MSc Program
Renewable Energy in Central and Eastern Europe

Energy audit and option analysis for renewable energy potential at a Hungarian sawmill

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Budapest, October 2010

Affidavit

I, Dibáczi Julianna Zita, hereby declare

1. that I am the sole author of the present Master Thesis, "Energy audit and option analysis for renewable energy potential at a Hungarian sawmill", 73 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The major starting point of any renewable energy-based project is an accurate theoretical assessment of available renewable energy sources and analysis of an economically optimal location. The northeastern part of Hungary is an economically disadvantaged region with a high unemployment rate; for these reasons, it is important to find ways to reduce the region's energy dependence. The Nyírség microregion within this zone was chosen as the focus of this master thesis in order to augment general knowledge and investigate one specific site's ability to generate feasible future investments.

This master thesis evaluates the renewable energy potential and examines energy use at a typical industrial site within the Nyírség region. The research identifies and evaluates the renewable options for this site and suggests an implementation plan for reducing conventional energy consumption.

At this given site, solar energy utilization presented the most viable option, so a solar energy-based investment is assessed which could work in parallel with the plant's existing heating system. The final step was to provide an economic assessment to determine the financial viability of moving towards renewables.

The master thesis concludes that a financial break-even point for the proposed system is already in the range of the end of life span of such installations, where it is questionable whether they are fully paid off at all. With a 50% investment subsidy, the break-even point was calculated to be within 17 years of implementation. This means that currently, funding is not only important for accelerating the implementation speed, but highly necessary for any implementation at all.

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1 Introduction

In Hungary up to the 1990's, the price of energy was fairly cheap, almost nothing for either individuals or industrial customers. Unconventionally, the wasteful patterns of energy use were and unfortunately still are felt in some cases. Energy prices have risen significantly since the fall of Socialism and the customer patterns have been changing. Nowadays, the price of the energy and rational energy management are key factors, and renewable energy sources appears to be gathering momentum.

Within the last decade, different professional associations and technology based clusters have been founded that are connected to all kinds of renewable energy sources, in order to increase the general understanding, knowledge and application of renewables. Despite this fact, within the final energy consumption the renewable energy sources still have a very small share, only 4,8 % [Energy Centre, 2010]. Of course, Hungary's renewable energy policy defines obligations set by the Renewable Energy Strategy directive to be fulfilled by 2020:

- 13% share of RES in the final energy consumption
- At least 10% share of renewable energy in the final energy consumption of transport

The National Renewable Energy Action Plans (NREAPs), which are to be provided to the European Commission by June 2010, are national roadmaps of each country's expected path to its binding renewable energy target for 2020. The Hungarian Government extended this deadline to the end of September 2010. Therefore, the final scenarios are still under negotiation, which will be very important to define the country's expected renewable energy contribution, both in terms of capacity to be installed (MW) and of energy production (MWh), for each of the renewable energy technologies. It will also include information about support schemes to promote renewable energy in the country.

The eastern part of Hungary compared to the western part is an economically disadvantaged region, with a high unemployment rate. One of the main challenges of the North-Great Plain Regional Energy Agency (which was established in 2009) is to try to reduce the energy dependence of the region and raise awareness about the available renewable assets in the region. In keeping with that goal, this Master Thesis aims to examine the renewable energy potential for the Nyírség region.

Forest management is an important issue in the Nyírség region, and local wood processing is one of the major industries. Most of the wood products are heat treated, and for example the energy used to dry timber is approximately 60 to 70 % of the total energy used to manufacture timber. Therefore, within this Master Thesis one of the pallet producer sites in the Nyírség has been examined. The selected sawmill's energy needs are currently based upon fossil fuels, waste wood and wood. The available renewable energy sources have been examined for the Nyírség region, and an assessment made regarding which one is worth using to decrease the conventional energy needs of the wood dryer. Therefore, one of the main tasks has been a thorough and complete understanding of the existing system, alongside clarification of the physical parameters at Fehér-Nyír Ltd.

1.1 What is the core objective / the core question?

The core aims of this thesis are:

- to evaluate the renewable energy potential at the study area (Nyírség) and to examine a typical sawmill's energy pattern within this region
- to give an overview of the available renewable energy technologies for the company and suggest an implementation plan for the future to reduce its conventional energy consumption
- to provide an economic assessment for determining whether the investment is worth making or not, under the existing conditions

1.2 Structure of work

This work consists of 5 chapters which summarize all of my research. Figures and tables are incorporated into the text, while the background calculation sheets (MS Excel) can be found in the appendix at the end of the thesis.

Chapter Two commences with an analysis of the research completed to date on environmental characteristics and presents information about the renewable energy potential at the study area (Nyírség). The renewable energy source potential analysis covers all sources except hydro, because of the geographical features.

The third chapter focuses on the selected sawmill's existing energy system and the trends in its energy consumption. This chapter looks at the viable options – based on compatibility with the existing system – for utilization of renewable energy sources to decrease conventional energy consumption.

The fourth chapter discusses the viability of such an investment through a detailed economic analysis. Feasibility is a general requirement for any investment and should be checked carefully.

The fifth chapter presents the recommendations and conclusions of the research and calculations.

1.3 Citation of main literature

In the second chapter, the solar and wind energy potential analyses are based on the Hungarian Meteorological Service and NASA database. The NASA database has free access and seems a fully comprehensive guide and it was quite interesting to compare the different statistics for the study area.

In accordance with EU Regulations, the option and economic analyses were carried out based on the Guide to Cost Benefit Analysis of Investment Projects, published by the European Commission.

The references listed at the end of the work include all sources cited, as well as books, documents, reports and other materials used to develop the general framework and focus for this research.

2 Description and renewable energy potential analysis of the region

Hungary is located in the Carpathian Basin between latitudes 45°45’ and 48°35’ North and longitudes 16°05’to 22°58’ East. Total la nd area is 93 033 km^2. Hungary is a landlocked country, with the nearest sea (the Adriatic) some 200 km from the border. The country is strategically located along main land routes between Western Europe and the Balkan Peninsula as well as between Ukraine and Mediterranean basin. The country neighbours with Austria, Croatia, Romania, Serbia, Slovakia, Slovenia and Ukraine. The terrain is characterised by limited relief (minor differences in elevation), the highest point being 1014 m above sea level, the lowest at 75.5 m. The majority of the land is lowland, with 84% of the total area lying below 200 m above sea level. The two major rivers, the Danube and Tisza, divide the country into three large regions.

Table 1: Country indicators [Hujber, Richter et al. 2009.]

Size of country	Total land area: 9 303 300 ha Utilised agricultural area: 63% Utilised forest area: 21% Nature protection area: 9%
Population indicators	Inhabitants: 10.06 million Inhabitants per km^2: 108 inhabitants/km^2
Economic indicators	Gross Domestic Product in 2007: 67 422 million € Gross Domestic Product per capita: 6702 €
Energy indicators	Gross inland consumption: 1125 PJ Total production of primary energy: 427 PJ Primary production of renewable energy: 59.4 PJ Final energy consumption: 706 PJ RES shares of final energy consumption: 4,8 % Share of RES within electricity consumption : 3.9 % Net energy imports: 62 % CO_2 emissions per capita: 5.36 tonnes

The study area of the Thesis is located on the Great Hungarian Plain, the biggest flatland of the Carpathian basin. The Great Plain covers nearly 100 thousand km^2 of territory and is divided into two main regions: the Southern Great Plain and the Northern Great Plain. The area focused on in this thesis is located on the Northern Great Plain, and within it is the Nyírség microregion.

The Nyírség region is relatively poor in natural resources. However, tree plantations, arable land and clay are important assets. Forest management is an important issue in this region. Data from the National Forestry Database, which was prepared by the State Forestry Service in January 2003, indicates that ca. 240.000 m^3 thick firewood (which is equal to 167 095 t with the assumption of 30% moisture content) and ca. 200.000 m^3 thin firewood (139 313 t) are available in the region. Typical deciduous species in this region are: acacia (*Robinia pseudoacacia L.*) and poplar (*Quercus robur L.*); the typical evergreen is the pine (*Pinus strobus L.*)

2.1 Geographical features

The examined sawmill is located in the vicinity of the cities of Debrecen and Nyíregyháza, and in the neighbourhood of a settlement called Nyírbogát.
The sawmill's EOV* coordinates are the following:

X_{EOV}: 277 476

Y_{EOV}: 875 867

*EOV [Uniform National Projection system]: The EOV is a plane projection system used uniformly for the Hungarian civilian base maps and in general, for spatial informatics.

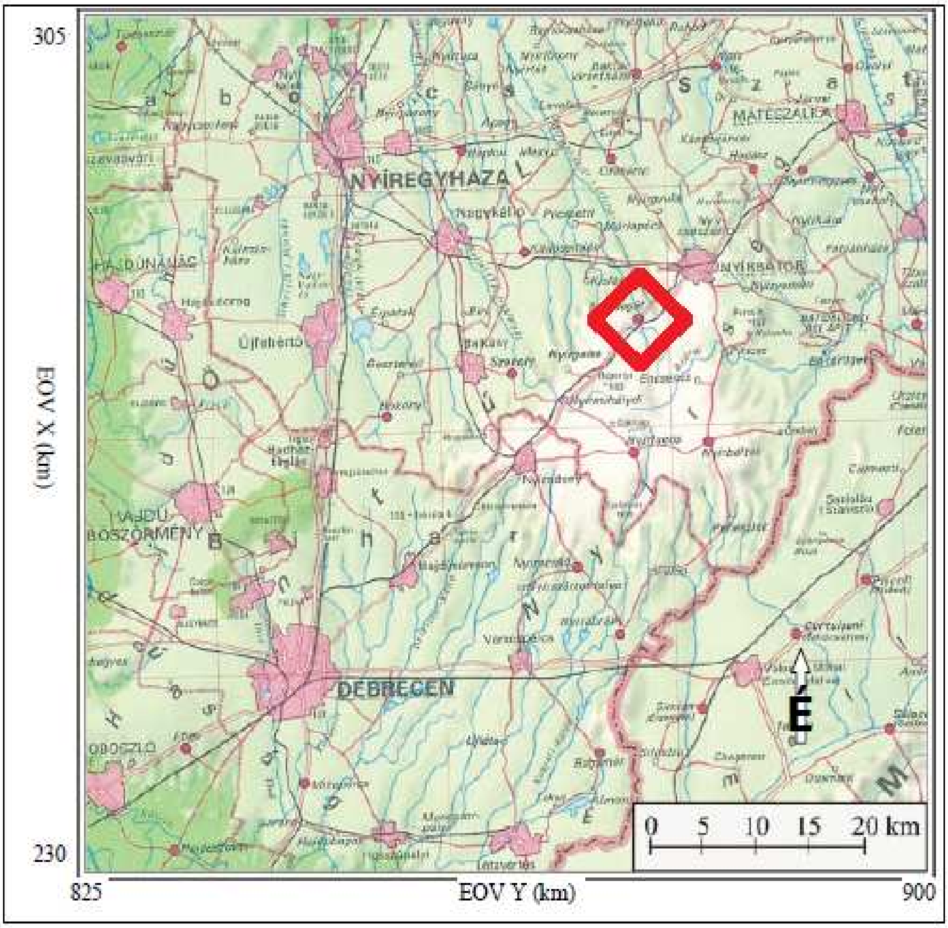

Figure 1: Topographical features of the examined Nyírség region [Eötvös Loránd University, 2010]

The elevation of the Nyírség area ranges from 100 m up to 183 m. The highest point of the Great Hungarian Plain, called Hoportyó, is located in the neighbourhood of Nyírbogát. The Nyírség region belongs to the Tisza River catchment area, but it is not rich in surface water. This is why this thesis does not include an assessment of the hydro energy potential in the region.

The climate of Hungary is continental, with a high average temperature of approximately 21°C in July; the absolute monthly maximum can be from 35°C to 42°C.The absolute monthly minimum temperature is of course in winter, and can be approximately -15°C, which is why this is the design temperature for heating systems, even though this may occur for only a couple of hours or days in a year. The annual average temperature is approximately 9 °C.

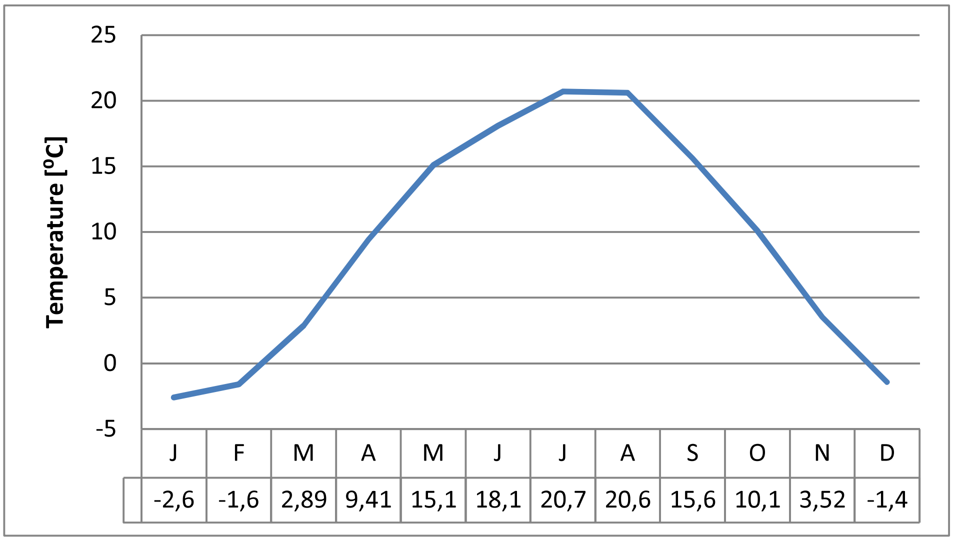

Figure 2: Air temperature at 10 m [Hungarian Meteorological Service]

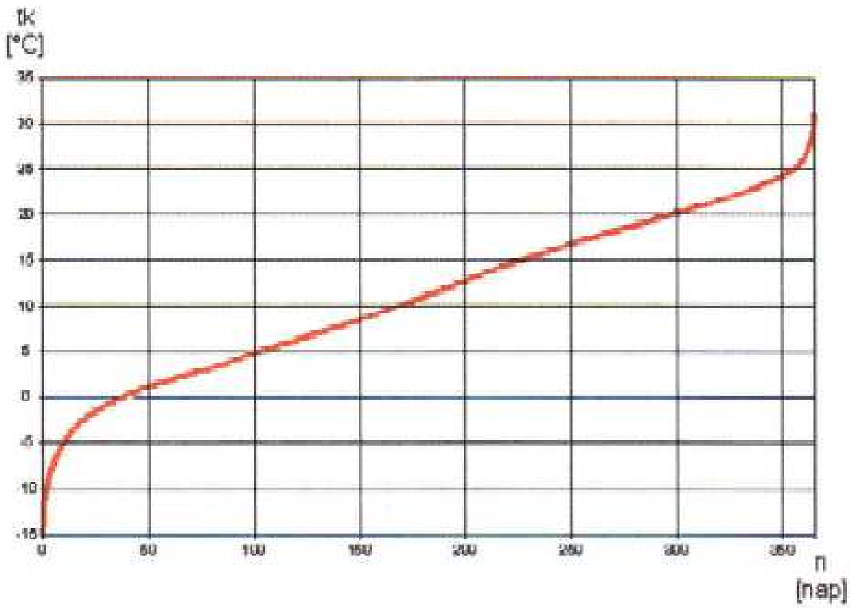

Figure 3: Annual temperature frequency [Völgyes, 1989.]

In Hungary, the regular heating season is approximately 4400 hours (~183 days), and the temperature is between -15 ºC and 0 ºC for up to 1056 hours (~44 days)

2.2 General Energy Profile of Hungary

Although total energy consumption decreased by 7% between 1990 and 2004 in Hungary, the 20% increase in gas consumption means that the share of imported fossil resources exceeds 60%. Together with nuclear fuel imports, primary energy dependency is over 70%. The overall trends of energy consumption, its volume and the increasing import dependency are clearly demonstrated by the total unaccumulated sources in figure 4. Average growth was 0.6% per year since 2000, the share of imports increased to 62% from 54%. The trend of growing imports is foreseen to continue as Hungary's proven energy reserves are small. Hungary has various energy sources, the most important ones being coal and lignite. Proven reserves of hard coal are estimated at some 5,000 PJ; reserves of lignite and subbituminous coals total 45,000-50,000 PJ. Sulphur and ash content is high in Hungarian coal therefore utilization and production is decreasing. Hungary has also proven oil reserves of between 120-770 PJ. The estimates for the country's natural gas reserves range between 300 and 2200 PJ. [Energy Information Administration]

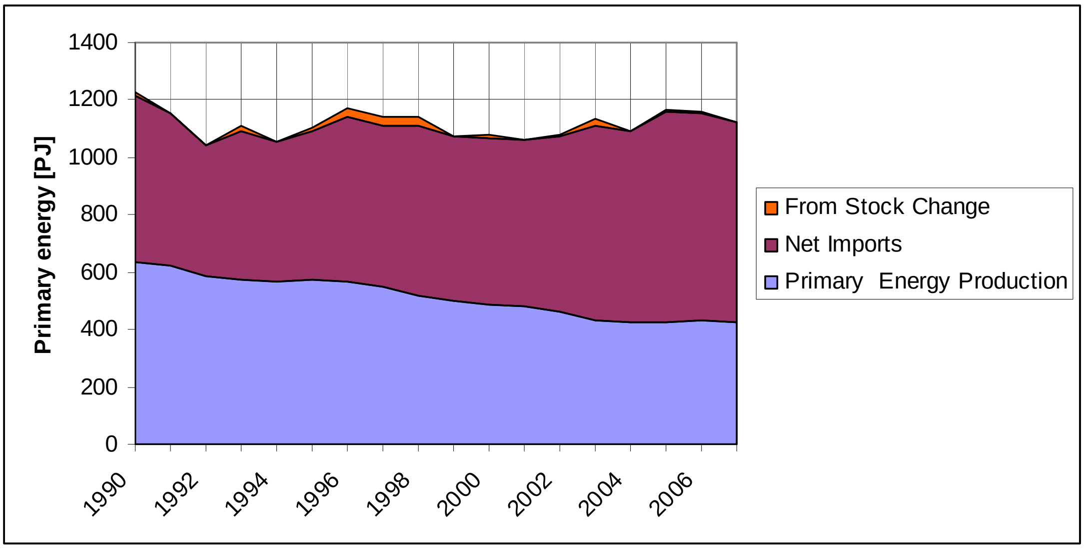

Figure 4: Changes in the total primary energy supply [Hujber et. al, 2009]

In accordance with Directive 2001/77/EC[1] Hungary undertook to increase the share of its electricity production from renewable energy sources to 3,6% by 2010 (at the time of the undertaking its share was less than 1%). Among the member states,

[1] The Appendix to Act XXIX/2004. (on amendments and repeals of legal regulations and other legislative changes related to Hungary's accession to the European Union) contains the target for Hungary.

Hungary targeted the lowest figure and was the first member state to fulfil it at 4,4% in 2005. The target figure was achieved by converting some power plant blocks from coal into biomass-fired or mixed-fired using renewable energy sources. In Hungary, the trends in the composition of energy use are even less favourable than the average of the European Union.

The share of total renewable energy sources has grown considerably in recent years in Hungarian energy supply. While in 2000 they accounted for 3,3% in primary energy use, in 2005 they represented 4,3% and in 2009 they had a share of 7,6%. A period of stagnation in the middle of the nineties was followed by more intense growth, chiefly resulting from a boost in electricity production from biomass, promoted by a favourable subsidy scheme. Hungarian experts, however, have severe doubts whether a similar growth path can be sustained in the future.

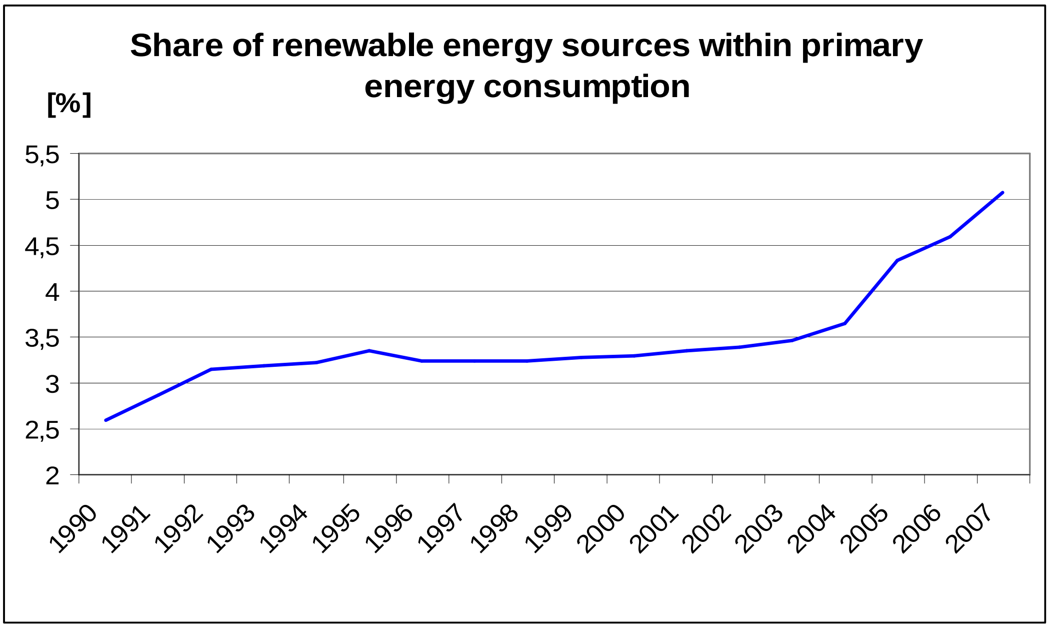

Figure 5: Share of renewable energy sources [Hujber et al., 2009]

In Hungary the most important renewable energy source is biomass, accounting for nearly 90% of all renewable energies in 2006. Biomass is followed by geothermal energy, renewable waste and hydro power but these sources significantly fall behind biomass use.

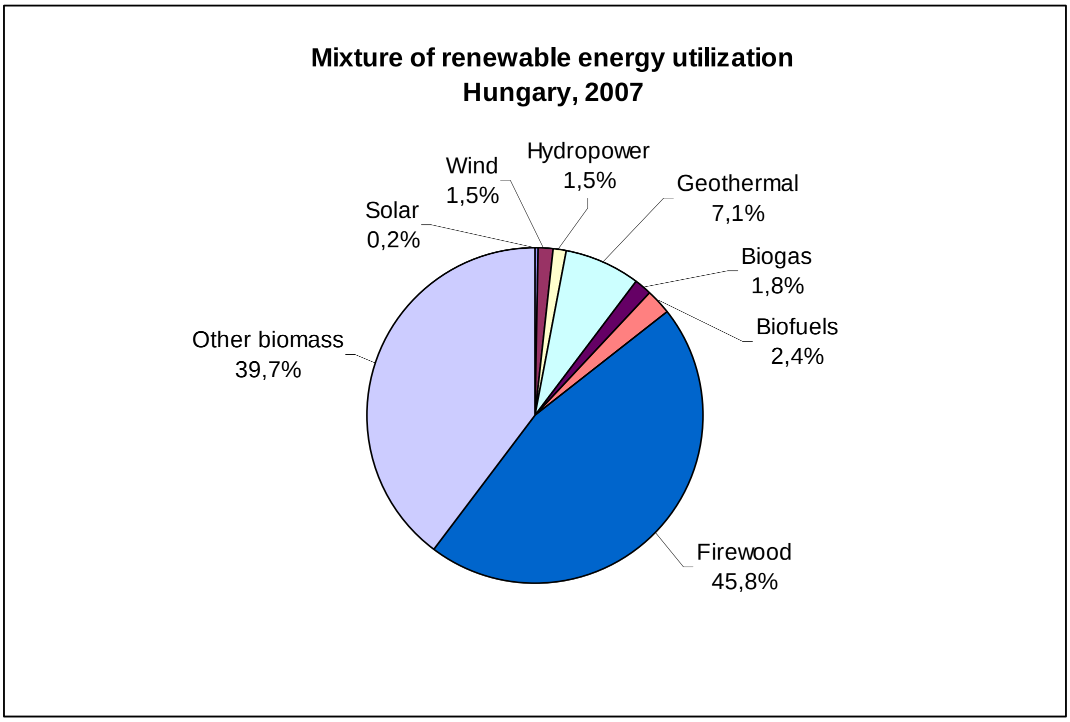

Figure 6: Mixture of renewable energy utilization excludes communal waste [Hujber et al, 2009]

Hungary mostly uses firewood for heat and electricity production from biomass. It is burnt directly or occasionally co-combusted to generate heat or electricity to a smaller extent. In 2006 the majority of renewable energy sources was utilized for the production of heat, especially for heating households. This fact is unfairly little mentioned owing to the lack of a separate support system even though electricity produced from renewable energy sources was the driving force behind the growing use of renewables. The share of renewables used in heat production (64%) continued to be higher even in 2007 than the share of green power generation (34%) in the total use of renewable energy sources (calculated at a heat equivalent). Hungary set a target for a blending level of 4,7% for biofuels for 2010. This target is expected to be met without difficulties as in the neighbouring countries the number of biofuel factories has greatly increased. It is desirable, however, that expensive imports should be replaced by factories based in Hungary producing the required volume of biofuel. The necessary agricultural crops are available but the number and the capacity of biofuel plants should be substantially boosted. There were plans and initiatives to facilitate such a boost but the majority of these projects were cancelled and most of the biofuel factories were ultimately built in the neighbouring countries. [Energy Centre, 2010]

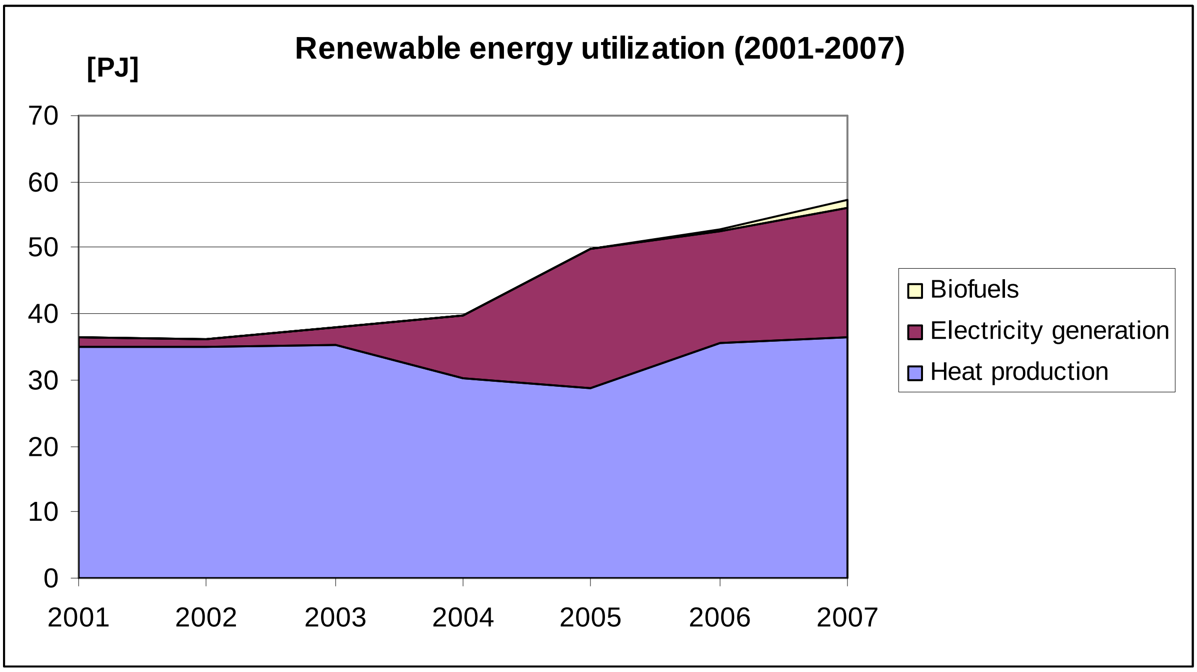

Figure 7: Renewable energy utilization [Hujber et al, 2009]

It needs mentioning that Hungarian energy statistics have no exact data about the residential sector's consumption of energy sources (e.g. firewood, other biomass) other than network energies. A statistical survey conducted in 2009 found that the residential sector's use of biomass for heating (mainly firewood and other wood waste) considerably exceeds the estimates, implying that the share of renewable energy sources used in Hungary is probably higher than the statistical figure and the dominance of renewable-based heat is somewhat more pronounced.

2.2.1 Renewable-based Electricity Generation

As a result of the subsidy scheme the use of renewable energy use sources (particularly biomass) for electricity generation has grown robustly in Hungary since 2003. In 2005 power generated from renewable energy sources accounted for 4,4% of the total electricity produced. In 2006, there was a major decline with the share of renewables falling to 3,6% but since then a continuously growing tendency has been confirmed. By 2007 the share of renewables climbed back to 3,9%. Hungary therefore managed to meet its target of 3,6% before the deadline in 2010 in accordance with Directive 2001/77/EC. This target, however, is quite low compared to the undertakings of other EU member states (when this target was set renewable energy sources represented less than 1% of electricity production).

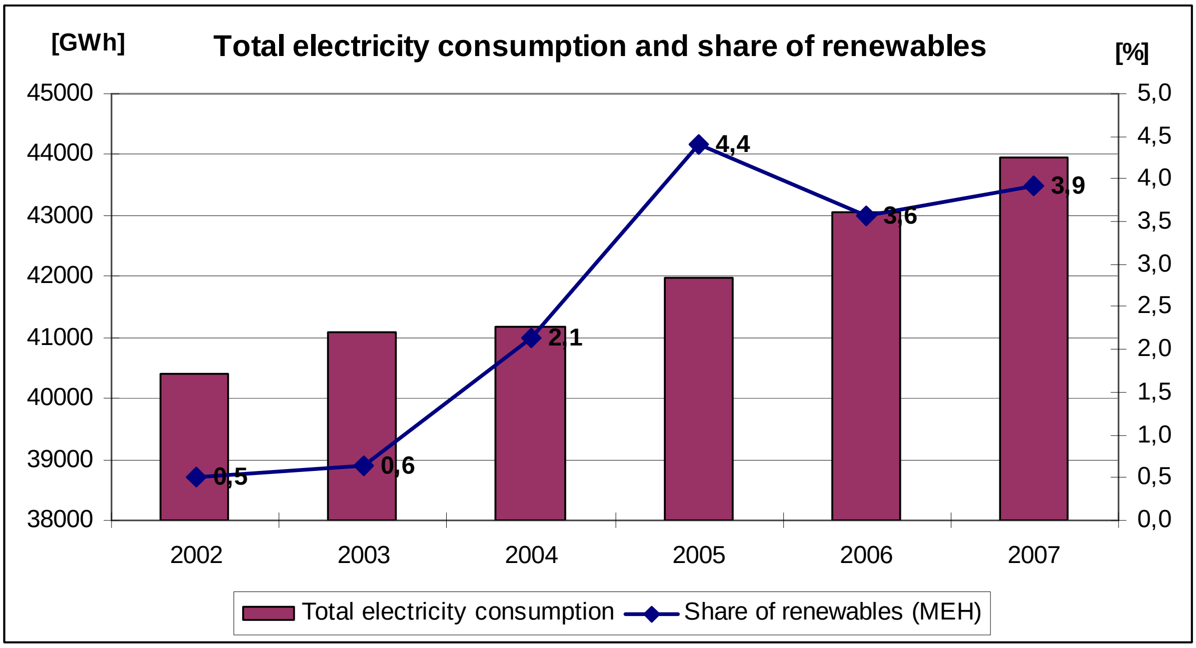

Figure 8: Total electricity consumption and share of renewable sources [Energy Centre, 2010]

Electricity production from renewable energy sources was given a boost after 2003 by the conversion of existing power plant capacities into biomass-fired (Pécs Power Plant – 49 MW, Kazincbarcika Power Plant – 30 MW, Ajka Power Plant – 20 MW) and a switch in coal-fired power stations to the co-burning of coal with firewood and other agricultural crops (but with no conversion - Tiszapalkonya and Mátra Power Plants). These two technologies constitute the cheapest and easiest implemented methods of renewable energy use. With a few exceptions, however, these technologies have a very low efficiency: the average efficiency of electricity production in converted power plants is below 30%. The aforementioned high-capacity plants generally fail to utilize heat created as a by-product of power generation, although in numerous cases there is a district heating system in the near vicinity requiring large amounts of heat. The explanation lies in the existing support system which only subsidizes electricity production from renewable energy sources, with the result that power plants are not interested in utilizing heat that is the by-product of power generation. In addition, concerns of sustainability and environment protection have also arisen relating to these solutions. High-capacity power plants have a relatively high demand for raw materials, requiring them to obtain the necessary amounts of biomass from more distant areas than their immediate neighbourhood. Biomass is transported from large distances by rail or road, considerably impacting the energy balance and sustainability of the activity in a negative way. The high raw material demand of power plants takes up the majority of sustainably-logged timber capacities in Hungarian forests. A large number of the contracts concluded between power plants and forest companies will become ineffective between 2010 and 2015. The regulatory and support environment should be changed before this period in a way that favours the creation of decentralized systems. In addition, to remedy the above discussed problems of sustainability, the sustainability criteria established by Directive 28/2009/EC will likely be included in the Hungarian regulations in the coming years .

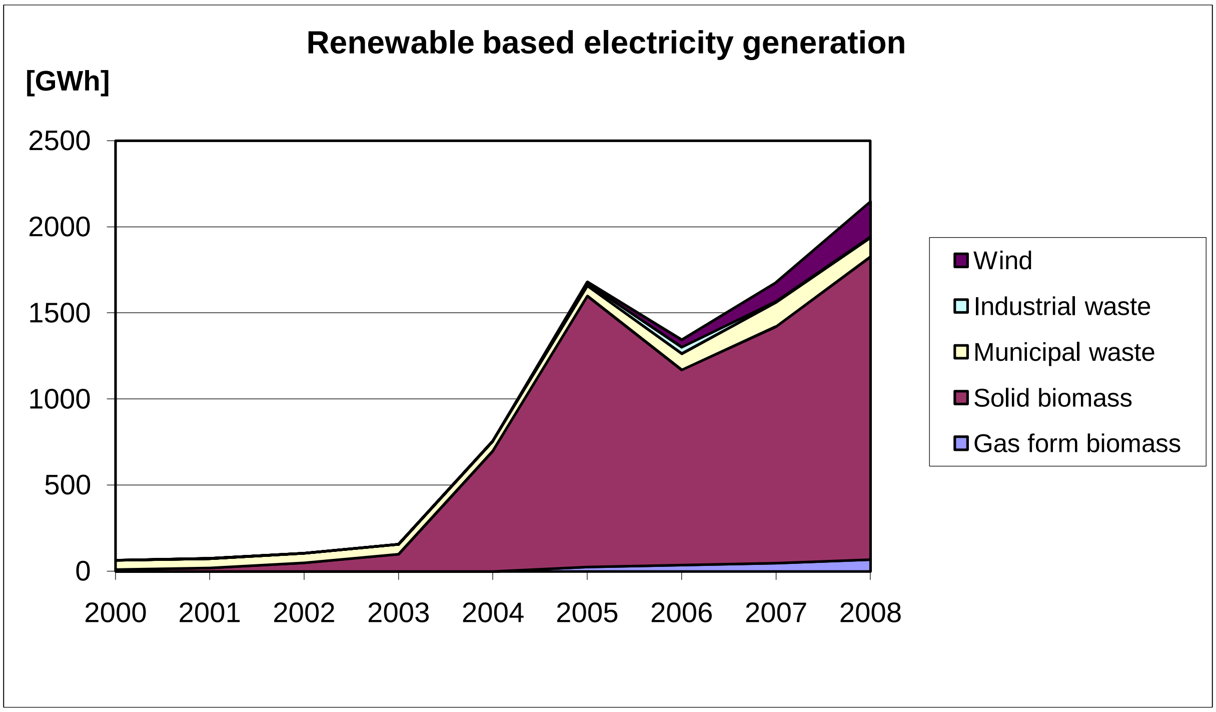

Figure 9: Share of renewable energy within primary energy consumption [Energy Centre, 2010]

In Hungary only electricity produced through the utilization of renewable energy sources is subsidized. Heat consumption, however, has a potential to justify the adequate subsidization of the heat market and a support system for renewable-based heat production and cooling should be developed.

In the majority of Hungarian district heating systems modern cogeneration technologies are used. Renewable-based heat production (unless cogeneration is replaced) would be relatively under-utilized in certain cases, further lowering the rate of return for the expensive investment.

In the existing support structure centralized district heating does not have a high enough potential to ensure the utilization of renewables, therefore they should be given a major role in decentralized heat production, the other important segment of the heat market. Residential gas tariffs subsidized by the state, however, present a massive obstacle to the wider use of technologies based on renewable energy sources.

Most of the residential customers are unaware of renewable energy based technologies and their benefits and in many cases such technologies are met with scepticism. Therefore every ongoing renewable energy project is important to change this tendency, and could give a real sense of decentralization in the energy sector.

2.3 Solar energy potential

Hungary lies in the middle of the Carpathian basin, on a relatively flat surface surrounded mainly by mountains, and has favourable solar conditions. The number of the annual sunny hours is between 1 900-2 200, and the average annual total of the incident sunshine is 1250 kWh/m^2.

Hungary has 1838 PJ theoretical potential and 4-10 PJ actual potential. The current use is about 0,1 PJ which means around 70 000m^2 surface area. The most common collector used in Hungary is the flat-plate collector; however, demand for flat-plate, vacuum, and unglazed collectors has been rapidly increasing. [Source: Hungarian Academy of Sciences]

300-500 kWp is estimated for PV capacity. The largest system is over 100 kWp, but the most common capacity is 10 kWp. About three-quarters of the applications are independent and used for electricity generation at highway, emergency phones, meteorological stations, safety equipments, public lighting, farm houses, electric fence, etc. Despite not having many applications using solar power itself, Hungary has manufacturing plants, such as Solar Thin Films Inc., which is a United States-based company with a machinery manufacturing subsidiary, Kraft Electronikai Ltd., based in Budapest, Hungary.

Although the domestic natural endowments are very favourable, solar energy utilization is still very low compared to the total energy consumption.

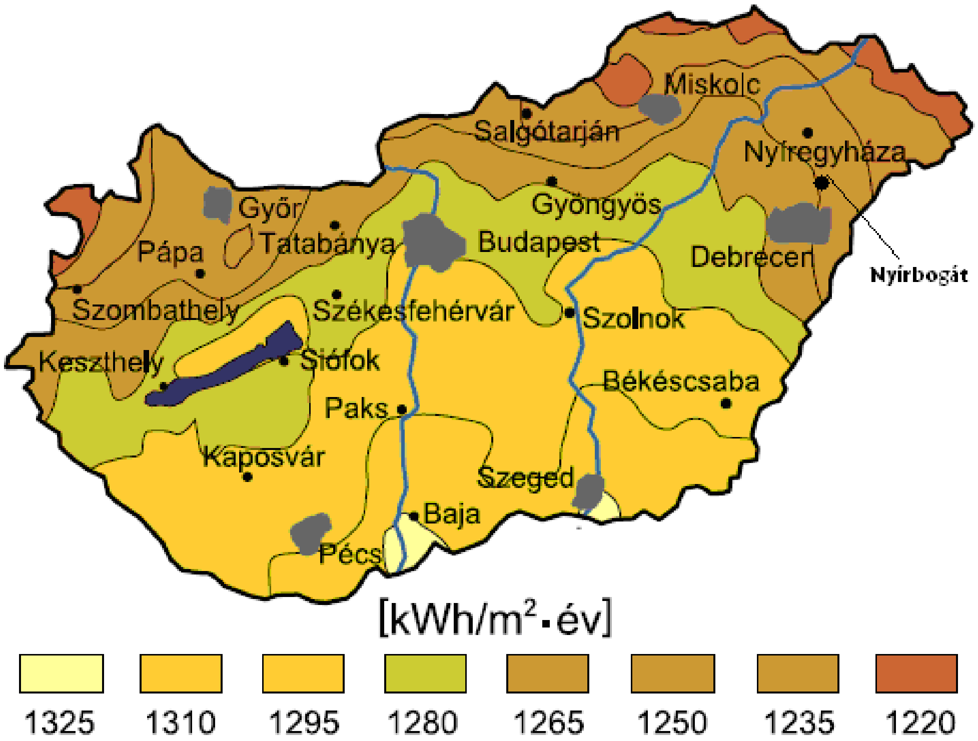

Figure 10: Solar radiation of Hungary on the horizontal surface [kWh/m^2year] [Naplopó Ltd., 2010.]

At different geographical locations, meteorological stations measure the daily solar radiation values on the horizontal surface and these are averaged over several months, as can be seen in Figure 10. The examined Nyírség area is located close to Debrecen.

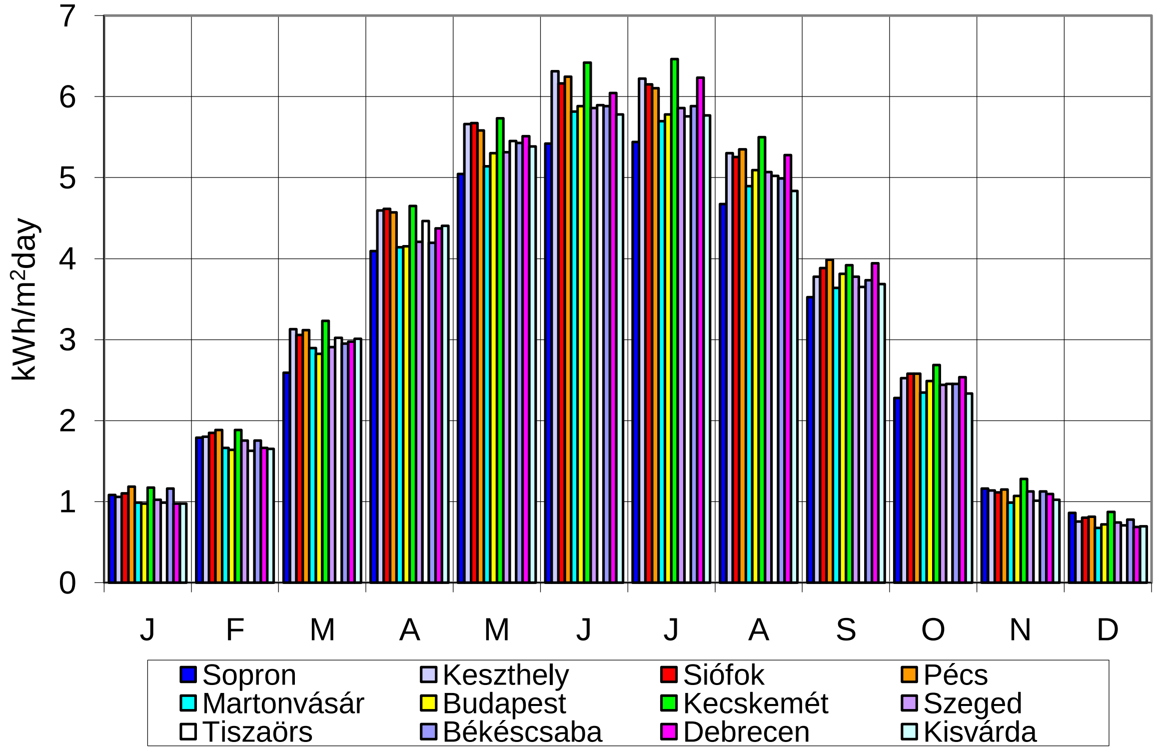

Figure 11: Solar global radiation [Pálfy, 2004]

The optimum angle provides the maximum radiation; in the area examined, the monthly average radiation for different tilted surfaces are listed in Table 2. For the monthly mean value, net radiation to the tilted surfaces varies from about 1,6 to 5 kWh/m^{-2} daily.

Table 2: Solar radiation at the Nyírség [NASA database]

	Direct Sunlight [hours / month]	Direct Sunlight [hours / day]	Optimal angle [°]	Solar Radiation at 45° [kWh/m^2/day]	Solar Radiation at 32° [kWh/m^2/day]
J	278	8,98	62	1,95	1,8
F	288	10,3	55	2,98	2,83
M	369	11,9	42	3,84	3,81
A	405	13,5	27	4,33	4,51
M	465	15,0	14	4,79	5,17
J	474	15,8	8	4,81	5,30
J	477	15,4	11	4,97	5,41
A	440	14,2	23	5,01	5,29
S	378	12,6	37	4,00	4,04
O	338	10,9	51	3,04	2,92
N	283	9,43	60	2,05	1,91
D	267	8,60	64	1,61	1,48
Annual average			37,7	3,62	3,71

Note: Radiation on tilted surfaces is not calculated when the clearness index (K) is below 0,3 or above 0,8. (*Clearness Index [1]:* ratio of clear & cloudy days)

2.4 Wind energy potential

According to research conducted by the Hungarian Academy of Sciences, the Hungarian theoretical wind energy potential is 36 000 PJ/year, which translates into conversion of available potential energy which is assumed to be 532 PJ/year. Due to the current regulations of Hungary and the sensitive areas, only 7,7-7,8 percent of the country's territory is available for wind energy utilization. [Source: Szalai et al., 2005]

In Hungary the first wind turbine was built in 2000 and the installed capacity reached about 177 MW in 2009, and 295 MW in 2010. Hungary has 32 wind farms installed, ranging from 250 kW to 50 MW in capacity.

The current 330 MW cap on wind energy connection to the grid is placed by the Transmission System Operator (MAVIR) and should be significantly increased by 2020 and might be able to reach 920 MW. Companies who are willing to connect to the electricity grid must undergo a tendering process, calls for bids to establish wind power capacities. The Hungarian Energy Office gave permission for 330 MW in 2006, which probably will be reached in the next year, because the current installed capacity is almost 300 MW. In 2009 a new call was open for an additional 410 MW, which was cancelled at the evaluation phase in 2010. Therefore, Hungarian wind energy sector is in a tenuous situation because of the strict licensing requirement, changing legislative framework, and inflexible grid.

Hungary is located in the Carpathian basin, and the most significant wind potential is located in the north-western region of the country. According to the local legislation of the examined Nyírség area, there is no restriction on wind power investment. As can be seen in the diagram, the prevailing wind is North, North-East in the Nyírség.

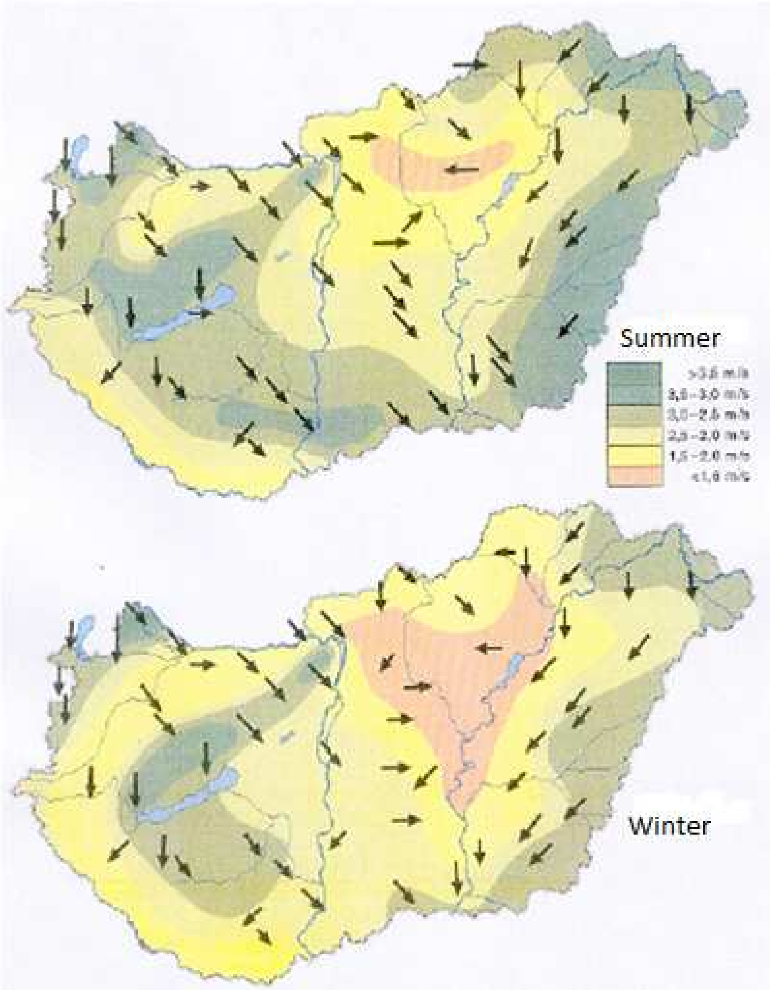

Figure 12: Prevailing wind in Hungary [Hungarian Meteorological Service, 2010]

The annual average wind speed is around 5,5-6 m/s at 100 meter height, according to the Hungarian Meteorological Service database.

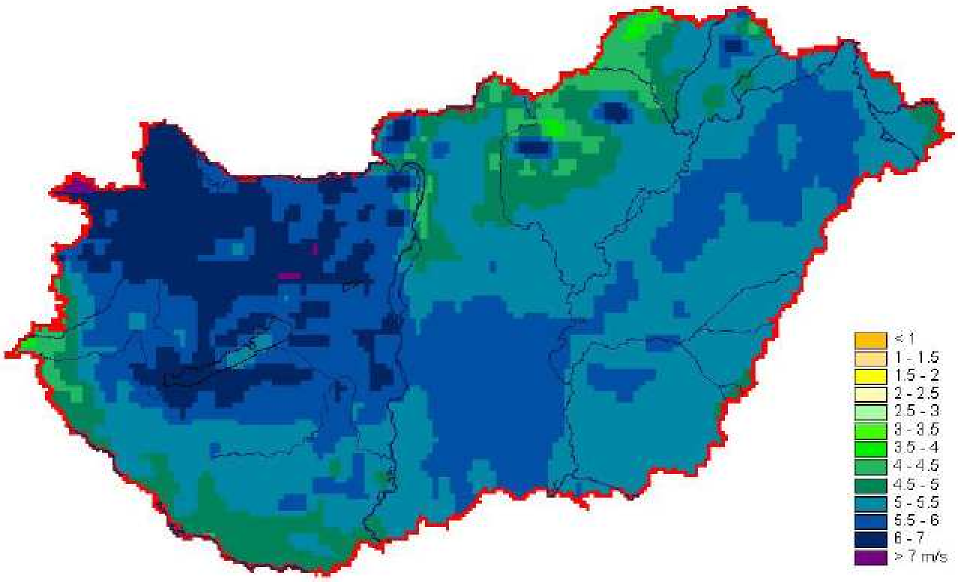

Figure 13: Annual average wind speed at 100 m [Hungarian Metrological service, 2010]

The energy content of the wind varies with the cube (the third power) of the average wind speed. The figure 14 shows the average wind speed in the region at 50 m through the year, and it can be stated that it differs from 3 to 11 m/s. The highest wind speed is in winter at approximately 10,8m/s.

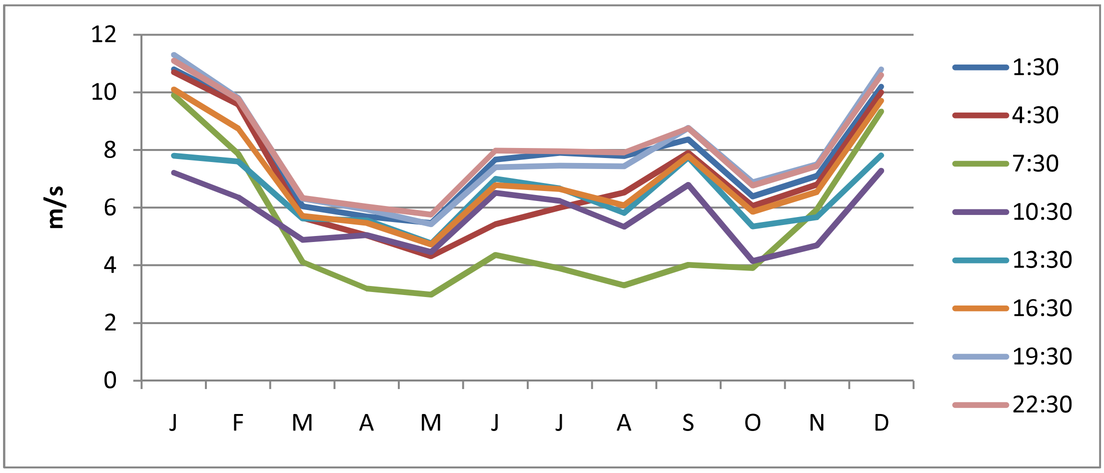

Figure 14: Monthly average wind speed [NASA database, 2010]

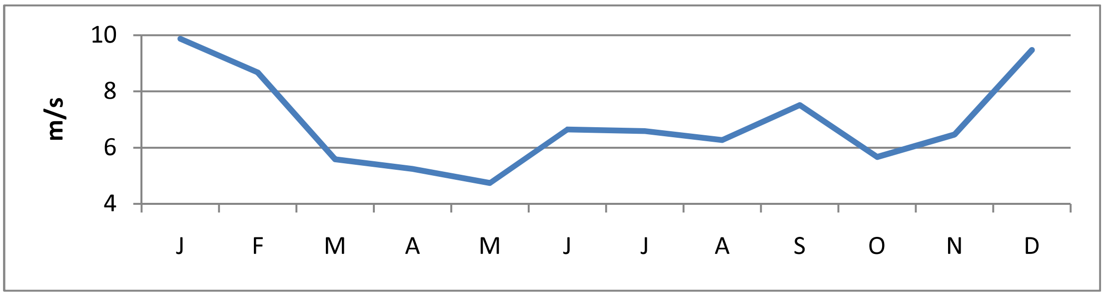

Figure 15: Annual average wind speed [NASA database, 2010]

The annual average wind speed is around 6 m/s; based on these data, it can be stated that the examined area is IV/A class. In Hungary the wind condition is not as good as on some other parts of the continent, but tests have determined some sites where wind energy can be used.

The International Electrotechnical Commission (IEC) creates and publishes standards for wind turbines among other electrical and electronics equipments. The IEC 61400 deals with wind turbine generators (WTG). Turbine classes are determined by three parameters: the average wind speed, extreme 50-year gust, and turbulence.

Table 3: WTGS class [Hansen, 2008]

WTGS class	I	II	III	IV
V_{ref} (m/s) extreme 50-year gust	50	42,5	37,5	35
V_{ave} (m/s) average wind speed at hub height	10	8,5	7,5	6,0
Turbulenc class: A	0.16			
Turbulenc class: B	0.14			
Turbulenc class: C	0.12			

A wind resource assessment based on onsite wind measurements can provide not only the annual average wind speed, but also provide turbulence and extreme wind conditions. This experimental data is necessary to select the class of a wind turbine.

The power of the wind is also dependent on air density [kg/m^3], the prevailing wind direction in the region, the frequency of wind direction, height level, regularity of the wind speed at daily and annual level, conditions of the region's topography, et al.

The power of the wind passing perpendicularly through a circular area is:

$$P=0,5 * \rho * v^3 * \pi * r^2$$

Where P = the power of the wind measured in W [Watt].
Ρ= (rho) = the density of dry air = 1.225 measured in kg/m^3 (at average atmospheric pressure at sea level at 15°C).
v = the velocity of the wind measured in m/s (metres per second). π= (pi) = 3.1415926535...
r = the radius of the rotor measured in meters.

The wind is distributed close to the Weibull distribution curve. For practical purposes one can calculate the probability for the wind being in the interval $v_i<v<_{vi+1}$

$$p(v_i < v < v_{i+1}) = \exp\left(-\left[\left(\frac{v_i}{A}\right)^k\right]\right) - \exp\left(-\left[\left(\frac{v_{i+1}}{A}\right)^k\right]\right) \; [-]$$

where A and k are found for a given site on the basis of measurements.

If the power for the turbine at a given wind speed is P(u), the annual production can be calculated as

$$E_{ann} = \sum \{8766\text{h} \cdot p(v_i < v < v_{i+1})\, P(v_m)\} \qquad [J]$$

Example

Typical values of the examined Nyírség area:

A could be A=6m/s and k=2. This will give the following distribution at the Nyírség region:

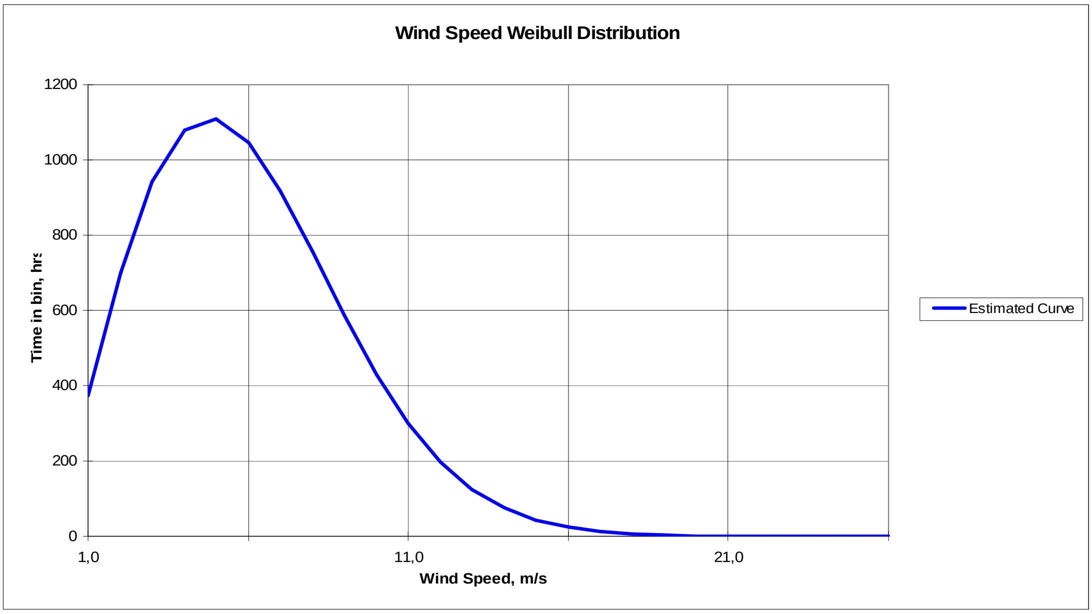

Figure 16: Production curve

Production curve: Let us imagine a power curve for a given stall controlled wind turbine given by

$$P(v) = \min\left(k_P\, v^3, P_N\right) \qquad [W]$$

with kp=0,1 kW/(m/s)^3 and P_N=200 kW

The nominal power 200 kW would be reached at a wind speed of 6m/s, this would result in a power curve as given the Figure 16.

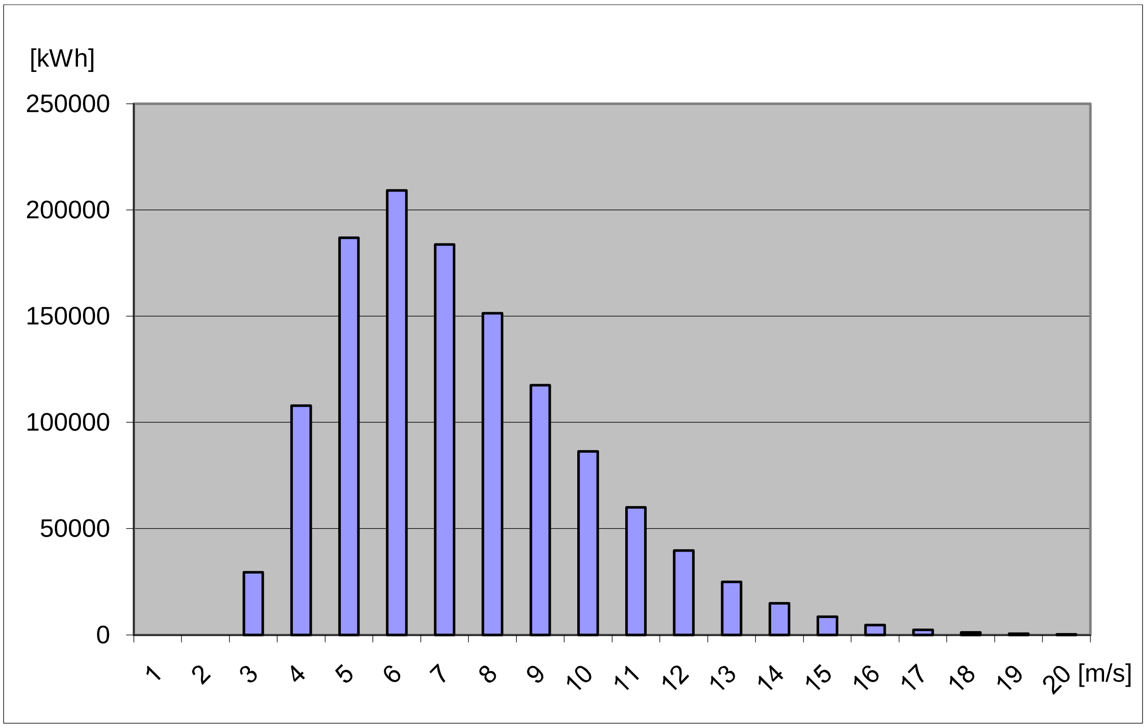

Figure 17: Estimated annual energy production

What would be an optimal maximum power? From figure 17 we can see that wind speeds above 12 m/s are very rare. On the contrary, the power production of a wind turbine rises with a power of 3. Figure 17 shows a calculation of the annual production as a function of the maximum power, P_{max}. The capacity factor is defined as CF-E_{ann}/(P_N8766h)

Conclusion: To answer this question we must know the price of the turbine, including tower and foundations, but more than about 200-300 kW does not seems reasonable.

The selected wind data was obtained from the NASA database and the Hungarian Meteorological Service, by giving the geographic location. The values indicate opportunity for wind energy investments in the region, but in the case of a bigger investment, local wind energy measurement is highly recommended because wind speeds are heavily influenced by the surface roughness of the surrounding area, of nearby obstacles (such as trees or other buildings), and by the contours of the local terrain. There are no wind turbines in the area currently, whose production results could be an excellent guide for local wind conditions. Around the examined area in Nyírbogát, there is a rounded hill upon which the turbine could be placed.

It is recommended to measure the wind speed at a prospective wind turbine site by fitting an anemometer to the top of a mast which has the same height as the expected hub height of the wind turbine to be used. It is possible to buy a professional, well calibrated ultrasonic 3 D anemometer with a data logger for 2 000 EUR. In this case, the recommended device is the R.M Young model 81000 in combination with a RS232 data logger. The data on both wind speeds and wind directions from the anemometer(s) are generally collected on electronic chips, a data logger, which may be battery operated for a long period. Wind speeds are usually measured as 10 minute averages, in order to be compatible with most standard software and literature on the subject.

2.5 Geothermal potential

The geothermal features of the Carpathian Basin are very favourable because the Earth's crust is thinner and the heat flow value is approximately 90-100 mW/m^2, which is roughly twice the continental average.

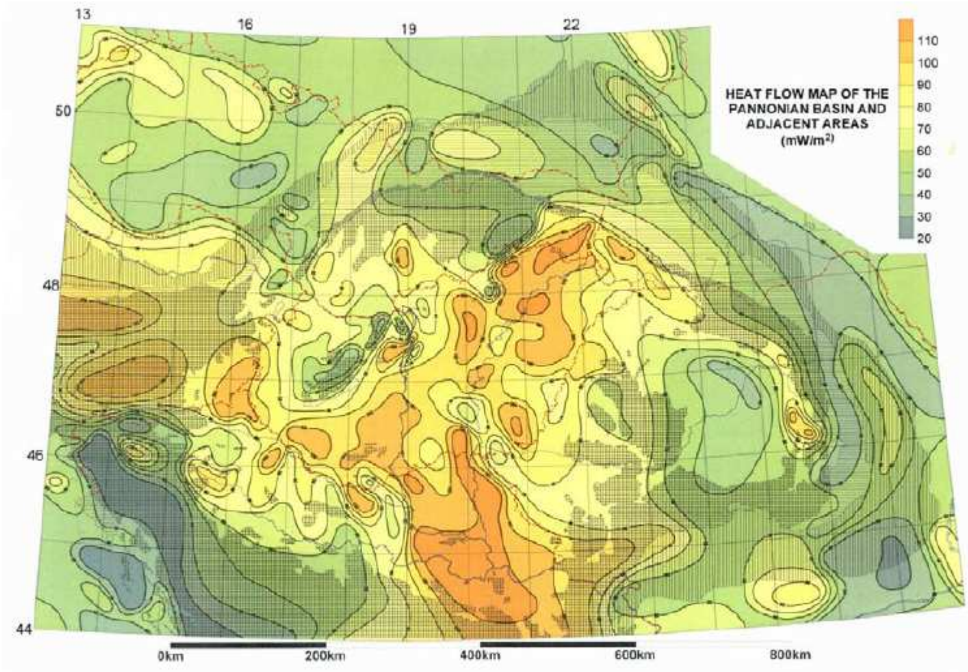

Figure 18: Heat flow map of the Pannonia basin [Bodó, 2005]

Hungary does not belong to a volcanically active area; the good geothermal conditions are due to magma upward conductive heat flow. The geologic hazard is considered to be low. The number of wells drilled in Hungary in the last 150 years is close to 100.000 and in 15-25% of these wells, temperature measurements of some kind were carried out. A significant number of these drillings were very shallow: temperature distribution at shallow depths can be very disturbed due to atmospheric influences and intensive fluid migration. The next table shows the depleted and thermal wells data in Szabolcs-Szatmár-Bereg county. It can be stated that these wells has fair results, and these wells could be used for heating purposes, which is not a tendency nowadays. [Source: Bodó, 2005]

Table 4: Wells in Szabolcs-Szatmár-Bereg county [Gööz, 1999]

Location	Year of erection	Depth [m]	Well head temperature [ºC]
Nyíregyháza	1964	899	48
Nyíregyháza	1958	998	50
Nyíregyháza	1958	800	49
Nyíregyháza	1961	601	39
Nyíregyháza	1968	904	50
Nyíregyháza	1990	900	49,2
Nyíregyháza	1958	551	34
Kisvárda	1964	600	42
Kisvárda	1960	802	45
Mátészalka	1960	1009	56
Nyírbátor	1971	1000	50
Fehérgyarmat	1962	1005	45
Nagykálló	1969	980	43
Gemzse	1975	1078	50
Kemecse	1958	513	24
Nagyecsed	1968	590	17
Vásárosnamény	1978	945	57
Nyíregyháza	1964	900	48
Baktalórántháza	1971	862	45
Nagyhalász	1966	640	37
Nagyhalász	1967	430	30
Tiszavasvári	1969	1197	67
Nyíregyháza-Sóstó	1991	925	49,2
Kisvárda	1967	640	45
Csengersima	1991	1250	57

The examined area is sedimentary with an North-East-South directed shear zone that crosses the Pannonian basin. The depth of the late Pannonian basement is 1000-2000 m in the area.

The geological section of Figure 19 shows the structural pattern and lithology beneath Nyírség. Generally speaking, the geologic make-up of the territory is characterized by the fact that the Upper and Middle Pleistocene strata consist of medium-, small- and fine-grained sands of loamy character, and the porous strata are interlain by impervious layers which are of different facies (clay, loamy clay, fine-sandy loam). It is known throughout Nyírség and the base of the sequence at Nyírbogát is at approximately 320 m depth. In the region the Lower Pleistocene sequence is very coarse grain composition (gravel, sandy gravel, gravelly sand, coarse sand).

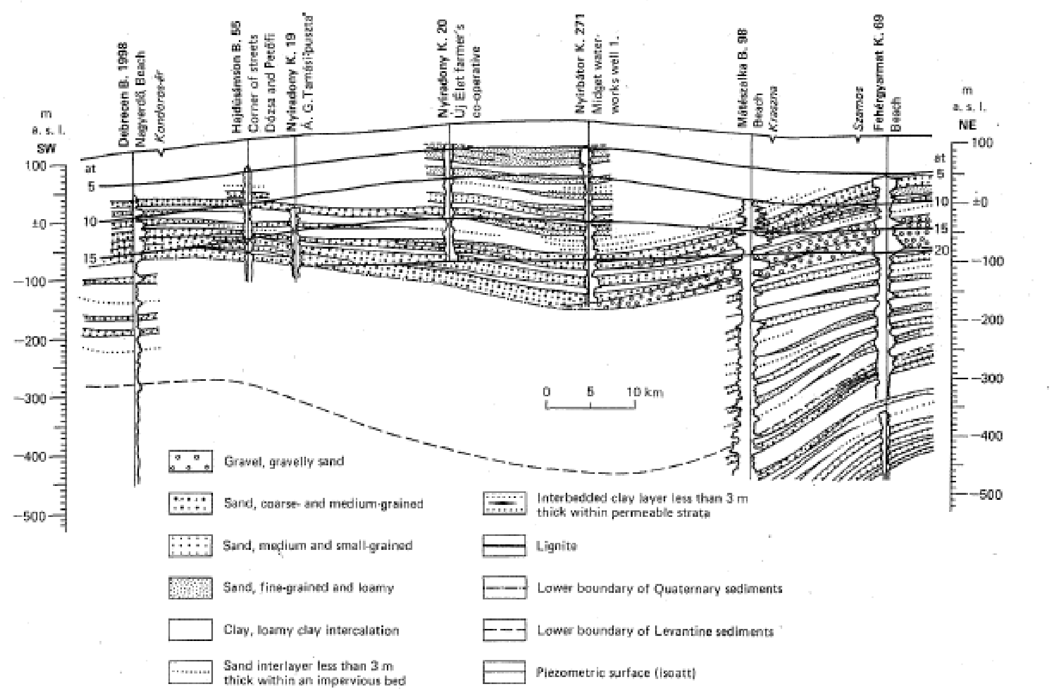

Figure 19: Geological surfaces between the Nyírség and the Szatmár plain [Gőöz Lajos, 1999]

Piezometric surfaces between the Nyírség ridge and the Szatmár plain [Source: International Association of Hydrological Sciences]

The geothermal gradient in the country is 50-63 ºC/1000 m. The porosity determines the thermal properties of rock, which in turn are determined by whether the pores are filled with water or air. The rock's heat capacity and thermal conductivity are greater when water-saturated, and there is water flow (migration) as well.

Table 5: Thermal conductivity of the area [Göőz, 1999]

Rock	Thermal conductivity λ [W/m²K]	Available heat capacity [W/m]
dry sand	0,2-0,4 (0,3)	<25
wet sand	1,1-2,1 (1,6)	55-70
gravel, detritus		>80
wet clay	0,8-1,5 (1,15)	45-60

According to the “Autonomous-house” research project, the average temperature at 100 m depth is around 15 ºC, as can be seen in the Figure 20. This project takes place approximately 45 km from the area under study.

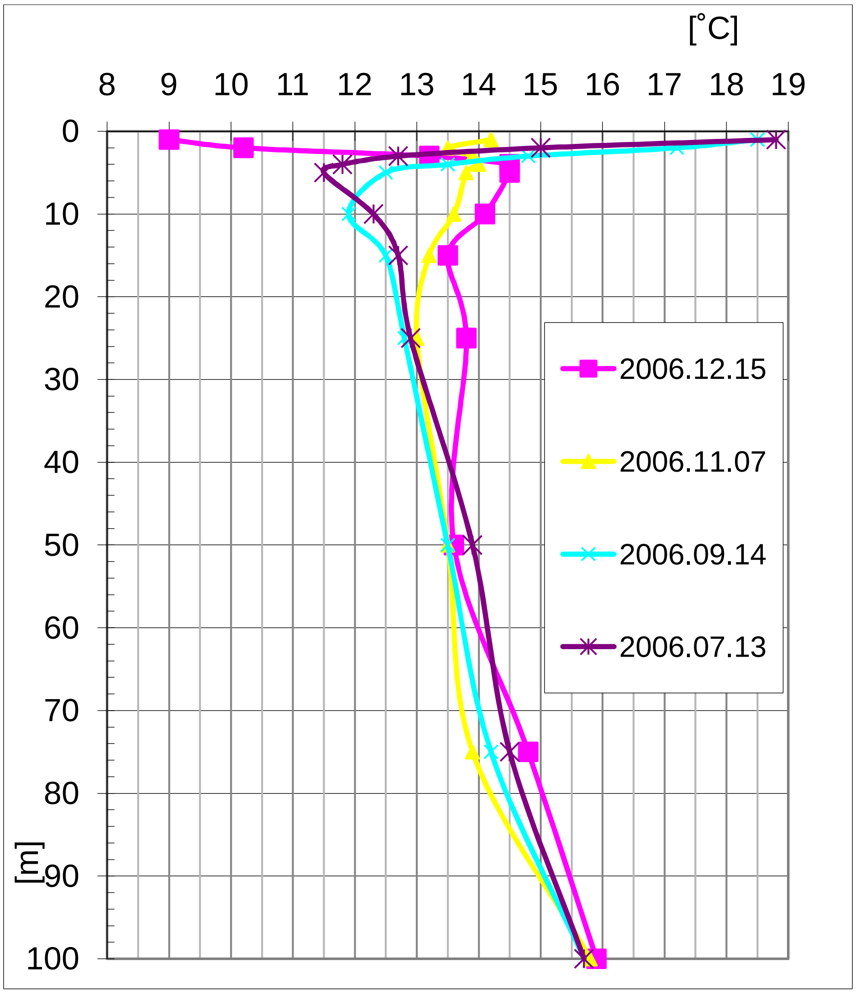

Figure 20: Temperature under the surface [Ing-Reorg, 2010]

In the study area, groundwater is used for drinking, industrial and agricultural activities. In recent years, a small depression in the groundwater level was observed, but it is approximately 4-6 m. Sharp fluctuations can be observed depending on the weather conditions.

In terms of the geothermal potential of the region, it can be stated that it has prosperous geothermal features because of the geologic features and the relatively high and rich groundwater level. These kinds of ‘hydro-geothermal’ systems have fair, well-known adaptable technology, such as ground-water source heat pumps or a closed loop ground source heat pump technology.

2.6 Comparison of the different renewable energy theoretical potential in the Nyírség region

Fortunately there are more and more assessments, measurements are available and accessible about renewable energy in Hungary nowadays, but it is still needed to expand these activities and emphasize the advantages of these technologies.

A major starting point for any renewable energy-based project is an accurate theoretical assessment of that energy and the assessment of an economically optimal location. Most of the technologies require that on-site measurements are being carried out, since the most reliable results, the smallest errors, local conditions only this way can be obtained. However, the site of the future investment are often forced by other factors such as price of the produced energy, needs of waste heat, long term political and market conditions and et cetera.

Nevertheless, it is really important to use the estimated area-specific characteristics to generate new renewable energy based investments. Different models offer a number of spatial extrapolations as a relatively cheap solution to get at least an order of magnitude about the different possibilities at a given site.

The Nyírség region is economically disadvantaged region in Hungary, the unemployment rate is very high, that's why is really important to try to reduce the energy dependence of the region, and increase the knowledge about the available renewable assets of the region. The three major renewable energy sources - solar, geothermal and wind energy - have been examined for the Nyírség region. It can be stated that unfortunately such kind of major, representative pilot projects have not been carried out in the region to date, which could give good feedback.

It can be stated that the wind potential of the Nyírség region is not the best within the country, because the region is only IV/A wind class, and many terrestrial and atmospheric parameters influence the wind field close to the ground. So for even a small wind turbine investment it is highly recommended to measure the local wind conditions, and since it is not available at the examined site, in Nyírbogát, it is recommended to install a well calibrated ultrasonic 3 D anemometer, as it is defined in chapter 2.4.

It is well known that the geothermal features of the Carpathian Basin are very favourable, but somehow it has no major share of our energy mix, and in the Nyírség region it is only used for thermal bath purposes. But it seems that it has good potential for use in heating directly, as a supplementary heating or with heat pumps. This region also has quite a good measurement database (depleted wells) which could be realistic for such investments and it is highly recommended to raise this knowledge and generate publicity.

The reputation of solar energy seems the most promising at the Nyírség region, because the database seems reliable, no further measurement is needed, and a solar investment seems the least risky. Preparation phases are the shortest compared to the two above mentioned renewable energy source based investments. That is why solar energy is chosen for further object of this master thesis.

3 Current energy system and option analysis at the plant

The factory produces and exports wooden packaging, such as pallets, wooden boxes, house logs and firewood. Most of their wood products are heat treated and re-barked.

3.1 Existing equipment and energy consumption patterns

At the moment, Fehér-Nyír Ltd. has its own wood chips heating system, powered by two steam furnaces with a total nominal power capacity of 250 kW. This meets the hot water demand, heats the office and production works, and runs the two industrial wood dryers. The wood dryers operate with hot water which heats up the circulating air in the kiln. Approximately 23 000 kg wood are burned annually for heating purposes (approximately 65 kg/day). The two wood dryers operate using hot air, at an approximate temperature of 90ºC.

The moisture content of freshly felled timber varies from over 200% to as little as 40%. Once felled timber starts to dry, and providing it is not in contact with a moisture body and is protected from rain, it will eventually have a moisture content that is in equilibrium with the surrounding air; this might be as high as 20% in a humid environment and as low as 6% in a hot, dry climate. [Source: Langrish et al, 2010] The elements that control the drying rate are the relative humidity of the air, air temperature, and airflow across the timber surfaces. In a kiln, the temperature and relative humidity are maintained at higher levels than in the open air, while powerful fans control the air velocity.

At this study site the initial moisture content of the wood is typically equal to 60% and the final moisture content after drying is 18%.

There are no regular peaks in annual heat consumption at the factory because the drier operates throughout the year and the energy needs of the heating season are not so significant.

The other significant resource consumed by the factory is electricity, supplied by the E.ON East Hungarian Electricity Public Limited Company [E.ON Tiszántúli Áramhálózati Zrt.], and mainly derived from nuclear energy and fossil fuels. The data in 21. figure presents monthly values of electricity consumption at Fehér-Nyír Ltd.

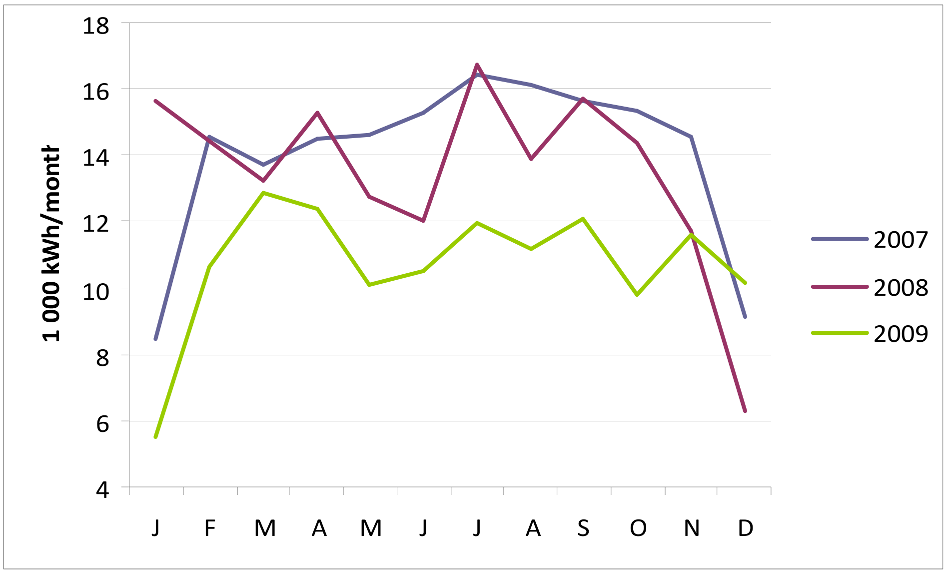

Figure 21: Electricity consumption of Fehér-Nyír Ltd. [Electricity bills]

The natural gas pipeline is not available to the factory and there are no plans to connect to it.

3.2 Option analysis for renewable energy potential at the site

The utilization of solar energy seems quite promising at this site, as has been established in Chapter 2. In this chapter, the viability of solar energy-based drying technology is examined, with the intention of stimulating wider consideration and introduction of such a pioneer technology in the region. Feasibility is definitely a general requirement for any investment and should be checked carefully.

The basic objective of this section is to compare the viability of operating the two wood driers with renewable energy sources at the examined sawmill site. Industrial drying is an energy intensive process which is carried out in a wide range of industries, including chemical, foodstuffs, paper, and many others. In the lumber industry, the removal of water from solids by evaporation is an important issue, as it defines the quality of the final product. The required heat is usually transferred to the moisture via a hot gas, normally air, which also acts as a carrier gas for the removal of vapour. Around 60% of the sawmill’s total energy consumption is used in the drying operations, which makes this a key element in the factory’s expenses and supports the contention that it is worth examining the possibility of decreasing these costs. One possibility for at least partially replacing conventional energy sources would be to utilize solar energy.

3.2.1 Business as usual, baseline scenario

It is helpful to describe a baseline scenario, using a forecast of the future if no renewables projects were implemented. Without any major investment, the existing energy system will probably continue operating at the sawmill in the future; among the incurring operational costs, a high percentage will be that of conventional energy and the maintenance of the conventional system.

Fehér-Nyír Ltd. mainly uses poplar and acacia, which will be very valuable and marketable in the future as well and makes it important to deliberate asset management.

KPMG Consulting Ltd. made a model of the price and trade of biomass in Hungary, which intended to determine and predict the biomass evolving equilibrium price. This study was based on computer-aided estimations of the expected trends in biomass prices for the 2010-2020 period. KPMG's model and the GreenX modelling approach have some similarities, but the theoretical backgrounds and purposes of their analyses are different.

It is based on an evaluation of the current agricultural and forestry database over the past five years, and the prices for 2009 can be seen in the figure 22.

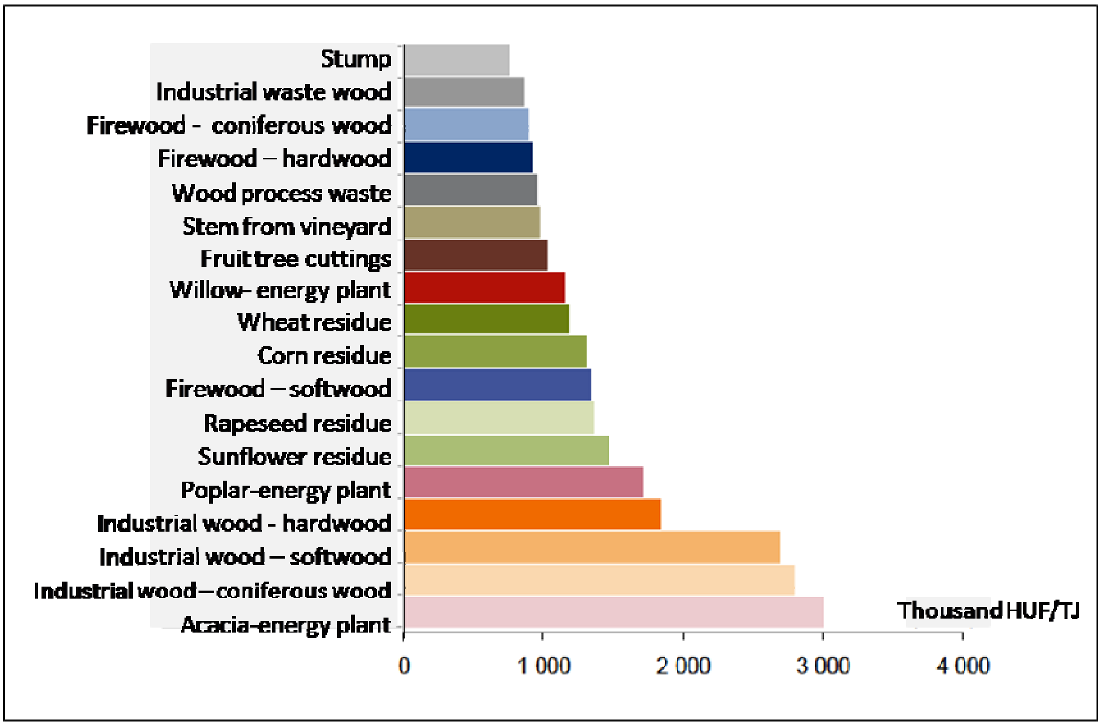

Figure 22: Price of raw material [KPMG Ltd., 2010]

The product price forecasts for the period 2010-2020 are shown in the figure 23.

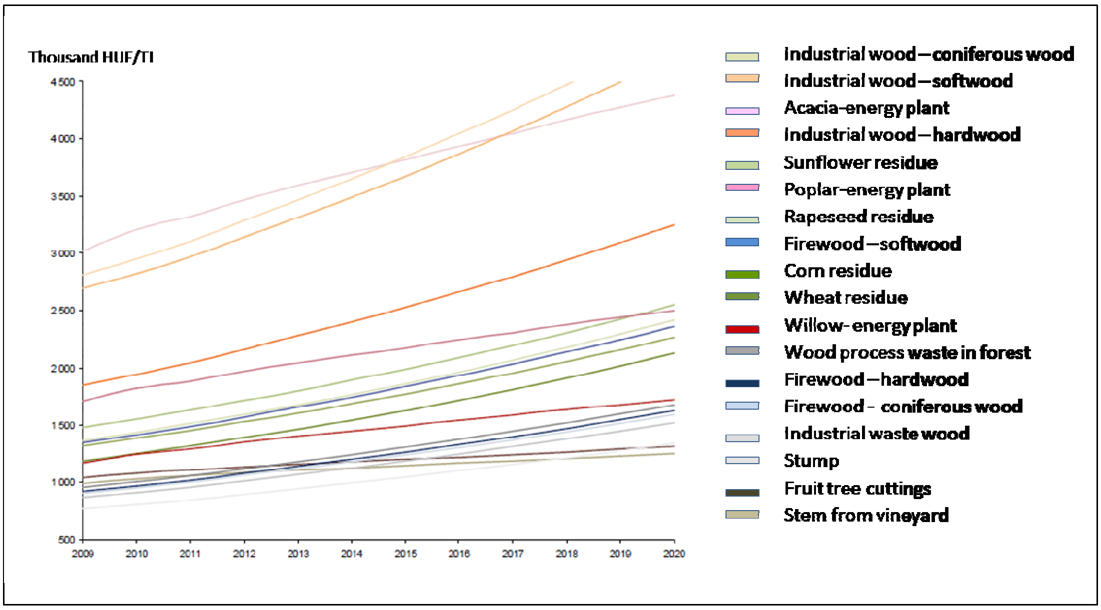

Figure 23: Market price of raw material till 2020 [KPMG Ltd., 2010]

Market prices after running the average prices can be seen in the table below:

Table 6: Price of raw material converted from HUF (1EUR=270HUF) [KPMG Ltd., 2010]

Average price (thousand EUR/TJ)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Wood industry	7,6	7,9	8,3	8,9	9,5	10,2	11,0	11,7	12,5	13,2	14,0	14,8
Residential	3,5	3,7	3,8	4,0	4,2	4,5	4,7	4,9	5,1	5,3	5,7	6,3
Wood fired power and heating plants	3,5	3,7	3,8	4,0	4,2	4,5	4,7	4,9	5,1	5,3	5,7	6,3
Wood and agricultural residues fired power and heating plants	3,5	3,7	3,8	4,0	4,2	4,5	4,8	5,3	5,9	6,6	7,0	7,4

The table clearly shows that the average prices for the industry will develop significantly, higher than the estimated price for retail, because:

- Till 2020 the demand for timber from the current 18.2 PJ rises to 33.7 PJ
- From 2016, a significant demand for imports rises in the market
- The current 7,6 thousand EUR/TJ (2043 thousand HUF/TJ) increases to 14,8 thousand EUR/TJ (3999 thousand HUF/TJ) average

Based on KPMG's model, the household demand will significantly increase too, from the current 21 PJ to 30.9 PJ till 2020, rising by an average annual rate of 3.53%.

3.2.2 Solar System Connection Optimization with Current Wood Chips Heating System

Solar-based wood dryers can be divided into two categories: greenhouse type solar dryers and solar dryers with external collectors. Research studies around the world have shown that solar dryers give a reasonable technical and economic performance, which justifies their feasibility in many countries.

A greenhouse tunnel dryer was built in Argentina (Reuss et al. 1997) and the results gained from that project confirm the advantages of solar wood drying. The drying time was much shorter than with open air drying. Damage of the wood during drying could be avoided and operating costs were low, since neither special control equipment nor fuel were necessary.

Hot water solar systems would function inside the dryer the same way as any hot water dryer; that is, solar-heated water is the same as water heated by other means. At Fehér-Nyír Ltd. the dryer operates with hot water having a temperature of around 90 ºC. Therefore, the hot water dryer design does not need to be discussed in this thesis.

Air drying of timber usually has a series of disadvantages, such as time expenditure, drying defects in the wood and inadequate final moisture content. To avoid these drawbacks, kiln drying is used in many cases, but this involves higher investments in equipment and greater operating costs. One method that obviates or reduces the disadvantages of air-drying and, at the same time, reduces the costs of kiln drying, is drying with solar heat. For the most part, fossil fuels are currently used to dry timber products. Solar energy can replace a large part of this unrecoverable energy carrier, since solar energy can supply heat at the temperatures most often used to dry wood (i.e. from 40 to 100 ℃). Solar timber dry ers therefore offer an attractive solution. In the various studies on solar heat drying published in recent decades, it has been shown that operating conditions are influenced by numerous factors, such as location, climate, wood species, dimensions and type of kiln used. Therefore it is not possible to generalise, and each situation, location and particular application of the technology must be studied in detail. [Gan, 2010]

Modelling wood drying is important for solar dryer design in order to improve performance and efficiency, optimize dimensions and to predict the drying process. Many mathematical models have been proposed to describe the operation of solar dryers. All proposed different drying models based on the most common heat and mass transfer operations. They numerically and experimentally investigated the drying process and their studies show that generally there is reasonable agreement between predicted and experimental results. [Gan, 2010; Petri, 2003]

At the sawmill which is the focus of this study, a commercial drier model KWB 111 is used that has been slightly adapted for attachment to a solar water collector. The single-row, low-capacity kiln has a 7 m^3 saw timber volume, and timber stacks have the following dimensions: width 1,500 mm, height 1,750 mm, and length 6,000 mm. The kiln is designed to dry poplar and broad-leaved sawn timber or bulks at 90-100 ℃ (maximum) drying temperature.

The basic kiln design consists of a well-insulated drying compartment and a separate water heating solar collector, for easy construction and favourable orientation as well as tilt at an angle approximately equal to the latitude. The collector is external to the drying chamber, so the collector area and orientation are not limited by the geometry of the kiln.

The existing heating system is taken into account to speed up drying and to support the drying process during periods of low solar radiation or in wintertime, as well as to increase the average nightly temperature.

The following system configuration proposals were designed to fit specific criteria:

- A technically feasible and efficient combination that operates in parallel with the existing wood chips heating system
- Safe and easy implementation with little or no maintenance needed throughout its normal operation
- Designation of some of the existing tanks to allow for the sun’s energy to be utilized throughout all solar collecting hours

- The flow can be forced to continue in its current wood chips heating configuration, in the event that the sun does not supply the needed energy
- The solar collectors can act as a pre-heating unit as well as a direct energy supply to the reservoir system
- The energy given directly to the tank reservoir water is a direct cost savings when compared to the wood chips
- Utilize the existing tank as well, without compromising the system's ability to provide the quantity of hot water needed during the nights and winter periods

3.2.3 Solar collector selection

Solar thermal collectors are the key component of active-solar systems and are designed to meet specific temperature requirements and climate conditions. There are several types of solar collectors: residential and commercial building applications that require temperatures below 80ºC typically use flat-plate or transpired air collectors, whereas those requiring temperatures greater than 80ºC use evacuated-tube or concentrating collectors.

The basic characteristics of the evacuated-tube collector will be reviewed briefly in this section, in order to provide an explanation and guide through the dimensioning process.

To summarise, the evacuated-tube collector is recommended for the water heating needs of Fehér-Nyír Ltd. because: it can heat water up to 80ºC with an acceptable efficiency, as demonstrated in Figure 24.

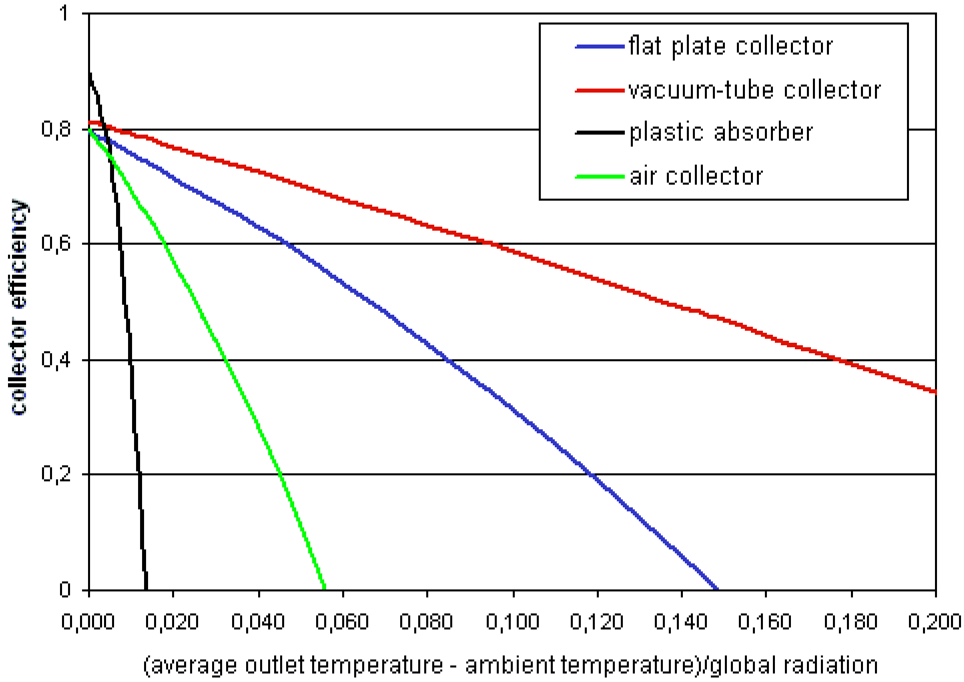

Figure 24: Collector efficiency curves for various types of collectors [Federal Ministry of Traffic, Innovation and Technology, 2010]

An evacuated-tube collector contains several rows of glass tubes connected to a header pipe. Each tube has the air removed from it (evacuated) to eliminate heat loss through convection and radiation. Inside the glass tube, a flat or curved aluminum or copper fin is attached to a metal pipe. The fin is covered with a selective coating that transfers heat to the fluid that is circulating through the pipe. There are two main types of evacuated-tube collectors:

1. Direct-flow evacuated-tube collectors

A direct-flow evacuated tube collector has two pipes that run down and back, inside the tube. One pipe is for inlet fluid and the other for outlet fluid.

2. Heat pipe evacuated-tube collectors

Heat pipe evacuated-tube collectors contain a copper heating pipe, which is attached to an absorber plate, inside a vacuum-sealed solar tube. The heat pipe is hollow and the space inside is also evacuated. Inside the heat pipe is a small quantity of liquid, such as alcohol or purified water plus special additives. The vacuum enables the liquid to boil at lower temperatures than it would at normal atmospheric pressure. When sunlight falls on the surface of the absorber, the liquid in the heat tube quickly turns to hot vapor and rises to the top of the pipe. Water or glycol flows through a manifold and picks up the heat. The fluid in the heat pipe condenses and flows back down the tube. This process continues as long as the sun shines. Heat pipe collectors must be mounted with a minimum tilt angle of around 25° in order for the internal fluid of the h eat pipe to return to the hot absorber.

There are several international brands on the market currently and the final proposal is for a particular vacuum-tube solar collector produced by Vaillant. This company has been producing solar water heating units since 2002, proving reliable service and quality. Vaillant produces a variety of panels sizes. The auroTHERM VTK 1140 evacuted tube collector with high efficiency and manufactured in Germany, is the recommended panel for this application.

Advantages of the Vaillant VTK 1140 evacuted-tube collectors:

- Produce one of largest surfaces in the market
- Proven design integrity
- Dependable
- Long life
- Competitive quality price ratio
- Excellent customer service

Table 7: Recommended solar collector [Vaillant, 2010]

Type	auroTHERM VTK 1140
Producer	VAILANT Saunier Duval Kft. 1116 Budapest Hunyadi street 1. Phone:+36 1 464 7800 E-mail: vailant@vailant.hu Information: www.vailant.hu
Outside dimensions	1,6 x 1,39 x 0,1 m
Area	Outside: 2,28 m^2 Transparent: 2,00m^2
Absorber	Stainless steel and glass
Weight	37 kg
Recommended pressure	9,9 Bar
"U-value"	k1= 0,8118 W/m^2K k2=0,0031 W/m^2K
Gross sales price/piece	316 500 Ft 1 155 EUR

A well-proportioned solar system depends on a variety of factors. Special software programs designed for specific solar collector manufacturers are generally used to calculate the required surface area for large installations. These programmes are used to simulate the process of nature in conjunction with the panels. In this thesis, a generalized sizing procedure for solar hot water systems will be applied in the absence of specific sizing software. The following section will describe the procedure and calculations used to size the solar system.

This thesis is oriented towards a specific definition of the existing system concerning the type of drying process and its characteristics, following parameters that have been defined in advance:

- the current heating system is centrally organized and based on the use of wood chips. Consequently, the calculation is based on the assumption that no additional pipes are necessary for the distribution between hot water storage and dryer;
- north-south orientation: with no deviation from south (0°), it is possible to use an exactly south-oriented roof;
- angle of the panels is fixed with the roof pitch (45°);
- Reservoir capacity, which currently consists of 1 tank holding a total of 5 $m^{3;}$, a new "solar tank" will be mounted in the tank room, which is $5m^3$, and one of the most important characteristic of this system

Starting with these predefinitions, the calculation was done in a similar way, taking into consideration different conditions in the Nyírség region. In principle, there are two expectations for the installation of solar collectors, which are in fact contradictory. A high coverage to save as much conventional fuel as possible, versus a high specific yield (kWh/m^2 a) to allow a favourable price for the provided heat. With an increase of solar coverage, the specific yield decreases due to higher collector temperatures (lower efficiency) and more times of stagnation (due to heat which cannot be used any more in the hot water storage) (IBS-HLK, 2010).
Thus, in an optimization process, a solution to deal with this trade-off has to be found. To meet this challenge, a calculation of the technical requirements and the supplementary solar hot water provision has been done in several work steps. The following lists identifies the most important assumptions and applied recommendations, mainly based on available literature.

(1) Total hot water demand

The amount of hot water needed is easily predictable, because the dryer operates throughout the year. According to operation experience, the system with the 5 m3 volume storage tank is working properly, and for the solar system, an additional 5000 litre tank was used as the solar hot water storage tank. As a rule of thumb, the following recommendation was found for the storage tank and collector surface relationship in the available literature: the average volume is 100 L per m^2 collector surface (IBS-HLK, 2010)

(2) Total energy required for hot water supply in general

In the second step, the total energy required for hot water supply was calculated. As has already been stated, this energy demand is basically a function of temperature differential (between the water entering the system and the provided hot water) and water consumption (required amount of hot water):

$$E = r_w * C_p * Q_v * D_m * (T_C - T_A)$$

E = Energy required to heat water [MJ/ month]
D_m = Days per month [day/month]
T_A = Temperature of water entering system [varying °C]
T_C = Temperature to administered to "client" [90°C]
Q_v = Volumetric flow per day (5 [m^3/day])
C_p = Heat Capacity of Water (4,186 [kJ/kg*K])
r_w = density of water (1000 [kg/m^3])

Finally, circulation losses which occur due to the necessity of circulation of hot water in the pipe system of the building have been considered. Circulation losses are calculated as a function of [Hastings, 2000]:

$$E_{cl} = l * W_{cl} * (T_p - T_S) * f$$

E_{cl} = Energy required due to circulation losses [Wh/day]
l = length of the pipe system [150 m]
W_{cl} = losses per m (well insulated pipe) [0,214 W/mK]
T_S = Average temperature of the surrounding of the pipe [15°C]
T_p = Average temperature within the pipe [55°C]
f = circulation working per day [16 hours]

The total energy required (energy to heat water plus circulation losses) is used as a basis for further calculation.

(3) Effective heat capacity: Provision of hot water by solar energy and collector efficiency

In principle, the amount of hot water provided by solar collectors is dependent on the size of the collector surface and the solar radiation at the analysed location. In terms of the potential yield of solar radiation (E, see below) the following parameters have been considered:

- solar radiation per month at the analysed location
- orientation and angle of the collector surfaces.

The collector efficiency has been calculated on the basis of average optical losses and thermal losses due to temperature differences (Schmidt 2009).

$$W_N = E - W_0 - W_V$$

$$\text{with: } W_0 = E * (1-\eta_0) \text{ and } W_V = k_1 * (T_{coll} - T_{outside})$$

W_N = effective heat capacity of the collector [kWh/m^2]

E = solar radiation (south oriented surface with 50° angle)

W_0 = optical losses

W_V = thermal losses

η_0 = optical efficiency [0,855] heat transmission factor: absorbtion factor 0,95 X transmission factor through glass 0,9

k_1 = heat loss coefficient [3,37 W/(m2*K)]

T_{coll} = temperature in the collector [72 ℃]

$T_{outside}$ = temperature outside (monthly average) [℃]

The result of this calculation step demonstrates the effective heat capacity of the collector per m^2 collector surface, depending on the area of collector surface, which is defined in the subsequent step.

(4) Determination of installed collector surface area

Due to the size of the factory, the available roof surface – a north-south oriented double-pitched roof – is not a limiting factor. In order to reach the basic aim of maximum feasible coverage by solar energy, and thus a maximum possible collector area, the size of the installed collector area was finally determined as a collector surface of about 60 m^2 with a solar thermal coverage of about 39% annually. The following three proposals successfully fulfil the above criteria, however, Option B has been chosen as the optimal configuration based on its technical efficiency.

Table 8: Configuration proposals

Option	Collector surface [m^2]	Annual solar coverage [%]
A	38	25
B	60	39
C	90	58

The annual efficiency of the proposals can be seen in the figure 25.

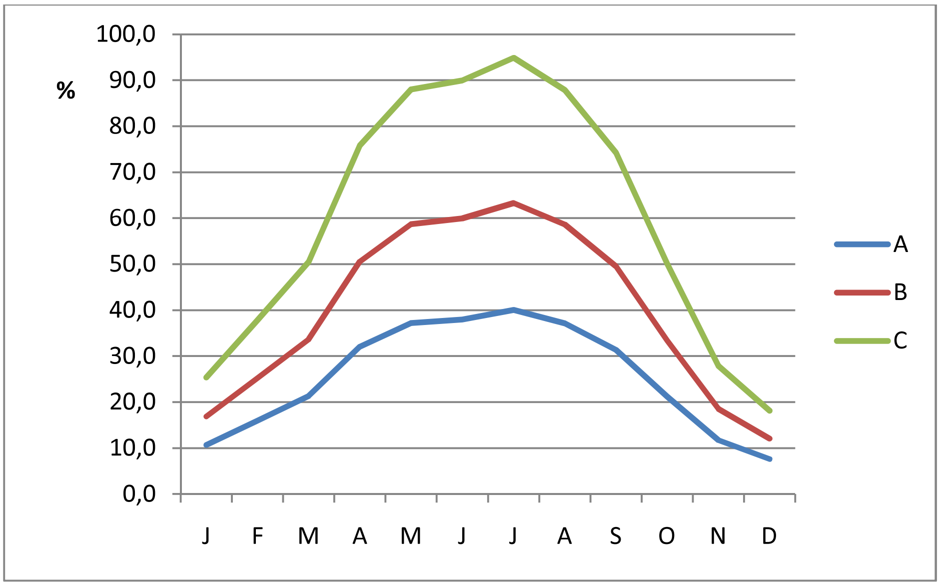

Figure 25: Annual efficiency

(5) Required size of hot water storage tank

Thus, based on the recommendations a back casting of those rules (as rule of thumb) leads to a final decision concerning the size of the storage tank needed for the example at hand: one hot water storage tank assigned as a solar tank having a volume of 5000 litres.

(6) FINAL RESULT of the technical assessment

The full calculation of the technical configuration can be seen in Appendix 2. Here, only the final results of the technical assessment are shown and the following key figures have been calculated as inputs for the economic assessment:

Table 9: Results of technical assessment

Object	Technical option	Result
Total energy demand for hot water provision [MJ]	-	646 806
Coverage of hot water demand by solar thermal installation [%]	A	25
	B	39
	C	58
Size of collector surface [m^2]	A	38
	B	60
	C	90

The recommended option will be defined in the following chapter which investigates the financial feasibility.

4 Financial planning

Energy efficiency in drying, as in most other areas, usually requires capital investment. The investment can be considered worthwhile if the resulting cost savings are sufficiently attractive. The two most commonly used parameters for measuring the return on investment are the simple payback period and the internal rate of return.

In this assessment, two scenarios are analysed:

- Real scenario without any subsidies
- One scenario with subsidy co-financed by the European Regional Development Fund and the Hungarian Government: The New Hungarian Development Plan for 2007-2013 utilizes cohesion and structural funds. One of the biggest priority areas is environment; energy developments aim at the fulfilment of objectives defined in the horizontal policy of sustainability. Strategic considerations related to energy supply require the reduction of conventional fuel utilisation, with regard to the security of supply (cutting import dependence), cost-effectiveness (replacing increasingly expensive energy sources), as well as environment and climate protection. The main tools for achieving the above are improving energy efficiency, better energy savings, and increasing the share of renewable energy. The examined region is a disadvantaged region, that is probably why 50 % co-financing would be possible for the project under the Environment and Energy Operation Program.

In both of the above cases, the following values are calculated, which are often used for the evaluation of an investment:

- Net present value (NPV)
- Internal rate of return (IRR)

The following parameters are taken into account:

- The reference time horizon in the energy sector – based on internationally accepted practice and recommended by the European Commission – is 15-25 years. For this solar technology the maximum recommendation is taken into account.
- The European Commission recommends that a 5% financial discount rate in real terms be used as an indicative benchmark for investment projects co-financed by the Funds. [Source: European Union Regional Policy]

The net present value (NPV) equals an investment's future net cash flows minus the initial investment. It includes the initial investment costs as well as the subsequent profits. If it is positive, the investment should be made (unless an even better investment exists), otherwise it should not. The internal rate of return (IRR) gives a net present value of all cash flows from a project that is equal to 0. In general the higher the internal rate of return is, the more desirable it is to invest in the project and the project with the highest IRR should be realized first. The internal rate of return expressed in percentage terms is the rate of interest at which investing the money in a financial institution (such as bank) will generate cash flow equal to that generated by the energy savings.

The initial investment includes the costs of the solar collectors and other equipment, and the costs of planning and implementation. Costs for those components were taken from specific offers requested from solar thermal companies, as well as from available price lists of such companies. The operating costs are the expenses related to the operation of the solar thermal system, which are the electricity costs for the pump and the maintenance costs for the system.

In the analysis the following assumptions were considered:

- Electricity demand according to the literature: 2% of solar fraction [Hastings, 2000], due to additional energy demand for operation (pumping between collectors and hot water storage) (1)
- Maintenance costs: according to prices given by enterprises or according to the literature (0,3% of total investment costs [Hastings, 2000])

The prices introduced into the calculation are based on the analysis of actual local prices of energy providers in the region. The wood price based on the KPMG study as defined in Chapter 3.2.1. As revenue, the costs of savings due to the substitution of the wood chips heating system by the solar thermal system is determined.

4.1 Conclusion

Following the calculation outline described above, the following results can be presented (background details can be seen in Appendix 3).

Table 10: Results of economic assessment (see Appendix 3)

	Option A	Option B	Option C
Without financial support			
Internal rate of return (IRR)	2,3 %	4,7 %	4,5 %
Net present value (NPV)	-10 957	- 1 860	-3 831
With subsidy			
Internal rate of return (IRR)	8,2 %	11,4 %	11,2 %
Net present value (NPV)	7 290	21 310	31 371

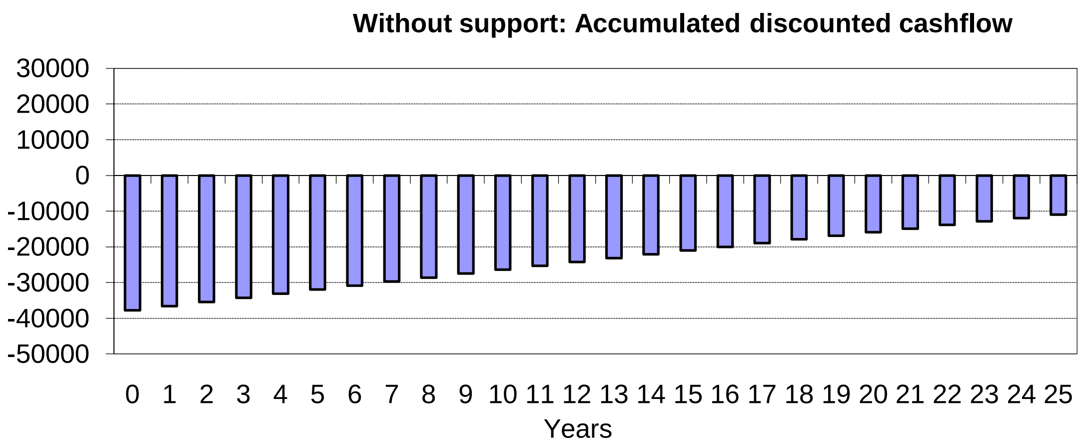

Figure 26: Discounted cash flow without subsidy

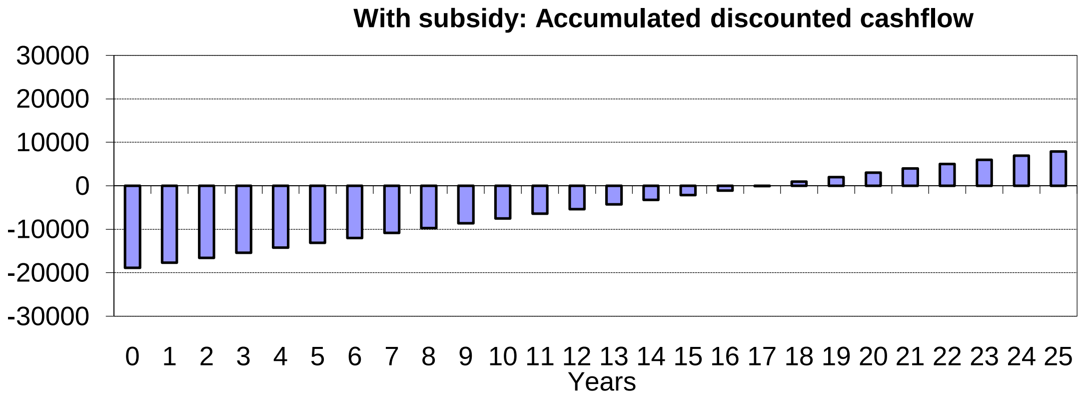

Figure 27: Discounted cash flow with subsidy

The economic assessment of the analysed region shows that, unfortunately, such investment is not economically feasible without funding and even with funding, it is less attractive. The situation for the implementation of solar thermal installations for hot water provision is very hard. Pay-off periods are already in the range of the end of the life span of those installations, which may not even be completely paid off at all.

Nevertheless, it must be stated that if the project were to receive a subsidy, Option B offers the most attractive investment: a break-even point was calculated to be within 17 years of implementation. In such cases, funding is not only important for accelerating the implementation speed, but highly necessary if any implementation is to occur at all.

Given the actual discussion on the national as well as EU levels, a higher increase in fossil fuel prices will probably improve the results of renewable energy-based investments in the future.

5 Conclusion

This report commences with geographical, economic and energy profile descriptions of the region and then focuses on renewable energy potential analysis. The three major renewable energy sources - solar, geothermal and wind energy - have been examined for the Nyírség region. Hydro power does not come within the scope of this region because of its geographical features.

Wind energy potential of the Nyírség region is not the best within the country, because this region is only IV/A wind class. Measurement of local wind conditions with a well-calibrated, ultrasonic 3D anemometer is highly recommended in the future, because many terrestrial and atmospheric parameters influence the wind field close to the ground, and wind measurements at the examined site are not available except by extrapolation. In this case, the recommended device is the R.M Young model 81000 in combination with a RS232 data logger.

Geothermal resources in the Nyírség region are only used for thermal bath purposes, although heat flow (approximately 90-100 mW/m^2) shows good potential at some given sites, even for direct heating, supplementary heating purposes or with heat pumps. This region also has quite a good measurement database - depleted wells - which could establish future investments and would be highly recommended to gain publicity or generate campaigns for stakeholders.

The reputation of solar energy seems the most promising at the Nyírség region, where the average annual total of incident sunshine is 1250 kWh/m^2. The database seems reliable, no further measurement is needed, and currently an investment in solar seems the least risky. Therefore, solar energy was chosen for further evaluation in the context of this master thesis.

These fundamental considerations have been taken into account at the Fehér-Nyír Ltd. sawmill, where firstly the existing energy system and the consumption patterns have been assessed. Their main products - wood pallets - are heat treated, and the energy demand for timber drying is a major part of the total energy used to manufacture timber. A solar energy-based development is assessed which could work in parallel with their existing wood chips heating system, not a replacement.

The calculation incorporated in the sizing of the required collector area has included an analysis of the existing surrounding environment and the available radiation. This also included a comprehensive explanation of the thermal energy conversion within said collectors. The recommended evacuated-tube collector model is the VTK 1140, produced by Vaillant. The overall collector area calculations were based primarily upon solar energy storage capacity, 5 m^3, and available solar energy, 1300 kWh per year. This rendered a recommendation of 60 m^2 of collector surface area, translating into a purchase of 30 panels.

The total estimated price of the system, including the purchase of the panels, is 46 340 €. Finally, an overall economic analysis was offered to prove the viability of this system as an investment. This estimation took into account the rising prices of raw materials, the average energy savings offered by the solar system, and the estimated equipment costs. A break-even point of the proposed system was calculated to be already within the range of the end of life span of those installations. With a 50% investment subsidy, a break-even point was calculated to be within 17 years of implementation. In such cases, funding is not only important for accelerating the implementation speed, but highly necessary for any implementation at all.

Although investments do not grow rapidly in the Nyírség region nowadays, the results of this research show that some of the renewable energy sources have promising potential. Completing this initial phase and following further measurements and assessments, new projects can be made feasible to decentralize the energy sector in this region and scale up a sustainable energy plan for the future.

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Appendices

Appendix 1: Estimated wind production and annual energy production curve

Appendix 2: Technical calculation

Appendix 3: Economic calculation

Appendix 1: Estimated wind production and annual energy production curve

Turbine input			
Rotor diameter	RD	150	[m]
Rated generator power	Pr	200	[kW]
Rated Rpm	Rpm_{Rated}	8	[rev/min]
Hub height	H_{Hub}	100	[m]
Rated Wind Speed	v_{Rated}	6	[m/s]
Cut-in Wind speed	v_{Cut-in}	2	[m/s]
Cut-out Wind speed	$v_{Cut-out}$	25	[m/s]
Wind field Input			
Mean Windspeed	V_{mean}	6	[mph]
Anemometer height	H_{Ane}	100	[m]
Windshear exponent	α	0,143	[m]
Air density	ρ_{air}	1,225	[kg]

x, m/s	Weibull Prob	y, number of hours at x m/s	PowerCurve	Energy Production Estimate, in KWh	Energy in the wind, in KWh
1	0,042691611	373,978509670	0	0,0000	4047,8568
2	0,079973855	700,570966226	0	0,0000	60662,5433
3	0,107563545	942,256658274	31	29445,5206	275366,7327
4	0,123106220	1078,410483439	100	107841,0483	747037,7827
5	0,126449316	1107,696011587	169	186923,7020	1498680,6413
6	0,119364323	1045,631467028	200	209126,2934	2444617,3403
7	0,104869323	918,655265640	200	183731,0531	3410555,9717
8	0,086400822	756,871197918	200	151374,2396	4194405,6753
9	0,067080793	587,627744927	200	117525,5490	4636692,7003
10	0,049241786	431,358046217	200	86271,6092	4668919,6067
11	0,034257442	300,095191742	200	60019,0383	4323302,1115
12	0,022626755	198,210371155	200	39642,0742	3707222,0999
13	0,014207363	124,456500806	200	24891,3002	2959553,0950
14	0,008489412	74,367246777	200	14873,4494	2208738,5080
15	0,004831373	42,322828915	200	8464,5658	1546062,1871
16	0,002620471	22,955328018	200	4591,0656	1017705,0825
17	0,001355310	11,872518655	200	2374,5037	631346,9944
18	0,000668718	5,857970654	200	1171,5941	369779,8139
19	0,000314887	2,758413460	200	551,6827	204785,2434
20	0,000141551	1,239987086	200	247,9974	107370,6647
21	0,000060762	0,532277605	200	106,4555	53354,9320
22	0,000024913	0,218234617	200	43,6469	25151,8640
23	0,000009758	0,085479345	200	17,0959	11257,0135
24	0,000003652	0,031990963	200	6,3982	4786,7366
25	0,000001306	0,011441662	200	2,2883	1935,0297
26	0,000000446	0,003911162	0	0,0000	744,0539
0	0,003644287	31,923956453	0	0,0000	0,0000
	1	8760		1229242,1715	39114082,2814

				Powercurve coefficients	
Rated generator power	Pr	200	[kW]	d	-6,25
Rated Wind Speed	v_{Rated}	6	[m/s]	e	75
Cut-in Wind speed	v_{Cut-in}	2	[m/s]	f	-225
Cut-out Wind speed	$v_{Cut-out}$	25	[m/s]	g	200

Generic Powercurve Wind Speed x, m/s	
1	0
2	0
3	31
4	100
5	169
6	200
7	200
8	200
9	200
10	200
11	200
12	200
13	200
14	200
15	200
16	200
17	200
18	200
19	200
20	200
21	200
22	200
23	200
24	200
25	200
26	0

Appendix 2: Technical calculation

Characteristics of the analysed building	
HOT WATER DEMAND (hwd)	
total hot water demand per day (l)	*5000*
BUILDING CHARACTERISTICS	
north-south orientation: deviation from south (°)	0
roof pitch (°) = angle of the panels	45
CIRCULATION	
length of pipes (circulation) in m	150
losses per m (well insulated pipe) W/mK	0,214
average temperature in the pipe ℃	90
average temperature ℃	15
circulation working for xx h per day	16
losses due to circulation (kWh) per day	38,5
WATER STORAGE TANK	
capacity: hwd per day times	1
capacity of the tank (l)	5000
ENERGY DEMAND FOR CIRCULATION PUMP (kWh/year)	700,8

	A			B			C		
	solar fraction [MJ/month]	Generally supplied % by the solar	E contributed by wood chips [MJ/month]	solar fraction [MJ/month]	Generally supplied % by the solar	E contributed by wood chips [MJ/month]	solar fraction [MJ/month]	Generally supplied % by the solar	E contributed by wood chips [MJ/month]
J	6 360	10,7	53 089	10043	17	49 407	15064	25	44 385
F	8 569	16,0	45 127	13530	25	40 166	20296	38	33 401
M	12 398	21,3	45 753	19576	34	38 576	29364	50	28 787
A	17 013	32,0	36 124	26862	51	26 274	40293	76	12 843
M	19 442	37,2	32 871	30697	59	21 615	46046	88	6 266
J	18 503	38,0	30 238	29216	60	19 525	43824	90	4 917
J	19 917	40,1	29 800	31448	63	18 268	47173	95	2 544
A	18 449	37,1	31 268	29130	59	20 587	43696	88	6 021
S	15 864	31,3	34 761	25048	49	25 577	37572	74	13 053
O	11 750	21,1	43 807	18552	33	37 004	27828	50	27 728
N	6 686	11,8	50 218	10557	19	46 347	15836	28	41 068
D	4 492	7,6	54 309	7092	12	51 708	10638	18	48 162

SOLAR RADIATION	J	F	M	A	M	J	J	A	S	O	N	D	Total
SOLAR RADIATION (horizontal surface, kWh/m2)	30	50	92	125	168	166	179	153	108	73	34	22	1 201
Optimal angle	64	59	47	32	19	12	16	28	43	56	62	64	
SOLAR RADIATION (at optimal angle, kWh/m2)	49	75	120	140	170	160	177	166	135	109	54	36	1 389
SOLAR RADIATION (vertical surface, kWh/m2)	50	70	96	90	91	79	90	99	100	99	54	36	952

Calculation of solar thermal contribution - Hungary -Nyírbogát														
			Option A	Option B	Option C							Option A	Option B	Option C
	E - solar radiation at the 45 °angel [kWh/m2]	reducing factor due to south orientation	brutto collector surface [m2]	brutto collector surface [m2]	brutto collector surface [m2]	W_0 - optical losses of the collector	Wv - thermal losses	η	T outside air ℃	T collector	W_N - effective heat capacity kWh/m2	total heat capacity kWh	total heat capacity kWh	total heat capacity kWh
J	55	1	38	60	90	7,94	0,31	0,85	-1,6	90	46	1 766,78	2 789,66	4 184,49
F	74	1	38	60	90	10,67	0,30	0,85	1,1	90	63	2 380,36	3 758,47	5 637,70
M	106	1	38	60	90	15,42	0,28	0,85	5,6	90	91	3 443,96	5 437,83	8 156,74
A	146	1	38	60	90	21,14	0,27	0,85	11,1	90	124	4 725,76	7 461,72	11 192,58
M	167	1	38	60	90	24,14	0,25	0,85	15,9	90	142	5 400,44	8 527,01	12 790,51
J	158	1	38	60	90	22,98	0,24	0,85	19	90	135	5 139,80	8 115,48	12 173,22
J	171	1	38	60	90	24,73	0,23	0,85	20,8	90	146	5 532,60	8 735,68	13 103,53
A	158	1	38	60	90	22,91	0,24	0,85	20,2	90	135	5 124,80	8 091,78	12 137,67
S	136	1	38	60	90	19,71	0,25	0,85	16,4	90	116	4 406,57	6 957,74	10 436,61
O	101	1	38	60	90	14,61	0,27	0,85	11	90	86	3 263,82	5 153,41	7 730,11
N	58	1	38	60	90	8,34	0,29	0,85	4,8	90	49	1 857,29	2 932,57	4 398,85
D	39	1	38	60	90	5,62	0,30	0,85	0,4	90	33	1 247,71	1 970,07	2 955,10

Appendix 3: Economic calculation

Investment costs €		Technical Option A 25 %		Technical Option B 39%		Technical Option C 58%	
Parameter	*Depreciation term (years)*		Gross		Gross		Gross
Vacuum tube collector	25	38 m2	21 947	60 m2	30 495	90 m2	45 742
Water storage tank	25	3000 l	9 796	5000 l	7 595	7000 l	10 126
Pump, regulator, liquid, well (150 m)			6 696		5 107		7 071
Planning & Installation			4 464		3 143		7 464
Total			37 755		46 340		70 404

Operation costs per year €			
Parameter	Option A	Option B	Option C
Electricity	142	224	336
Maintenance	378	463	704
Total	519	687	1 040
Revenue	1 year		
Savings (natural gas)	1746	2 756	4 135

		Option A		Option B		Option C	
	E including circulation losses [MJ / month]	solar fraction [MJ/month]	E contributed by wood chips [MJ/month]	solar fraction [MJ/month]	E contributed by wood chips [MJ/month]	solar fraction [MJ/month]	E contributed by wood chips [MJ/month]
J	59 449	6 360	53 089	10 043	49 407	15064	44 385
F	53 696	8 569	45 127	13 530	40 166	20296	33 401
M	58 152	12 398	45 753	19 576	38 576	29364	28 787
A	53 136	17 013	36 124	26 862	26 274	40293	12 843
M	52 312	19 442	32 871	30 697	21 615	46046	6 266
J	48 741	18 503	30 238	29 216	19 525	43824	4 917
J	49 717	19 917	29 800	31 448	18 268	47173	2 544
A	49 717	18 449	31 268	29 130	20 587	43696	6 021
S	50 625	15 864	34 761	25 048	25 577	37572	13 053
O	55 556	11 750	43 807	18 552	37 004	27828	27 728
N	56 904	6 686	50 218	10 557	46 347	15836	41 068
D	58 801	4 492	54 309	7 092	51 708	10638	48 162
	646 806	159 444	487 363	251 753	395 053	377 630	269 177
kWh	179 668	44 290		69 931		104 897	

Source	Price €/TJ	Price €/MJ	Solar based energy (MJ)	Wood chips substituted by solar in € (Savings)	
Raw material cost Source (wood chips heating system)	10949	0,010949	159 444	1 746	Option A
Raw material cost Source (wood chips heating system)			251 753	2 756	Option B
Raw material cost Source (wood chips heating system)			377 630	4 135	Option C

Option A

time horizon	25 years
Financing	100% equity
Discount rate (%)	5,0

Overview input data	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Investment	37755	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Electricity	0,000	-141,7	-143,9	-146,0	-148,2	-150,4	-152,7	-155,0	-157,3	-159,7	-162,0	-164,5	-166,9	-169,5	-172,0	-174,6	-177,2	-179,9	-182,5	-185,3	-188,1	-190,9	-193,7	-196,7	-199,6	-202,6
Maintenance	0,000	-377,5	-383,2	-389,0	-394,8	-400,7	-406,7	-412,8	-419,0	-425,3	-431,7	-438,2	-444,7	-451,4	-458,2	-465,0	-472,0	-479,1	-486,3	-493,6	-501,0	-508,5	-516,1	-523,9	-531,7	-539,7
Revenue	0,000	1745,7	1807,4	1871,2	1937,2	2005,6	2076,4	2149,7	2225,6	2304,1	2385,5	2469,7	2556,9	2647,1	2740,6	2837,3	2937,5	3041,1	3148,5	3259,6	3374,7	3493,8	3617,2	3744,9	3877,0	4013,9

national financial support of 50% of total investment costs 18 877

2. Economic analysis without financial support

Cash flow	-37754,9	1226,5	1280,3	1336,2	1394,2	1454,5	1517,0	1581,9	1649,3	1719,2	1791,7	1867,0	1945,2	2026,3	2110,4	2197,7	2288,2	2382,2	2479,7	2580,8	2685,7	2794,4	2907,3	3024,3	3145,7	3271,6
Accumulated cash flow	-37754,9	-36528,5	-35248,2	-33912,0	-32517,8	-31063,3	-29546,4	-27964,5	-26315,2	-24596,0	-22804,3	-20937,3	-18992,1	-16965,9	-14855,5	-12657,8	-10369,6	-7987,4	-5507,7	-2926,9	-241,3	2553,2	5460,4	8484,8	11630,5	14902,1
Discounted cashflow	-37754,9	1168,1	1161,3	1154,2	1147,0	1139,6	1132,0	1124,2	1116,3	1108,2	1100,0	1091,6	1083,1	1074,6	1065,9	1057,1	1048,3	1039,3	1030,3	1021,3	1012,2	1003,0	993,9	984,6	975,4	966,1
Accumulated discounted cashflow	-37754,9	-36586,9	-35425,6	-34271,4	-33124,3	-31984,7	-30852,8	-29728,5	-28612,3	-27504,1	-26404,1	-25312,5	-24229,3	-23154,8	-22088,9	-21031,8	-19983,5	-18944,2	-17913,8	-16892,5	-15880,3	-14877,3	-13883,4	-12898,8	-11923,4	-10957,3

3. Economic analysis with the national financial support

Cash flow	-18877,5	1226,5	1280,3	1336,2	1394,2	1454,5	1517,0	1581,9	1649,3	1719,2	1791,7	1867,0	1945,2	2026,3	2110,4	2197,7	2288,2	2382,2	2479,7	2580,8	2685,7	2794,4	2907,3	3024,3	3145,7	3271,6
Accumulated cash flow	-18877,5	-17651,0	-16370,7	-15034,5	-13640,3	-12185,9	-10668,9	-9087,0	-7437,8	-5718,6	-3926,8	-2059,8	-114,6	1911,6	4022,0	6219,7	8507,9	10890,1	13369,8	15950,5	18636,2	21430,6	24337,9	27362,2	30507,9	33779,5
Discounted cashflow	-18877,5	1168,1	1161,3	1154,2	1147,0	1139,6	1132,0	1124,2	1116,3	1108,2	1100,0	1091,6	1083,1	1074,6	1065,9	1057,1	1048,3	1039,3	1030,3	1021,3	1012,2	1003,0	993,9	984,6	975,4	966,1
Accumulated discounted cashflow	-18877,5	-17709,4	-16548,2	-15393,9	-14246,9	-13107,3	-11975,3	-10851,1	-9734,8	-8626,6	-7526,6	-6435,0	-5351,9	-4277,3	-3211,4	-2154,3	-1106,0	-66,7	963,7	1985,0	2997,2	4000,2	4994,1	5978,7	6954,1	7920,2

National subsidy: 50% of total investment

Option B

time horizon	25 years
Financing	100% equity
Discount rate (%)	5,0

Overview input data	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Investment	46340	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Electricity	0,000	-223,8	-227,1	-230,5	-234,0	-237,5	-241,1	-244,7	-248,4	-252,1	-255,9	-259,7	-263,6	-267,6	-271,6	-275,6	-279,8	-284,0	-288,2	-292,6	-296,9	-301,4	-305,9	-310,5	-315,2	-319,9
Maintenance	0,000	-463,4	-470,3	-477,4	-484,6	-491,8	-499,2	-506,7	-514,3	-522,0	-529,8	-537,8	-545,9	-554,0	-562,4	-570,8	-579,4	-588,0	-596,9	-605,8	-614,9	-624,1	-633,5	-643,0	-652,6	-662,4
Revenue	0,000	2756,4	2853,7	2954,5	3058,8	3166,7	3278,5	3394,2	3514,1	3638,1	3766,5	3899,5	4037,1	4179,7	4327,2	4479,9	4638,1	4801,8	4971,3	5146,8	5328,5	5516,6	5711,3	5912,9	6121,6	6337,7

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2. Economic analysis without financial support

Cash flow	-46339,6	2069,2	2156,2	2246,5	2340,2	2437,4	2538,2	2642,9	2751,4	2864,0	2980,8	3102,0	3227,7	3358,0	3493,3	3633,5	3779,0	3929,8	4086,2	4248,4	4416,6	4591,0	4771,9	4959,4	5153,8	5355,4
Accumulated cash flow	-46339,6	-44270,4	-42114,1	-39867,6	-37527,4	-35090,0	-32551,8	-29909,0	-27157,6	-24293,6	-21312,7	-18210,8	-14983,1	-11625,0	-8131,8	-4498,2	-719,3	3210,5	7296,7	11545,1	15961,8	20552,8	25324,7	30284,1	35438,0	40793,4
Discounted cashflow	-46339,6	1970,7	1955,8	1940,6	1925,3	1909,8	1894,1	1878,2	1862,3	1846,2	1830,0	1813,7	1797,3	1780,8	1764,3	1747,8	1731,2	1714,6	1697,9	1681,2	1664,6	1647,9	1631,3	1614,6	1598,0	1581,5
Accumulated discounted cashflow	-46339,6	-44368,9	-42413,1	-40472,5	-38547,2	-36637,5	-34743,4	-32865,2	-31002,9	-29156,8	-27326,8	-25513,1	-23715,8	-21935,0	-20170,7	-18422,9	-16691,7	-14977,1	-13279,2	-11598,0	-9933,4	-8285,5	-6654,2	-5039,6	-3441,5	-1860,1

3. Economic analysis with the national financial support

Cash flow	-23169,8	2069,2	2156,2	2246,5	2340,2	2437,4	2538,2	2642,9	2751,4	2864,0	2980,8	3102,0	3227,7	3358,0	3493,3	3633,5	3779,0	3929,8	4086,2	4248,4	4416,6	4591,0	4771,9	4959,4	5153,8	5355,4
Accumulated cash flow	-23169,8	-21100,6	-18944,3	-16697,8	-14357,6	-11920,2	-9382,0	-6739,2	-3987,8	-1123,8	1857,1	4959,0	8186,7	11544,8	15038,0	18671,6	22450,5	26380,3	30466,5	34714,9	39131,6	43722,6	48494,5	53453,9	58607,8	63963,2
Discounted cashflow	-23169,8	1970,7	1955,8	1940,6	1925,3	1909,8	1894,1	1878,2	1862,3	1846,2	1830,0	1813,7	1797,3	1780,8	1764,3	1747,8	1731,2	1714,6	1697,9	1681,2	1664,6	1647,9	1631,3	1614,6	1598,0	1581,5
Accumulated discounted cashflow	-23169,8	-21199,1	-19243,3	-17302,7	-15377,4	-13467,7	-11573,6	-9695,4	-7833,1	-5987,0	-4157,0	-2343,3	-546,0	1234,8	2999,1	4746,9	6478,1	8192,7	9890,6	11571,8	13236,4	14884,3	16515,6	18130,2	19728,3	21309,7

National subsidy: 50% of total investment

Option C

time horizon	25 years
Financing	100% equity
Discount rate (%)	5,0

Overview input data	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Investment	70404	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Electricity	0,000	-335,7	-340,7	-345,8	-351,0	-356,3	-361,6	-367,0	-372,5	-378,1	-383,8	-389,6	-395,4	-401,3	-407,4	-413,5	-419,7	-426,0	-432,4	-438,8	-445,4	-452,1	-458,9	-465,8	-472,8	-479,8
Maintenance	0,000	-704,0	-714,6	-725,3	-736,2	-747,2	-758,5	-769,8	-781,4	-793,1	-805,0	-817,1	-829,3	-841,8	-854,4	-867,2	-880,2	-893,4	-906,8	-920,4	-934,2	-948,2	-962,5	-976,9	-991,6	-1006,4
Revenue	0,000	4134,6	4280,6	4431,7	4588,1	4750,1	4917,8	5091,4	5271,1	5457,2	5649,8	5849,2	6055,7	6269,5	6490,8	6719,9	6957,1	7202,7	7457,0	7720,2	7992,7	8274,9	8567,0	8869,4	9182,5	9506,6

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2. Economic analysis without financial support

Cash flow	-70404,3	3094,9	3225,3	3360,5	3500,9	3646,6	3797,7	3954,5	4117,2	4285,9	4461,0	4642,6	4831,0	5026,4	5229,0	5439,2	5657,2	5883,3	6117,8	6360,9	6613,1	6874,5	7145,6	7426,7	7718,2	8020,3
Accumulated cash flow	-70404,3	-67309,4	-64084,1	-60723,6	-57222,7	-53576,1	-49778,4	-45823,9	-41706,8	-37420,8	-32959,8	-28317,2	-23486,3	-18459,9	-13230,8	-7791,6	-2134,4	3749,0	9866,8	16227,7	22840,8	29715,3	36860,9	44287,6	52005,8	60026,1
Discounted cashflow	-70404,3	2947,5	2925,4	2903,0	2880,2	2857,2	2833,9	2810,4	2786,7	2762,7	2738,7	2714,4	2690,1	2665,6	2641,0	2616,4	2591,6	2566,9	2542,1	2517,2	2492,4	2467,6	2442,7	2417,9	2393,2	2368,4
Accumulated discounted cashflow	-70404,3	-67456,8	-64531,4	-61628,4	-58748,2	-55891,0	-53057,1	-50246,7	-47460,1	-44697,3	-41958,7	-39244,2	-36554,2	-33888,6	-31247,5	-28631,2	-26039,5	-23472,6	-20930,6	-18413,3	-15920,9	-13453,4	-11010,7	-8592,7	-6199,6	-3831,1

3. Economic analysis with the national financial support

Cash flow	-35202,2	3094,9	3225,3	3360,5	3500,9	3646,6	3797,7	3954,5	4117,2	4285,9	4461,0	4642,6	4831,0	5026,4	5229,0	5439,2	5657,2	5883,3	6117,8	6360,9	6613,1	6874,5	7145,6	7426,7	7718,2	8020,3
Accumulated cash flow	-35202,2	-32107,3	-28882,0	-25521,4	-22020,5	-18373,9	-14576,2	-10621,7	-6504,6	-2218,7	2242,3	6884,9	11715,9	16742,3	21971,3	27410,6	33067,8	38951,1	45068,9	51429,9	58043,0	64917,5	72063,1	79489,8	87208,0	95228,3
Discounted cashflow	-35202,2	2947,5	2925,4	2903,0	2880,2	2857,2	2833,9	2810,4	2786,7	2762,7	2738,7	2714,4	2690,1	2665,6	2641,0	2616,4	2591,6	2566,9	2542,1	2517,2	2492,4	2467,6	2442,7	2417,9	2393,2	2368,4
Accumulated discounted cashflow	-35202,2	-32254,6	-29329,2	-26426,2	-23546,0	-20688,8	-17854,9	-15044,6	-12257,9	-9495,2	-6756,5	-4042,1	-1352,0	1313,6	3954,6	6571,0	9162,6	11729,5	14271,6	16788,8	19281,2	21748,8	24191,5	26609,4	29002,6	31371,0

National subsidy: 50% of total investment