communications and transportation models; (iii) environmental and natural resources management models; (iv) fiscal policy models; (v) institutional, regulation and negotiation models; (vi) labor, income, employment and population models; (vii) monetary, banking and investment policy models; (viii) production, prices and consumption models; (ix) technological and R&D models; (x) welfare economics models; (xi) economic growth models; (xii) miscellaneous economic models. According to the same research of Estrada (2015), economic model is an important technical-theoretical analytical tool, which is being widely used for the purpose of adapting the uses of any research technique, method, methodology and research focus. Author concluded that any economic modeling should consider different factors; all the factors maintain a quantitative and qualitative transformation.

2.3. Sensitivity analyses methods

Sensitivity analysis is the scientific method of determining the amount of variation a system has in response to a range of input. The sensitivity analysis is based on the variables that affect valuation in general. This type of analysis determines how different values affect a particular dependent variable under a given set of circumstances. In other words, sensitivity analyses study how various sources of uncertainty in an economical model contribute to the model overall uncertainty (Simski, 2019).

Simski (2019) concluded that this technique is used within specific boundaries that depend on some input variables. This model is also referred to a simulation analysis. Sensitivity analysis is performed with suppositions that are different from those used in the primary analysis. Sensitivity analysis responds to the question if the results of the study will change with other assumptions.

For this research, sensitivity analysis will be performed in order to determine how some critical values such as discount rate or energy price affect the viability of solar thermal system in both countries. Investors can use sensitivity analysis to determine the effects that different variables have on their investment returns. Sensitivity analysis permits forecasting by using historical data. By studying some of the variables and the possible outcomes, important decisions can be made about the economy or about making investments.

2.4. Technical aspects that affect costing

In sequence to describe a costing methodology that permits discovering the average cost of solar thermal system according to the system size and specification, technical aspects of solar thermal components need to be analysed. Since a number of technical factors exist that affect the costs of a solar thermal system construction, for instance, the type of solar collector, the size and structure of the facility, design and materials of system components. Despite all the technological considerations, the cost of a solar-thermal system may differ by up to 20% from the average, depending on the collector design and building exposures and materials of components (Ferreira et al., 2019).

This research will focus on solar thermal systems with a liquid water solution energy carrier. The principal components of a solar thermal system are the solar collector, the circulation pump and a controller (in the case of forced circulation systems), the storage tank and the circuit of pipes. These are the most important components when sizing solar thermal systems considering the heat energy production.

The solar collector is the main component of solar thermal systems that has in purpose to capture the solar energy and transmit it to the working fluid that circulates inside. The cost of solar thermal systems strongly depends on the quality of the solar collector. Among liquid based solar collectors for domestic hot water heating there are two types, which are most widely used: flat plate and evacuated tube. Flat plate collectors are the most common application in Europe and particularly in Portugal. In this research work it will be examined the solar thermal system with this type of solar collector as they are less expensive and some studies concluded that evacuated tube collectors does not reach the expected energy yield (Valančiu et al., 2015).

According to Carvalho, Calado, Teixeira and Barbosa (2015) the basic design of flat plate collector includes: a plane absorber, tubes for the heat carrier, glazing and insulation. The glazing is added to increase the temperature in the collector; it is normally made of a transparent material, for instance tempered glass, acrylic or plastic and helps to keeps the heat inside and promotes greenhouse effects. The absorber plate is usually framed in aluminium; the absorber itself can be made of aluminium or copper depending on the type of system. Furthermore, solar collectors with metal absorbers can supply higher temperatures and has the highest efficiency. The choice of material affects the final price of solar collector. For domestic use, the temperature must be around 45 °C but normally it accumulates up to 60 °C.

Another type of collectors used in solar thermal systems for domestic hot water heating is evacuated tube solar collectors, which includes two-layered glass cylinders with vacuum in between which helps to prevent the solar radiation losses. The benefits of this type of collector are availability to produce the higher temperatures and generally better overall efficiency. Although, evacuated tube collectors are vulnerable to overheating because of the vacuum insulation, even though they can provide temperature higher than 60 °C (Carvalho et al., 2012).

A set of equations modelling the thermodynamics of solar thermal system were presented by Ferreira et al. (2019). Equation [1] states the useful power collected by the thermal fluid.

In this equations P is a useful power (in watt, W), it can be calculated by the correlation between the solar collection area A_{solar} in (m^2), solar irradiation level I_g in (kWh/m^2), in this equation α is a collector absorptance, τ is a solar collector aperture transmittance, U_L in (W/m^2K) is the overall heat losses coefficient, t_f is the temperature variation between the mean temperature of the thermal fluid and t_a in (℃) is the ambient temperature. When using directly the mean temperature of the fluid, irrigation factor $F^{\prime}$ need to be introduced.

$$P = A_{solar} \times F^{\prime} \times \left[I_g \times \tau \times \alpha - U_L \times \left(t_f - t_a\right)\right] \qquad [1]$$

The efficiency of a solar collector describes how proficient it is utilising the energy received from the sun. There are several ways of improving the efficiency of a solar collector and minimizing the heat loses. To minimise heat losses, glazing with high transmittance to decrease the convective loses in addition to an absorber with selective properties should be added (Vela Solaris, 2012). Collector efficiency is described by the ratio between the captured and the received energy. Rewriting equation (1), the efficiency of the collection $\eta_{collection}$ can be explained by the equation [2].

$$\eta_{collection} = \frac{P}{A_{solar \times I_g}} \qquad [2]$$

In this case T^* is the temperature for effective performance, at that point the efficiency might be calculated as the Equation [3] for a certain mass flow of thermal fluid. Value of $F^{\prime}U_{L0}$ is the linear losses coefficient,

$$\eta_{collection} = F^{\prime} \times (\tau \times \alpha) - \left(F^{\prime}U_{L0}\right) \times T^* - \left(F^{\prime}U_{L0}\right) \times I_g \times {T^*}^2 \qquad [3]$$

A pump is used to circulate working fluid from tank storage to the solar collector and after return the heated liquid to the storage tank. Equation [4] shows that the mass flow in the circulation pump V_{pump} depends on the collection aperture area A_{solar} (m^2), thermal properties of the thermal fluid that is used in the system, the specific heat $c_{ptfluid}$ and the density ρ_{tfluid} in (kg/m^3). The mass flow rate of the pump is relying on the preferred temperature increase through the collector.

$$V_{pump} = \left(\frac{10F^{\prime}U_{L0}}{c_{p\ tfluid}} \times A_{solar} \times 3600\right) \times \frac{1}{\rho_{tfluid}} \qquad [4]$$

The thermal fluid of the solar thermal system is a mixture of antifreeze with water in appropriate concentrations to prevent it from freezing and keep it in the optimal temperature. Moreover, by adding antifreeze to the thermal liquid some facilities can be modified and that affects the costs (Vela Solaris, 2018). The use of storage tanks has the advantage as the energy demand exist even when is low solar radiation.

Equation [5] allows saying that there is a correlation between the percentage of solar energy and the optimal volume of the tank storage per unit area of the solar collector. As a larger tank has a bigger capacity, but at the same time require more energy to heat its contents to a certain temperature. A general standard of calculation is each square meter of solar collectors demand storage tank volume of 50-75 litres with a layer of insulation added to minimise the heat loses (Lebeña & Costa, 2008).

$$50L < \frac{V_{storage}}{A_{solar}} < 75L \quad [5]$$

For this equation $V_{storage}$ is the optimal volume of the tank storage, A_{solar} is the collection aperture area. For larger applications it is required to connect multiple storage tanks.

Furthermore, there are several limitations when installing the solar thermal system on a roof. Individual collectors, other buildings and trees, can obstruct solar irradiation from reaching the collectors so the installation should be planned to avoid it as the efficiency of collector will be reduced by about the same amount as the shade cover. The angle of the solar collectors should be considered for the snow to slip off, and roof need to have enough area for the fallen snow. Moreover, the roof must be able to resist the load exposed on it, including the construction and any additional weight so maybe it will request extra expenses for strengthening of the roof (Carvalho et al., 2015).

2.5. Economic model for profitability

In order to achieve the objective of the study, while concluding the cost analysis, economic model for solar thermal system components is going to be identified and implemented to reference scenarios.

The current economic model was based on the approach developed by Ferreira et al. (2019) and includes the cost equations for each component of forced circulation solar thermal systems. This economic model consists on the derivation of a cost expression for each component of solar thermal system: solar collector, circulation pump and storage tank and also take into account the installation costs, costs of thermal fluid and cost of circulation system. Each cost equation implicates two variables: physical variable and quality variable. Regarding the current issue, the physical variable represents a size of a component in a system, while the quality variable embodies the efficiency. As a consequence the cost estimation can be reached to estimate the overall cost of the solar thermal system for a specific range of combined power production. Cost equations are determined taking into account that the cost of each component is based on a reference case and consider a cost coefficient, a factor of size for each component, and a quality factor, in this case, the efficiency of solar collector.

The basic formulation for purchase cost is presented in the Equation [6]. In this equation, C_{ref}

is the reference cost coefficient that corresponds to a cost per unit of a physical variable, F_{ref} is the reference variable value, F_i is the physical variable value, b is the sizing exponent of a system component.

$$C_i = C_{ref,i} \times F_{ref} \times \left(\frac{F_i}{F_{ref}}\right)^b \qquad [6]$$

Following current methodology, cost equation for solar collector going to be introduced. Equation [7] refers to the cost of solar collector and explains that the purchase cost of the solar collector C_{solar} is getting influenced by two variables: the area of a solar collector A_{solar} and the solar collection efficiency $\eta_{collection}$. The variable that affects costing of this component the most is the area of a solar collector A_{solar}. The solar collector cost equation is introduced by the equation [7] in which $C_{ref,solar}$ correspond to the reference cost coefficient for solar collector, $A_{ref,solar}$ is collection aperture area for a reference case(also known as area of glazing for flat plate collectors), b_{solar} is the area sizing factor and c is the efficiency exponent. The value for the collection efficiency should be acquired from the equation [2], considering a load profile and climate conditions.

$$C_{solar} = C_{ref,solar} \times A_{ref,solar} \times \left(\frac{A_{solar}}{A_{ref,solar}}\right)^{b_{solar}} \times \left(\frac{1}{1-\eta_{collection}}\right)^c \qquad [7]$$

Considering solar thermal system with forced circulation, cost equation for circuit pump will be introduced. Equation [8] defines the purchase cost of a circulation pump and applies just for the solar thermal systems with forced circulation. The purchased cost of a pump C_{pump} is analysed taking into account the flow rate V_{pump} as the main operational variable that impact the costs of this component. The value of V_{pump} can be obtained from the equation (4). The value $C_{ref,pump}$ is relating to the constant reference cost of the pump, $V_{ref,pump}$ is the pump flow rate for a reference case and b_{pump} is the sizing exponent. The flow rate of the pump is based on the temperature through the collector and getting affected by the pipe dimensions and pipe material (copper or steel).

$$C_{pump} = C_{ref,pump} \times V_{ref,pump} \times \left(\frac{V_{pump}}{V_{ref,pump}}\right)^{b_{pump}} \qquad [8]$$

Regarding the storage tank cost, it is introduced by the equation [9], the physical variable that mostly affects the cost of this component is the storage volume $V_{storage}$ in (m^3). Reference cost coefficient for storage tank corresponds to $C_{ref,storage}$; the reference storage volume is assumed to be $V_{ref,storage}$; the sizing factor for a storage tank for this case is $b_{storage}$. There is a difficulty with choosing the proper size of a storage tank to avoid both the efficiency decrease and heat loses. Furthermore, tank size directly affects the preferable temperature as a bigger storage tank has a bigger capacity, but requires more energy to keep the certain temperature level. Similarly, higher temperatures detain more energy, but at the same time provoke bigger heat losses. Concerning heat losses, large storage tank is more advantageous because of the reduced ratio between surface and volume.

$$C_{storage} = C_{ref,storage} \times V_{ref,storage} \times \left(\frac{V_{storage}}{V_{ref,storage}}\right)^{b_{storage}} \quad [9]$$

Concerning the total investment costs of solar thermal system is equivalent to cost of all main components of the system together with installation costs, cost of a thermal fluid and the fixed costs for circulation system. Consequently, the total investment costs can be calculated by the equation [10]. As for the capital of all the main components of solar thermal system, it corresponds to the sum of the purchase cost of each component: the pump cost C_{pump}, the storage tank cost $C_{storage}$ and the solar collector cost C_{solar}. In addition to the construction itself, total investment costs include installation cost and maintenance costs such as consultation from electricians and plumbers or cleaning charges. The cost for maintenance of a solar thermal construction is estimated to be 1 % of the total investment cost each year and added to an installation costs. The installation costs $C_{installation}$ normally represents a variable percentage of the investment of main components and include also the engineering expenses, the costs of the thermal fluid C_{tfluid} is assumed to be 1%. The circulation system cost $C_{circulation\ system}$is a fixed cost, as the prices do not differ notably for domestic applications.

$$C_{inv} = \sum_{i=1}^{6} C_i = C_{pump} + C_{storage} + C_{solar} + C_{installation} + C_{circulation\ system} + C_{tfluid} \quad [10]$$

At that time, the curves of purchase cost equations for the main components of a solar thermal system can be gained and the sizing factor can be modified for systems with different reference scenarios.

3. Empirical Results and Analysis

3.1. Optimization of economic model

Solar thermal systems are a promising technology that allows the optimal use of the solar energy sources. Its use has a great potential for applications in the residential sector in Portugal and Ukraine. This study aims to develop a costing methodology for the solar thermal-system based on economic model implemented to reference scenarios in both countries. The economic model was formulated considering the purchase cost of each component of solar thermal system, which was based on thermodynamic and economic constraints.

In this economic model key objectives were defined for optimization of solar thermal system: to minimize the total investment cost of a system with the highest collector efficiency and minimum possible volume of storage tank.

Based on the information from several commercial models and research of Ferreira, Silva and Teixeira (2019), the collection efficiency can be approximated to a second-degree polynomial function, and can be calculated from the equation (3) and presented in the equation (11). Figure 6 shows the efficiency curve of solar collector.

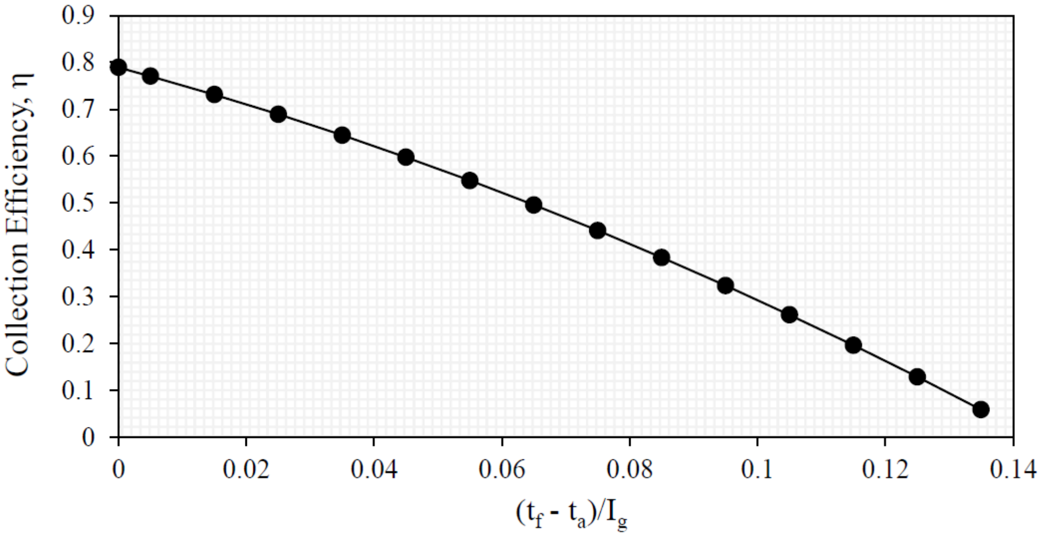

Figure 6. Efficiency characteristic curve of solar collector

Source: Ferreira, Silva & Teixeira (2019, p.29)

The performance parameters for solar collector to achieve the highest efficiency for both scenarios were found. Average values were achieved from a study done by the ESTIF (European Solar Thermal Industry Federation) in Europe (2020). The linear loses coefficient $F'U_L$ for flat plate glazed collector for the Portuguese scenario is assumed to be 3.6800 W/m^{2}K. The linear loses coefficient $F'U_L$ for flat plate glazed collector for the Ukrainian conditions is 3.778 W/m^{2}K.

The term T^* represents the maximum temperature that solar collector can reach for a certain temperature of the ambient (from the equation 3), $T^* = \frac{t_f - t_a}{I_g}$. In this equation $I_g$is a solar irradiation level. The temperature variation between the mean temperatures of thermal fluid is fixed, and varies 15℃ $\leq t_f \leq 180$℃, and the ambient temperature assumed to be an average annual value $t_a = 15$℃ for both cases.

When using directly the mean temperature of the thermal fluid, it is important to present a corrector factor or the irrigation factor F', which reduce the useful power and takes the value of 0.7892 for Portuguese scenario and 0,79 for Ukrainian scenario (ESTIF, 2020). Solar collector efficiency can be calculated from the equation (3).

For the reference scenario in Portugal solar collector efficiency takes the value of

$$\eta_{collection} = 0.7892 - 3.6800 \times T^* - 3.6800 \times I_g \times (T^*)^2$$

For the reference scenario in Ukraine solar collector efficiency is presented by the next equation

$$\eta_{collection} = 0.79 - 3.778 \times T^* - 3.778 \times I_g \times (T^*)^2$$

The specific daily hot water consumption Cons$_{dhw}$ need to be determined by taking into account the ratio between the water needs per person and water needs per day and the occupancy of the building (i.e. area of the building divided by the number of residents). The thermal requirements for domestic hot water Q_{dhw} in (kWh× $year^{-1}$) can be calculated by the equation (11).

$$Q_{DHW} = Cons_{dhm} \times \left(\frac{4.187}{3600}\right) \times \Delta T \times 365 days \quad [11]$$

In this equation ΔT is a temperature increase from the grid water temperature up to 60℃. Specific heat capacity for water is a constant value and is equal to 4,187 kJ/kg-K.

3.2. Validation of economic model

During the present research, it was quantified the economic model for solar thermal system that need to be validated for reference scenarios in Portugal and in Ukraine. By applying this economic model to reference scenarios an average cost of solar thermal systems will be established. Characteristics of utilization the domestic hot water in both countries will be taken into account.

For a reference case in Portugal it was chosen the new build residential building located in Porto, with an occupation of 3 people, daily need of hot water in Portugal is assumed to be 40 L of water per each person by established norms. The temperature increase required for hot water in this reference scenario can be assumed as the reference value of 35°C. For this case, the daily water consumption is equal to 120 L day^{-1}. As was mentioned before; in the northern hemisphere it is optimal to orient the solar panel to the South (45°) to face Equator. According to Greenstream Publishing (2019) the optimal year round angle of inclination is 49° for this reference case. Yearly sum of direct normal solar irradiation (DNI) in Porto is 1745 kWh/m^2 (Solargis, 2020).

For a reference case in Ukraine was selected the residential building located in Lutsk (city in the eastern Ukraine), with an occupation of 3 people, daily need of hot water in Ukraine is higher than in Portugal and takes the value about 50 L of water per each person. The temperature increase required for hot water of this reference value is also will be 35°C. The panel orientation was considered the same to the South (45°). Greenstream Publishing (2019) found that the optimal year round angle of inclination is 39° for this location in Ukraine. For this case, the daily water consumption is up to 150 L day^{-1}. Yearly sum of DNI in Lutsk is lower than in Portugal and is equal to 1100 kWh/m^2 (Solargis, 2020).

The input data for validation of model for both references cases are introduced in a Table 5. For both references cases the value of density ρ_{tfluid} and the specific heat $c_{ptfluid}$ were determined for a water solution of 60°C.

Table 5. Solar collector consideration for validation of economic model

Reference case	Portugal	Ukraine
Location	Porto	Lutsk
Yearly sum of solar irradiation (DNI)	1745	1100
Panel direction	South (45°)	South (45°)
Panel collection efficiency	0.7892	0.79
Optimal year angle of inclination	49°	39°
Daily water consumption for a building	120 L day^{-1}	150 L day^{-1}
The temperature increase required for hot water (ΔT)	35°C	35°C
Thermal fluid solution	Water + 22.5 % of Propilenoglycol	Water + 22.5 % of Propilenoglycol
ρ_{tfluid}	4.045 kJ/kgK	4.045 kJ/kgK
$c_{ptfluid}$	1.002$\times 10^6$kg/m^3	1.002$\times 10^6$kg/m^3
Solar collection area	4 m^2	6 m^2

Source: Author´s own elaboration

Using the equation (11) the thermal requirements for domestic hot water can be calculated for both cases. According to Lebeña and Costa (2008) equivalent area of solar collection can suppress a demand of 500 kWh.*year-1.* Thus, for the reference scenario in Portugal, the required thermal energy to suppress the DHW needs is of about 1783 kWh.*year-1* which demands, at least, an equivalent area of 3,5 to 4 m^2 of solar collection. For the reference scenario in Ukraine, for this location the essential heat energy to suppress the DHW needs is up to 2228 kWh.*year-1*, which requires at least 5 m^2 of solar collection.

The size of storage tank for both reference cases assuming the minimum acceptable value of storage capacity can be calculated by the equation (5). As a consequence, the minimal volume of storage tank for reference case in Portugal is about 200 L. The minimal volume of storage tank for this area of solar collector for reference case in Ukraine is about 300 L.

In order to perform the cost analysis and define the cost of each component of solar thermal system the input data will be applied, simultaneously to both reference scenarios. Input data for each case separately will be applied to a set of equations (6-10) that define the cost of each component. The results of the economic model are presented in the Table 6.

Table 6. Results of economic model

Component	Valuable	Reference case	
		Portugal	**Ukraine**
Solar collector	$C_{ref,solar}$, reference cost coefficient for solar collector;	298.54 €/m^2	197,5 €/m^2
	$A_{ref,solar}$, collection aperture area;	3,72 m^2	5,4 m^2
	b_{solar}, the area sizing factor;	0,5	0,5
	c, the efficiency exponent;	0,1	0,1
	$\eta_{collection}$, collection efficiency;	0,7892≅ 0,8	0,79≅ 0,8
	A_{solar}, the area of a solar collector.	4 m^2	6 m^2
Circuit pump	V_{pump} , flow rate;	0,122 m^3/h	0,181 m^3/h
	$C_{ref,pump}$, constant reference cost of the pump;	322,45 €(m^3 /h)	283,3 €(m^3 /h)
	$V_{ref,pump}$, the pump flow rate for a reference case;	0,98 m^3/h	0,98 m^3/h
	b_{pump}, the sizing exponent.	0,3	0,3
Storage tank	$V_{storage}$, storage volume;	0,2 m^3	0,3 m^3
	$C_{ref,storage}$, reference cost coefficient for storage tank;	3647,45 €/m^3	3324 €/m^3
	$V_{ref,storage}$, the reference storage volume;	0,32 m^3	0,32 m^3
	$b_{storage}$, the sizing factor.	0,4	0,4
Total investment costs	C_{solar}, solar collector cost;	1353 €	1320 €
	C_{pump}, pump cost;	327 €	185 €
	$C_{storage}$, storage tank cost;	967 €	1037 €
	$C_{installation}$, installation costs;	211,76 €	203,36 €
	C_{tfluid}, cost of thermal fluid;	30 €	28 €
	$C_{circulation\ system}$, circulation system cost;	200 €	200 €
	C_{inv}, total investment cost.	3088,76 €	2973,36 €
Specific cost € per solar m^2		772,19 €/m^2	495,56 €/m^2

Source: Author´s own elaboration

For Portuguese scenario was chosen the most widespread application in Portuguese market solar collector SuperSol with an solar collector area 2 m^2 and collector aperture area 1,86 m^2. In order to satisfy the domestic hot water need for this reference case it will be needed solar collection area of 4 $m^{2,}$ solar aperture area for this collector is 3,72 m^2. Information about prices for solar thermal systems facilities and cost coefficients will be given by one of the largest suppliers of solar thermal systems in Portugal “Solius. Energias Renovaveis”.

For Ukrainian scenario was chosen the most widespread application of solar collector in Ukraine flat plate collector Atmosfera SPK-F4M with an solar collector area 2 m^2 and the aperture area of 1,8 m^2, it will be needed at least 5 m^2, as in the Ukrainian solar thermal systems market there is no offers of solar collectors with this area of solar collection, for this case it will be assumed the value of 6 m^2 of solar collection area. Prices for solar thermal systems facilities and cost coefficients for this reference scenario will be provided by one of the main suppliers of solar thermal systems in Ukraine “Termozona”.

The circulation system costs is a fixed value, 200 € since, for the range of individual domestic applications, the prices do not vary significantly neither in Ukraine and Portugal. The cost of thermal fluid of a solar thermal construction is estimated to be 1 % of the investment cost.

The installation costs will be based on its percentage of the total investment cost. Normally, the installation costs represent around 5-15 % of the costs of all components depending on access to the installation area (terrace or roof) and the size of the solar thermal system. For this economic model, installation cost is determined to be 7 % from the cost of all components.

3.3. Cost Benefit Analysis of Implementing a Solar Thermal System

The created economic model was validated for a reference cases in Portugal and Ukraine to estimate the capital investment cost of solar-thermal systems in both countries, performance parameters were calculated for two scenarios and will be compared.

The results of the economic model, assuming the minimum acceptable value of storage capacity showed that for Portuguese application, it is required at least a solar collector of 4 m^2 and a storage tank with minimum of 200 L. In this reference scenario, for a solar thermal system with a solar collector of 4 m^2 and a tank storage with a capacity of 200 L, the total investment costs are of about 3088,76 €, which represent a specific cost of 772,19 €/m^2. The achieved results are compatible with the commercial data from “Solius.Energias Renováveis”, which shows that the prices of this type of systems start at 2500€. Figure 7 shows the distribution of the solar thermal system components costs in a total investment costs for Portuguese scenario. Findings indicated that the solar collector and storage tank are the most expensive components of the thermal systems, representing, 44 % and 31 % respectively.

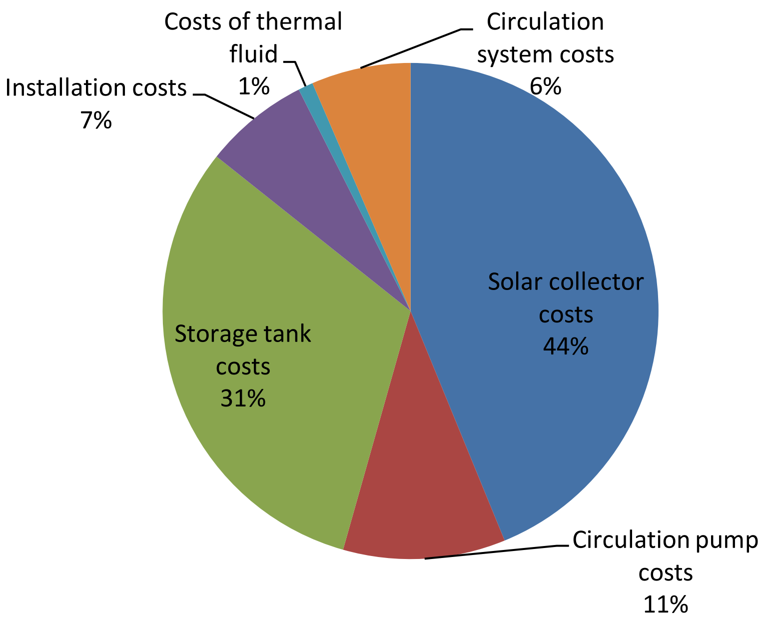

Figure 7. Breakdown of the investment costs for Portuguese scenario

Source: Author´s own elaboration

For a reference case in Ukraine, application requires a solar collector with minimum 5 m^2 and a storage tank with a capacity of 300 L minimum; it was decided to assume a value of 6 m^2 of solar collection area. In this application, for a solar thermal system with a solar collector of 6 m^2 and storage tank of 300 L the total investment cost is about 2973,36 €, which represent the specific cost of 495,56 €/m^2. The commercial data from the biggest supplier of solar thermal systems in Ukraine "Termozona", shows that the prices of this type of systems start at 2000 € depending on the solar collector area and storage tank capacity. Figure 8 present the distribution of costs of solar thermal system components in the total investments costs. Reportedly, similarly to the Portuguese scenario, solar collector price and a storage tank price is the most expensive components. The price of solar collector represents 48 % from the total investment costs and the price of storage tank represents 37 % in accordance.

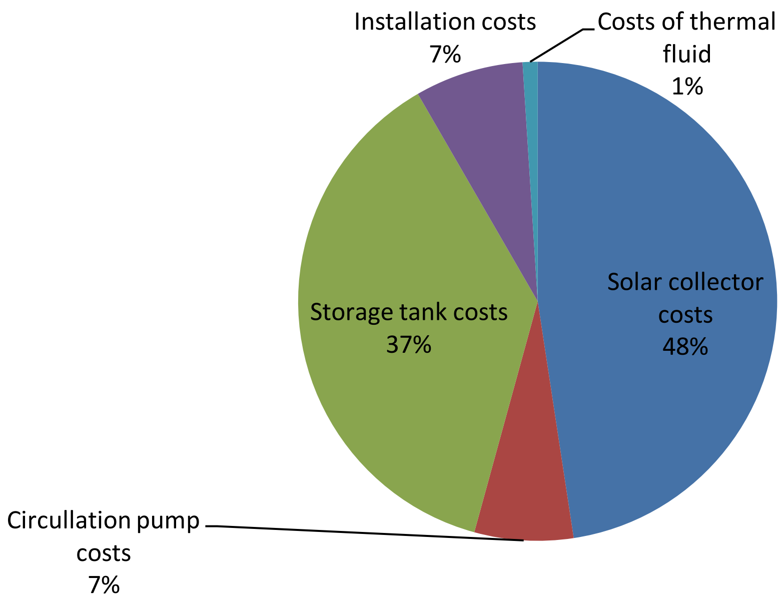

Figure 8. Breakdown of the investment costs for Ukrainian scenario

Source: Author´s own elaboration

Despite that Portugal has a better weather conditions for solar technologies installation and solar thermal system in Ukraine has a lower performance, this can be seen that the investment costs of solar thermal system for domestic hot water heating in Ukraine is lower than in Portugal, the specific cost of 495,56 €/m^2 in comparison with 772,19 €/m^2. It can be seen that the price and quality of solar thermal components differ substantially. Observable that solar thermal system for domestic hot water in Ukrainian scenario is much cheaper than the Portuguese one, even though it requires bigger solar collection area, but, in general, their expected working time is also lower. Moreover, in the Ukrainian solar thermal system market there is a lack of needed components exist and generally smaller assortment of products. It can be observed that the installation costs and cost of circulation system in both countries do not vary significantly.

It is necessary to assess the economic effects that will result from solar thermal system as alternative decision for domestic water heating. The cost competitiveness of solar thermal systems for domestic hot water is described by three main factors: the total investment costs of the solar thermal system installation, proper maintenance and the price of alternatives (electric boiler or natural gas). Furthermore, as solar energy is still free, it is not subject to price increases.

The calculation of the main financial parameters to measure the life cycle of solar thermal systems follows the criteria established by the Federal Energy Management Program (FEMP) used for the economic evaluation of renewable energy projects. Financial parameter allows measuring the economic performance of an alternative energy project, mainly in terms of costing. In order to answer the research questions if solar thermal systems for domestic hot water heating in Portugal and Ukraine are economically viable, financial values such as

Economic Life, Net Present Value (NPV), Internal Rate of Return (IRR) and Profitability Index (PI) going to be calculated and compared. These values are common financial indicators to determine the viability of small projects. In this analyze it is essential to examine electricity costs as well as domestic water costs to assist in the evaluation of the process, creating decision support and facilitating future strategy. Energy costs are likely to be relevant and significant in the analysis of such alternative projects. Additional measures of economic performance may be applied to each of the investment alternatives.

When applying this method, the following points will be estimated such as: (i) comparison between two or more mutually exclusive alternatives (for our case solar thermal system in comparison with electric boiler and solar thermal system in comparison with natural gas); (ii) alternatives must meet the minimum performance requirements established; (iii) all alternatives must be studied for the same base year and period of study; (iv) positive financial flows must be calculated from the saved costs of electricity or natural gas.

In sequence to analyse the economic benefits and viability of solar thermal systems the Economic Life of these projects for both references scenarios is going to be calculated taking into account the characteristics of hot water heating for domestic uses in both countries. The energy costs and the type of energy used play a major role in the analysis. For that same reason, market values should be considered.

In Ukraine the most widespread application of domestic hot water is through the direct central water system in which water is heating up by a natural gas. As was mentioned before, the domestic hot water need for the reference scenario in Ukraine is 150 L per day, the annual demand is about 54750 L or 54,8 m^3; the hot water tariff for domestic uses is 3,6 €/m^3, the cold water tariff is 0,8 €/m^3. On these terms, the annual cost of domestic hot water is about 198 €, the annual cost of cold water is 43,84 €. In this case, 154,16 € is the expenses for warming up the water for domestic uses in the case of the natural gas utilization and can be assumed as a price of natural gas needed for heating up this amount of water. As follows, the economic life for solar thermal system as alternative decision of DHW is around 20 years in comparison with natural gas.

Another common way of supplying the domestic hot water in Ukraine is through electric boiler; the required heat energy to suppress the DHW needs for this reference scenario is up to 2228 kWh.*year-1*. For the April of 2020 the energy tariff in Lutsk is 0,07 €/kWh.· According to the provided data the annual cost of energy for domestic hot water in Ukraine in the case of using the electric boiler is 155,96 €. The solar thermal system as alternative decision in this case has an economic life time around 20 year related to electric boiler utilization for heating the water.

It is mandatory to consider all financial parameters to outline the actual financial benefits of installing the solar thermal systems. Equation [12] indicates the Net Present Value which refers to the unadjusted rate or current price of solar thermal systems.

$$NPV = -C_o + \sum_{i}^{T} \frac{C_i}{(1+r)^i} \qquad [12]$$

In this equation, C_o is initial investment in €; C_i is cash flow in €; r is a discount rate, %; T is time period, years. Net Presence Value for the application of solar thermal system will be calculated in the Excel program.

Average energy price and water price for Ukraine was used for the calculation of potential savings. Few products such as oil and gas have prices that change with the inflation rate. Taking into account oil and gas prices for the last 10 years the predicted index for a gas prices increase is 2,5 % and for energy prices is 3 % in Ukraine (according to historical average oil and gas price growth). Discount or inflation rate in Ukraine is 5 %. As was calculated before, the economic life time of solar thermal system related to natural gas utilization for the purpose of water heating is 20 years. The value of NPV will be calculated by the equation (12).

$$NPV = -2973{,}36 + \frac{154{,}16}{(1+0{,}05)^1} + \frac{158{,}01}{(1+0{,}05)^2} + \frac{161{,}96}{(1+0{,}05)^n} + \ \dots + \frac{246{,}45}{(1+0{,}05)^{20}} = -\ 615{,}19\ €$$

Another solution for Ukrainian scenario is using solar thermal system for DHW as a substitute of electric boiler. Heat energy need to suppress domestic hot water needs is 2228 kWh.*year-1*. For the April of 2020 the energy tariff in Lutsk is 0,07 €/kWh, index for energy prices in Ukraine is 3 %. Net Presence Value for the solution of installing solar thermal system for domestic hot water comparing with electric boiler utilization going to be calculated. The economic lifetime of solar thermal system in this case is also 20 years.

$$NPV = -2973{,}36 + \frac{155{,}96}{(1+0{,}05)^1} + \frac{160{,}60}{(1+0{,}05)^2} + \frac{165{,}46}{(1+0{,}05)^3} + \ \dots + \frac{273{,}48}{(1+0{,}05)^{20}} = -\ 483{,}49\ €$$

Internal Rate of Return going to be calculated by the equation [13] to estimate the profitability of a potential investment. It is a discount rate that makes the NPV of all cash flows equal to zero.

$$0 = NPV = \sum_{n=0}^{T} \frac{C_i}{(1+IRR)^n} \qquad [13]$$

In this equation C_i is a cash flows in €, IRR is Internal Rate of Rate, %; T is time period in years, n is each period.

For Ukrainian scenario, in a case of solar thermal system in comparison with natural gas IRR going to be calculated. IRR is one of the most common methods of evaluation the investment projects and it shows the higher discount rate with which the investments of the project will be profitable.

$$0 = \frac{154,16}{(1+IRR)^1} + \frac{158,01}{(1+IRR)^2} + \frac{161,96}{(1+IRR)^3} + \ \dots + \frac{246,45}{(1+IRR)^{20}} \ ;$$

By using the excel calculator the value of IRR for this case is equal to 2,6 %. As was mentioned before the real inflation rate in Ukraine is 5%.

In a case of solar thermal system in comparison with electric boiler IRR going to be calculated,

$$0 = \frac{155,96}{(1+IRR)^1} + \frac{160,60}{(1+0,05)^2} + \frac{165,46}{(1+IRR)^3} + \ \dots + \frac{273,48}{(1+IRR)^{20}};$$

The value of IRR for this case is equal to 3,1 %.

Profitability Index (PI) also known as profit investment ratio going to be calculated by the equation [14].

$$PI = \frac{\sum_{t=1}^{n} \frac{CF}{(1+r)^t}}{|CF_0|} \qquad [14]$$

In this equation CF is a future cash flow, €; r is a discount rate, %; $CF_0$is the initial investment. The Profitability Index is going to be calculated also for two cases: solar thermal system as alternative decision for the natural gas solution from central water system and solar thermal system as alternative for electrical boiler. Firstly, the PI is going to be calculated for solar thermal system in comparison with central water system.

$$PI = \frac{\frac{154,16}{(1+0,05)^1} + \frac{158,01}{(1+0,05)^2} + \frac{161,96}{(1+0,05)^3} + \ \dots + \frac{246,45}{(1+0,05)^{20}}}{2973,36} = 0,79$$

Next Step is to calculate a profitability index of solar thermal system in comparison with electrical boiler by the equation (13).

$$PI = \frac{\frac{155,96}{(1+0,05)^1} + \frac{160,60}{(1+0,05)^2} + \frac{165,46}{(1+0,05)^3} + \ \dots + \frac{273,48}{(1+0,05)^{20}}}{2973,36} = 0,83$$

The performed financial analysis showed that heat from solar thermal system for domestic hot water in Ukrainian scenario is not competitive in comparison with the heat produced by conventional sources. Moreover, Economic Life of solar thermal systems in both alternatives is around 20 years. The NPV calculation results showed a negative value for both cases: solar thermal system in comparison with central water system and solar thermal system in comparison with electric boiler. As the achieved NPV for both cases is negative and calculated PI were lower than 1, it can be concluded that this solution is not profitable in economic perspective. Furthermore, the achieved value of IRR for both cases: solar thermal system in comparison with natural gas and solar thermal system in comparison with electric boiler are lower than inflation rate in Ukraine. General rule for acceptance of the investment in the projects is when IRR value is higher than a discount rate. Despite, worth to mention that alternative energy projects are not appropriate to evaluate just from financial perspective by using just the economic values, as ecological criteria as well as social issues are not taken into account.

It appears that the main reason of profitless of solar thermal systems is generally artificially low price of energy in Ukraine, as the government restricts the increase of the price on the energy power. If the current price for coal on the international market will be set in Ukraine, the energy price for consumer will also rise. Moreover, long economic life time of solar thermal systems also make this project less profitable, as the life span of such system is assumed to be 20 years and after this period of time the extra costs such as total or partial replacement of solar thermal system components will be needed.

Summing up, the cost analysis for Ukrainian scenario showed that solar thermal systems in this reference case do not emerge in an acceptable payback period, under the default economic conditions. However, with different rates of inflation and with some financial incentives from the government such as mandates, subsidies for alternative energy projects or governmental grants, the initial costs could be recovered in a shorter period of time.

In order to analyse the economic viability of solar thermal systems in Portuguese scenario the Economic Life is going to be calculated. In Portugal, the most common appliances that provide a supply of hot water for domestic uses are electric boilers and propane/ butane in the bottles. The most common way of heating up the water for domestic uses is through electric boiler. In Porto, as for April 2020 the tariff of energy is 0,15 €/kWh, the required heat energy to suppress the DHW needs is of about 1783 kWh.year-1, so the annual cost of energy required to warm up the water in a case of using the electric boiler is 267,50 €. The economic life acceptable for the implementation of solar thermal system as alternative decision in this case is 12 years. For a reference case in Portugal, the NPV for the solar thermal system installation in comparison with electricity going to be calculated by the equation (12). In accordance with the historical average oil price changes in Portugal since 2001, the index for energy prices is establish to be 4 % as the price of energy is a type of cost that deviates significantly from general inflation, the inflation rate in Portugal for 2020 is 0,4 %.

$$NPV = -3088{,}76 + \frac{267{,}50}{(1+0{,}004)^1} + \frac{278{,}20}{(1+0{,}004)^2} + \frac{289{,}34}{(1+0{,}004)^3} + \ldots + \frac{411{,}80}{(1+0{,}004)^{12}} = 820{,}78 \text{ €}$$

Propane / butane gas in a bottle is also a common way for domestic hot water in Portugal, but the price of gas may vary from supplier to supplier and that is making it hard to evaluate the cost of this alternative. Natural gas is not a really widespread solution for domestic water heating in this reference case, is more often used in the commercial applications.

For Portuguese scenario IRR is going to be calculated just for the solar thermal systems in comparison with electric boiler by the equation (13).

$$0 = \frac{267{,}50}{(1+IRR)^1} + \frac{278{,}20}{(1+IRR)^2} + \frac{289{,}34}{(1+IRR)^3} + \ldots + \frac{411{,}80}{(1+IRR)^{12}};$$

By using the excel calculator the value of IRR for this case were achieved equal to 4 %.

Profitability Index (PI) is going to be calculated for the Portuguese scenario by the equation (14).

$$PI = \frac{\frac{267,50}{(1+0,004)^1} + \frac{278,20}{(1+0,004)^2} + \frac{289,34}{(1+0,004)^3} + \ \dots + \frac{411,80}{(1+0,004)^{12}}}{3088,76} = 1,26$$

Results of the financial analysis showed that solar thermal system for domestic hot water in Portugal is more profitable in comparison with Ukrainian case. The achieved value of NPV is equal to 820,76 €, and the PI is bigger than 1 and equal to 1,26, the Economic Life is 12 years, so with a positive mean of NPV the payback period of his project will be less than 12 years. The value of IRR is equal to 4 %, while the inflation rate in Portugal is 0,4 %. Worth to mention, projects with a lower inflation rate have a higher present value. The calculations revealed solar thermal system in Portuguese scenario to be more economically effective than solar thermal system in Ukrainian scenario. It can be concluded that solar thermal system in Portuguese reference case is fully profitable (26 %).

3.4. Sensitivity analysis

Sensitivity analysis is a common practice when the results depend on assumptions where future development can have a significant impact on the result. At least one sensitivity analysis for energy prices and two scenarios for discount rates should be performed in order to get the vision of dependency.

For the sensitivity analysis of the discount rate for the macroeconomic calculation, one of the rates will be 4% expressed in real terms. A discount rate generally between 2% and 4%, excluding inflation will be the one that best reflects the benefits that investments bring.

According to the Department of Energy of the United States of America webpage (2020) with the annual publication of the index and discount rate, a discount rate of 3% must be used. The European Commission publishes semi-annual updates on these trends. A more recent update implies a 2,8% annual increase in gas and 2,5% for electricity. These increases are in real terms, not considering inflation.

It should be noted that an effect of the financial calculation principle is that for lower discount rates the overall costs are higher. Since future costs are discounted at a lower rate leading to a higher current value than global costs.

Economic analysis is particularly sensitive to the chosen economic scenario. The chosen scenario can make either an investment profitable or the other way around. The results of sensitivity analysis for discount rate are presented in the Table 7. The price variation over time is linked to the discount rate. Being an unpredictable variable, it is important to assess its influence in the analysis. It was considered a variable update rate and a constant energy variation rate.

Table 7. Results of sensitivity analyses for discount rate

Index of energy price	2,8 %	2,8 %	2,8 %	2,8 %	2,8 %	2,8 %
Discount rate	5 %	4 %	3 %	2 %	1 %	0,5 %
Portugal (Porto)						
NPV (€)	-360,43	-190,76	-5,32	197,67	420,26	539,61
PI	0,88	0,94	0,99	1,06	1,14	1,17
Ukraine (Lutsk)						
NPV (€)	-525,86	-281,21	-0,23	323,62	698,23	907,47
PI	0,82	0,91	0,99	1,11	1,23	1,31

Source: Author´s own elaboration

In both countries the similar situation is visible, solar thermal systems are becoming more economically viable and profitable with lower discount rates. For both cases the highest discount rate with which the projects are becoming profitable is close to 3 %. It can be assumed that profitability has a linear trend with the increase and decrease in the discount rate. The base case is more sensitive to the variation in the discount rate, with energy costs as the main cost in this analysis.

The price variation over time is also linked to the energy price rate. A variable energy price rate was considered, with a constant discount rate in both countries (3 %). Results of sensitivity analysis for energy price index are presented in the Table 8.

Table 8. Results of sensitivity analyses for energy price

Index of energy price	4 %	2,8 %	2 %	1 %	0,5 %
Discount rate	3 %	3 %	3 %	3 %	3 %
Portugal (Porto)					
NPV (€)	199,67	-5,32	-133,40	-284,46	-356,40
PI	1,06	0,99	0,96	0,91	0,88
Ukraine (Lutsk)					
NPV (€)	351,27	-0,23	-208,70	-443,61	-551,33
PI	1,11	0,99	0,92	0,85	0,81

Source: Author´s own elaboration

With the increase in the energy price and the constant discount rate, the viability of the solution increases. The increase is greater in the base case with energy as the main cost. Solar thermal systems are becoming more economically viable and profitable with the higher energy price index.

Conclusions, Limitations and Future Research Lines

Generally speaking, it has to be noted that, while discovering the subject alternative energy projects such as solar thermal systems it is vital to make a complex analysis, which will include not just financial indicators but ecological benefits of implementation of such projects as well as economical gain like reduced reliance on limited fossil fuels. Moreover, renewable energy projects cannot compete with conventional energy projects just in terms of economics alone. Multi- criteria approach should be used instead of just economics as a single criterion. In other words, a particular attention should be paid to the advantages possible to achieve in a long term such as eliminating the pollution that accompanies fossil fuel energy.

Solar thermal systems for domestic hot water particularly make sense for countries that rely on gas or oil imports to cover their needs or for countries with growing economies where the common solution is the use of electric boilers for water heating. Portugal and Ukraine is a good example of such countries as Portugal is strongly dependent on foreign countries in what concerns fossil fuels and in Ukraine the solar thermal system exploitation just gain the momentum. Worth to mention, the drivers of solar energy development in Ukraine and Portugal are similar, but the current situation is considerably different.

In respect with the results, it was indicated that in Portugal the solar thermal systems for domestic hot water are more economically viable than in Ukraine. The performed financial analysis showed than in Portugal the solar thermal systems for domestic hot water is fully profitable and has shorter payback period. Despite the price of such systems is generally higher in Portugal but lower level of inflation rate and higher index of energy prices provides better condition for solar thermal system market. The analysis of economical indicators showed that heat from solar thermal system for domestic hot water in Ukraine is still not competitive in comparison with the heat produced by conventional sources. Moreover, it can be assumed that economic viability of solar thermal systems in both countries has a linear trend with the increase and decrease in the discount rate and energy prices.

Solar thermal systems are generally more expensive than a conventional hot water heating system. However, they can save money in the long term, depending on the following aspects: the consumption of hot water, system performance, geographic location, financial availability and incentives and the cost of conventional fuels.

Both countries have experienced a period of strong development in solar energy for the last years but in Ukraine the photovoltaic technologies are more widespread application as government fosters the development by implementing the high rate of "green" tariff as well as lowering prices for photovoltaic equipment. In Portugal, the expansion of solar thermal technologies happens due to the influence of European Union policies, the national plans for energy efficiency, specific legislation to encourage the renewable projects and specific programs supporting solar thermal technologies. Among other important reasons, the installation of solar thermal systems for domestic hot water in new buildings is currently mandatory in Portugal.

The obvious conclusion is that not just availability of solar radiation important in solar technologies development but the policies adopted by each country are essential. Different legislation system, government determination, availability of special programs or grants, subsidies, tax credits for investment in alternative energy projects and even cultural and educational differences are just some of features that can regulate the success of the solar energy development in each country and determine the economic viability of solar technologies.

Regarding the studied topic of the solar thermal systems, current research greatly contributes to the scientific literature. Furthermore, based on the scarcity of the works dedicated to the analysis of economic viability of solar thermal systems, especially the ones that are based on the development of costing methodology to evaluate the viability (Ferreira & Silva, 2019) a current research is considered to be valuable scientific work. Consequently, created economical model is a helpful and universal instrument as a high correlation between the cost results and the market data was obtained. Current work is considered being valuable as it contributes to the expansion of knowledge in the area of viability of solar thermal systems in Ukraine and Portugal.

Undoubtedly, current work has a set of limitations, which alternatively makes it possible to highlight the future research lines. The first limitation is connected with the complexity of the analysis process, the system should be well defined, the proper sizing, configuration and dimensioning of solar thermal system components need to be observed, predictable and unpredictable characteristics have to be analyzed. Secondly, a different kind of system may be examined; alterations to the solar thermal system components could be done, for instance analysing the solar thermal system with evacuated tube solar collectors or combi-system. An alternative option is to focus on another application of solar thermal system such as home space heating and cooling, integration of solar thermal systems on district heating network or swimming pools heating. Moreover, a possibility is to find out the most profitable solution of a solar thermal system for DHW consumption values of various magnitudes and to estimate the best facility size, exclusively based on a domestic hot water demand. Thirdly, similar analyses could be done on other building types than residential houses; for instance, include measurements for hotels or hospitals. Lastly, another limitation for this research was a lack of scientific works with a same background, in order to make a comparison. With the purpose of obtaining more homogenous results, more extensive data set could be applied. This shapes another future research opportunity.

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References

Abbasi, T., Premalatha, M., & Abbasi, S. (2011). The return to renewable: Will it help in global warming control? *Renewable and Sustainable Energy Reviews*, 891–894.

Arbeitsgruppe Erneuerbare Energien-Statistik. (2020). AGEEstat. Retrieved from https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Arbeitsgruppe/arbeitsgruppe_ee.html

Ahmadi, M.H., Ghazvini, M., & Sadeghzadeh, M. (2018). Solar power technology for electricity generation: A critical review. *Energy Science and Engineering*, 1-22.

Alaa, A.F., Zuha, W.H., & Suhaidi, S. (2018). A review of transparent solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews*.

Apergis, N., & Danuletiu, D.C. (2014). Renewable Energy and Economic Growth: Evidence from the Sign of Panel Long-Run Causality. *International Journal of Energy Economics and Policy*, 578-587.

Apisolar. (2016). Observatório solar térmico 2015. Associação Portuguesa da Indústria Solar. Retrieved from (www.apisolar.pt).

Armstrong, J., & Hamrin, J. (2000). The Renewable Energy Policy Manual. Washington: *United States Export Council for Renewable Energy*.

ASIT. (2019). National Solar Energy Association. Building regulations stabilise Spanish market. Retrieved from https://www.solarthermalworld.org/taxonomy/term/30061

Blaschke, T., Biberacher, M., Gadocha, S., & Schardinger, I. (2013). Energy landscapes: meeting energy demands and human aspirations. *Biomass - Bioenergy*, 3–16.

Bomberg, E., & McEwen, N. (2012). Mobilizing community energy. N.France: *Energy Policy*.

Boyle, G. (1998). Renewable energy: Power for a sustainable future. Oxford: *Oxford University Press.*

Burt, E., Peter, O., & Susan, B. (2013). Scientific evidence of health effects from coal use in energy generation. Chicago, IL: University of Illinois at Chicago School of Public Health and Health Care without Harm.

Cai, S. (2018). Research status and development prospect of solar energy utilization technology. *Industry Observation*, 50-52.

Department of Energy of the United States of Americ. (2020). Webpage. Retrieved from https://www.energy.gov/

Dgeg. (2016). Direção geral de energia e geologia, Areas setoriais*. Energias renováveis/energia solar*. Retrieved from (www.dgeg.pt).

Dogan, E., & Seker, F. (2016). Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. *Elsevier*: Renewable Energy.

Eggert, C., Hecl, V., Jenkins, D., Marín, C., Mayer, D., Schweizer, P., & Zervos, A. (2005). Energy sustainable communities, experiences, success factors and opportunities in the EU-25, EREC, European Renewable Energy Council.

Elum, Z.A., & Momodu, A.S. (2017). Climate change mitigation and renewable energy for sustainable development in Nigeria: A discourse approach. *Renewable and Sustainable Energy Reviews*, 72–80.

Eliseeva, O.K., & Khazan P.V. (2016). Економіко-статистичний аналіз сонячної енергетики в регіонах України. (Economical and statistical analysis of solar power in Ukrainian regions). Dnipro:Statistic of Ukraine.

ESTIF. (2019). Solar Thermal Energy Technology. Retrieved from http://www.estif.org/st_energy/technology/introduction/
http://www.estif.org/st_energy/technology/solar_domestic_hot_water_heating_sdhw
http://www.estif.org/st_energy/technology/combisystems/

Eurostat. (2004) Energy yearly statistic. Retrieved from https://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-CN-06-001

European Solar Thermal Industry Federation. (2017). Solar Heat Markets in Europe: Trends and Market Statistics 2016. Brussels. Retrieved from http://solarheateurope.eu/wp-content/uploads/2017/11/Solar_Heat_Markets_2017

European commission. (2019). National renewable energy action plan NREAP Portugal 2020. Retrieved from https://ec.europa.eu/energy/en/topics/renewable-energy/national-renewable-energy-action-plans-2020

Evarts, J. C., & Swan, L. G. (2013). Domestic hot water consumption estimates for solar thermal system sizing. *Energy and Buildings*, 58–65. http://doi.org/10.1016/j.enbuild.2012.11.020

Faiers, A., & Neame, C. (2006). Consumer attitudes towards domestic solar power systems. *Energy Policy*, *34*(14), 1797-1806. doi: 10.1016/j.enpol.2005.01.001

Faninger, G. (2010). The Potential of Solar Heat in the Future Energy System. Faculty for Interdisciplinary Research and Continuing Education.

Ferreira, A., & Silva, A. (2019). Development of a costing methodology for solar thermal systems: application to Portuguese scenario. Proceedings of the 4th International Conference on Energy& Environment: bringing together Engineering and Economics, 64-70.

Ferreira, A., Silva, A., Teixeira, S. (2019). A multi-objective optimization of solar thermal system applied to residential building in Portugal. Proceedings of the 19th International Conference: Computational Science and Its Applications, 26-35.

Figueiredo, M. V. (2015). O solar térmico é mais competitivo no coletivo. *Edifícios e Energia*, 58-59.

García, J. L., Porras-Prieto, C. J., Benavente, R. M., Gómez- Villarino, M. T., & Mazarrón, F. R. (2019). Profitability of a solar water heating system with evacuated tube collector in the meat industry. *Renewable Energy*, 966–976.

Gil, L., Basilio, L., Cabrita, I., Torres, G., & Costa, M. R. (2017). Situação do solar térmico em Portugal. *Renováveis Magazine - Revista Técnico-Profissional de Energias Renováveis*, 48–52.

Greenstream Publishing. (2019). Solar Electricity Handbook. Retrieved January 1, 2019, from http://www.solarelectricityhandbook.com/solar-irradiance.html

Guédez, R., Topel, M., Spellingb, J., & Laumerta, B. (2015). Enhancing the profitability of solar tower power plants through thermoeconomic analysis based on multi-objective optimization. *Energy Procedia*, 1277 – 1286.

Herbut, P., Rzepczyński, M., & Angrecka, S. (2018). The Analysis of Efficiency And Investment Profitability of a Solar Water Heating System in a Multi-Family Building. *Journal of Ecological Engineering*, 75-80.

Hugo, A., & Zmeureanu, R. (2012). Residential solar-based seasonal thermal storage systems in cold climates: Building envelope and thermal storage. *Energies*, 3972–3985.

IEA-ETSAP and IRENA. (2015).Solar Heating and Cooling for Residential Applications Technology Brief. Retrieved from https://www.irena.org/documentdownloads/publications/irena_etsap_tech_brief_r12_solar_thermal_residential_2015.pdf

IEA-SHC. (2014). Solar Heat Worldwide: Market and Contribution to the Energy Supply 2012. Retrieved from www.iea-shc.org/data/sites/1/publications/Solar-HeatWorldwide-2014.pdf

IRENA, IEA and the Renewable Energy Policy Network for the 21st Century (REN 21). (2017). IEA/IRENA Renewables Policies Database. Retrieved 6 April, 2020, https://www.iea.org/policies/5101-renewable-energy-policy-network-for-the-21st-century-ren21

International Renewable Energy Agency (IRENA). (2020). Retrieved 6 April 2020, from https://www.irena.org/

Jacobssoon, S., & Johnson, A. (2000). The diffusion of renewable energy technology: An analytical framework and key issues for research. *Energy Policy*, 625-640.

Kabir, E., Kumar, P., Kumar, S., Adelodun, A., & Kim, K. (2018). Solar energy: Potential and future prospects. *Renewable Sustainable Energy Review*, 894-900.

Kalogirou, S. A. (2014). Solar Energy Engineering Processes and Systems: Second edition. *Elsevier*, 12-13.

Kaygusuz, K. (2001). Renewable Energy: Power for a Sustainable Future. *Energy Exploration & Exploitation*. Retrieved from https://doi.org/10.1260/0144598011492723

Kharecha, P., & Hansen, J. (2013). Coal and Gas are Far More Harmful than Nuclear Power. National Aeronautics and Space Administration (NASA). Retrieved from (http://www.giss. nasa.gov/research/briefs/kharecha_02/⟩ [Accessed February 2020].

Kishore V.V.N. (2010). Renewable Energy Engineering and Technology: principles and practice. *The Energy and Resources Institute*.

Krozer, Y. (2012). Renewable energy in European regions. Int. J. Innovation and Regional Development.

Kumar, L., Hasanuzzaman, M., & Rahim, A. (2019) Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. *Energy conversion and Management*.

Kveselis, V. Lisauskas, A., & Dzenajavičienė, F.E. (2014). Investigating possibilities to integrate solar heat into district heating systems of Lithuanian towns. Vilnius: *Environmental engineering.*

Lakatos, L., Hevessy, G., & Kovács, J. (2011). Advantages and Disadvantages of Solar Energy and Wind-Power Utilization. *World Futures*, 395-408. https://doi.org/10.1080/02604020903021776

Lebeña, E. P., & Costa, J. C. (2008). Instaladores de Equipamentos Solares Térmicos. In INETI/DGEG (Ed.), *Conversão Térmica da Energia Solar* (pp. 1–89). Lisboa: INETI/DGEG.

Letcher, T.M. (2016). Storing Energy: With Special Reference to Renewable Energy Source*. Technology & Engineering*.

Li, X., & He,B. (2017). Development Prospect of Solar Photothermal Power Station. *Energy and Environment*, 75-77.

Ma, D., Pan, Y., & Yang, S. (2019). Solar Power Generation Technology and Its Development Prospect. Fushun: School of Petroleum and Natural Gas Engineering. https://doi.org/10.1063/1.5116455

Machol, R. (2013). Economic value of U.S. fossil fuel electricity health impacts. *Environ Int*., 75–80.

Malyarenko, V.A., Tymchenko, S.P. (2018). Стан, проблеми та перспективи розвитку сонячної енергетики України. (State, problems and prospects of solar energetic development in Ukraine. Kharkiv: National academy.

Milani, D. (2012). Modelling framework of solar assisted dehumidification system to generate freshwater from "Thin air" . Thesis for: PhD.

Mo, Y., Yang,L.,& Huang, L. (2018). Review of various solar power generation technologies. *Dongfang Electric Comment*, 78-82.

Müller,S., Brown,A., & Ölz, S. (2011). Renewable energy: Policy considerations for deploying renewable. Retrieved from https://www.iea.org/publications/freepublications/publication/Renew_Policies.pdf.

National Commission for the State Regulation of Energy. (2019). *Національна комісія*, що здійснює *державне регулювання* у сфері *енергетики.* Retrieved from http://www.nerc.gov.ua/

Nielsen, J.E., & Sørensen, P.A. (2016). Renewable district heating and cooling technologies with and without seasonal storage. *Renewable Heating and Cooling*.

Organization of economic co-operation and development (OECD). (2020). https://www.oecd.org/about/

Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*. https://doi.org/10.1080/23311916.2016.1167990

Perales Benito, T. (2009). *Instalación de paneles solares térmicos*. Sevilla: Creaciones Copyright.

Perers, B., Furbo, S., Andersen, E., & Dragsted, J. (2017). Cost Performance for Small Smart Solar Thermal Systems outside district heating Networks. *DTU Civil Engineering*.

Piebalgs, A. (2007). Renewable make the difference. *European Commission*.

Popp, D., Hascic, I. & Medhi, N. (2011) Technology and diffusion of renewable energy. *Energy Economics*, Vol. 33, 648–662.

Psomopoulos, C.S. (2013). Solar energy: Harvest the Sun's energy for sustainable future. *Handbook of Sustainable Engineering*, 1065-1107.

Radivojevi, A.R., Pavlovi ,T.M., Milosavljević, D.D., & Djordjević, A.V. (2015). Influence of climate and air pollution on solar energy development in Serbia. *Science.*

Rahaman, M. H. and Iqbal, M., T. (2019). A Comparison of Solar Photovoltaic and Solar Thermal Collector for Residential Water Heating and Space Heating System. *European Journal of Engineering Research and Science.*

Reddy, S., Kaushik S.C., & Ranjan K.R. (2013). State of the art of solar thermal power plants. *Renewable Sustainable Energy Review*, 258-273.

Renewable Capacity Statistics. (2019) IRENA. Retrieved from https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019

Rescoop. (2020). Best practices report. *Intelligent Energy Europe*. Retrieved from http://rescoop.eu/renewable-energy-sourcescooperatives-20-20-20

Rodrigues, L. M., Calado, V. M. L., Machado, T.M, & e Lopes, J. C. (2015). Manual de Instalação de Sistemas Solares Térmicos. Publindústria.

Rooijen, S., & Wees M.T. (2006). Green electricity policies in the Netherlands: an analysis of policy decisions. *Energy Policy*, 60-71.

Sampaio, P.G.V., & González, M.O.A. (2017). Photovoltaic solar energy: Conceptual framework. *Renewable Sustainable Energy Review*, 590–601.

Sarbu, I., & Sebarchievici, C. (2017). Solar heating and cooling systems. Fundamentals, Experiments and Applications, 29-97.

Simske, S. (2019). Sensitivity analysis and big system engineering. Meta-Analytics.

Solar District Heating Guidelines 2020 | Collection of Fact Sheets. Deliverable of Solar District Heating project under "Intelligent Energy for Europe programme". Retrieved from http://www.solar-district-heating.eu/.

EurObserv'ER. (2020a). Solar thermal and concentrated solar power barometer 2015. Retrieved from https://www.eurobserv-er.org/solar-thermal-and-concentrated-solar-power-barometer-2015/

EurObserv'ER. (2020b). Solar thermal and concentrated solar power barometer 2016. Retrieved from https://www.eurobserv-er.org/solar-thermal-and-concentrated-solar-power-barometer-2016/

EurObserv'ER. (2020c). Solar thermal and concentrated solar power barometer 2017. Retrieved from https://www.eurobserv-er.org/solar-thermal-and-concentrated-solar-power-barometer-2017/

EurObserv'ER. (2020d). Solar thermal and concentrated solar power barometer 2018. Retrieved from https://www.eurobserv-er.org/solar-thermal-and-concentrated-solar-power-barometer-2018/

EurObserv'ER. (2020e). Solar thermal and concentrated solar power barometer 2019. Retrieved from https://www.eurobserv-er.org/solar-thermal-and-concentrated-solar-power-barometer-2019/

Sorensen, B. (1979). Renewable energy. *Energy Science and Engineering*.

SPIUG. (2019). Association of Manufacturers and Importers of Heating Appliances. Market for heating appliances in Poland. Retrieved from https://www.solarthermalworld.org/taxonomy/term/26511

Solargis (2020). Retrieved 9 April 2020, from https://solargis.info/

Streicher, W. (2016). Solar thermal technologies for domestic hot water preparation and space heating. *Renewable Heating and Cooling.*

Tabellini, G. (2005). Culture and institutions: Economic development in the regions of Europe. *GESIFO Working Paper*, No.1492.

Tarigan, E. (2018). Simulation and economic analysis of solar cooling for building in tropical climate of Surabaya, Indonesia. *EDP Sciences*.

Technology Roadmap - Solar Heating and Cooling. (2020). Retrieved 6 April 2020, from https://webstore.iea.org/technology-roadmap-solar-heating-and-cooling

The Economic Adjustment Programme for Portugal. 2011-2014 - European Commission. (2020). Retrieved 6 April 2020, from http://ec.europa.eu/economy_finance/publications/occasional_paper/2014/op202_en.htm

The OECD. (2019). Inventory of Support Measures for Fossil Fuels identifies. Organization of economic cooperation and development. Retrieved from https://www.oecd.org/fossil-fuels/data/OECD-Fossil-Fuels-Support-database-brochure-2019.pdf

The Solar Foundation. (2018). National Solar Jobs Censor. https://www.thesolarfoundation.org/national/

Tiwari, G. N., & Mishra R. K. (2011). Advanced Renewable Energy Sources. *Royal Society of Chemistry.*

Twidel, J., & Weir, A. D. (1986). Renewable Energy Resources. London: *ELBS Edition.*

UNFCC. (2020). COP21, Paris Climate Change Conference, 2015.

York, R., & McGee, J. A. (2015). Understanding the Jevons paradox. Environmental Sociology. DOI:10.1080/23251042.2015.1106060

Valančiu, R., Jurelionis, A., Jonynas, R., Katinas, V., & Perednis E. (2015). Analysis of Medium-Scale Solar Thermal Systems and their potential in Lithuania. *Energies*, 5725-

5737. doi:10.3390/en8065725

Verbruggen, A., Fischedick, M., Moomaw, W., Weir, T., Nadaï, A., Nilsson, L. J., Sathaye, J. (2010). Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy*.

IEA. (2020). World Energy Outlook 2019 Analysis. Retrieved 6 April 2020, from https://www.iea.org/reports/world-energy-outlook-2019