

Article Info

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Abstract

These days, professionals face more and more difficulties due to the rising need for energy. While adhering to global standards, shifting public perceptions encourage the use of renewable energy sources and improve electricity consumption efficiency. There are a number of challenges and activities associated with replacing the present outdated power plant system that may not have been considered so far. Applying complete life cycle analysis is crucial to ensuring sustainable energy production in order to provide a precise, thorough picture of these.

Keywords: electric power, power plants, renewable energy, life-cycle assessment

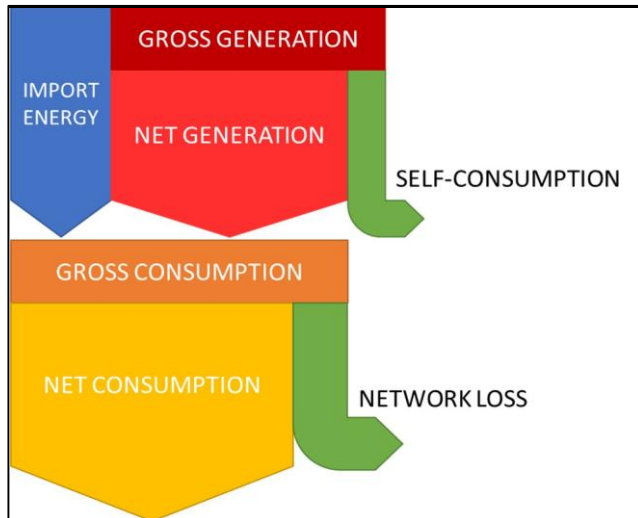
1. Structure of the Hungarian electric power system, electric power distribution

The electric power system's job is to consistently meet the energy needs of consumers. Reaching this objective is a difficult undertaking. Electricity is a commodity that is either difficult to store or cannot be kept in large amounts.¹ There must also always be an adequate supply of electric energy. However, the system may experience brief disruptions and volatility. On the other hand, customers' energy usage cannot be controlled or limited. For continuous energy supply, forecasts derived from the analysis of shifts in consumer behavior may be employed with excellent accuracy.

It's noteworthy to note that the electric sector, which generates power, is the biggest user. Numerous high-performance pumps and ventilators are run by power plants. Furthermore, it is necessary to cover the functioning of many lower performance equipment (such lights and instruments). Power plants' self-consumption might vary greatly from one another. The net electricity output, which may be split between residential and commercial users, is obtained by deducting the power plant's self-consumption from the electricity produced. The Hungarian Electricity System's self-consumption in the 1980s and 1990s was between 8 and 9%. This rate is now lower, at around 6-7%. The large electric grid causes a network loss in addition to self-consumption, which raises net power demand by about 10%.³ From the above, it is clear that the gross consumption is the sum of the net consumption and the network losses. Furthermore, the total home consumption is determined by adding the power plant system's self-consumption and gross consumption. Domestic energy output has not been able to meet all domestic needs in recent years. Because overseas manufacturers are also engaged in meeting local demand due to the interconnectedness of many nations' electric systems, the shortfall was not felt. In terms of the electric industry, Hungary is regarded as a transit nation. We mostly buy electricity from our neighbors in the north and send it to the southern Balkan nations. Our so-called electricity import balance is positive every year because we purchase more power than we transport. The domestic electricity shortfall is covered by this residual amount.⁴

Figure 1: Hungarian electric power balance chart

The role of power stations in the Hungarian electric power system



Within the electric power system, power plants, also known as power stations, are categorized in a number of ways: First, power plants may be classified as either cooperative or non-cooperative depending on how they operate. The national power network governs how cooperative power plants function. Non-cooperative power plants provide energy to a single customer or a group of customers while operating in island mode, which isolates them from the national power grid. Differentiating between public and industrial power plants is an additional grouping option. Industrial power plants are built to serve small consumer groups or industrial units. They only run in response to the plant's programmed needs. If there is excess energy that the plant does not consume, they may sell it to the public power grid. Public power plants are built especially to provide the public power grid, and they are committed to satisfying the needs of all consumers. The kind of energy source may be used to categorize public power plants. Approximately 5% of the energy generated in recent years came from biomass fuel, over one-third came from fossil fuels, and half came from nuclear power plants. Renewable energy and other sources provided the remainder. We may discuss base load, load following, and peaking power plants while delving into the function of public power plants in load balancing.

There wouldn't be a steady supply of energy without base load power plants. These power plants operate almost continuously at steady power and have a very high yearly utilization time (more than 5500 hours/year). Base load power plants need constant operation due to their lengthy startup and shutdown periods and lack of flexibility. These power plants must be contemporary and up-to-date in order to guaranty safe and effective operation, as they account for a significant portion of the electricity produced. Additionally, base load power plants often use inexpensive fuel to maintain low energy costs. Paks Nuclear Power Plant is one example of a base load power plant in Hungary. But unlike base load power plants, which run continuously, the demand for energy fluctuates all the time. Keeping up with load variations is the responsibility of load-following power plants. They can adapt to daily or weekly variations in the demand for energy, making them more flexible than base load power plants. Older base load power plants, such as Gönyü Power Plant, Tisza II Power Plant, and Dunamenti Erőműge Power Plant, often deteriorate with time into load-following power plants. Peaking power plants only run when the demand for energy is at its highest. They spend fewer than

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2000 hours a year at their peak. For this reason, it is only advisable to construct inexpensive power plants with poor efficiency and costly fuel. Gas turbine power plants are one kind of such power plant. Furthermore, it is possible to put up so-called stand-by power plants, although this should only be done in the event of an exceptionally high consumer demand. The maximum number of hours that reserve power plants may run each year is 100–200.⁵

In recent years, the use of renewable energy sources has grown in importance as a component of global and EU energy strategies. The cause of this is nearly the same for all nations: energy prices have skyrocketed in recent years due to the steady rise in energy demand and the corresponding demand for fossil fuels, as well as the gradual depletion of available reserves (apart from the decline in demand and the corresponding drop in prices brought on by the global economic crisis). It seems probable that this trend will persist in the future. High energy costs cause nations that import most of their fossil fuel requirements to continuously withdraw their cash. This is a very unfavorable economic scenario for them.^{6, 7} The residual supplies are concentrated in a few regions of the globe (mostly in the Middle East and post-Soviet republics) due to the steady depletion of fossil fuel deposits, which significantly reduces supply chain diversity. This makes nations without their own stockpiles less secure in their energy supply, making them politically vulnerable. The usage of fossil fuels, which have accumulated over millions of years, causes bound contaminants to be quickly released into the Earth's atmosphere, aggravating these issues. These pollutants are harmful to the atmosphere and have the potential to initiate or intensify processes (such climate change and global warming) that might soon cause significant harm and fatalities. Making economics and energy more "green" and energy-efficient comes at a high cost to the present generation; if this isn't done, future expenses will need to be increased. Hungary is particularly concerned about the negative impacts of using fossil fuels since it depends on imports for one-third of its power requirements and around two-thirds of its basic energy sources. The problem is made worse by the fact that 40% of Hungary's main energy comes from natural gas, the majority of which may be received from a single source via the gas pipeline that travels through Ukraine. The country's energy consumption is only slightly increasing, but since local primary energy source extraction is gradually declining, the percentage of imported energy sources is continuously rising. Hungary's energy usage is excessive in relation to its economic success, as shown by the fact that its energy intensity is much lower than that of wealthy nations.⁸

2. EU objectives

In recent years, the European Union has set more ambitious goals to boost energy efficiency and the use of renewable energy inside its borders in order to prevent the adverse impacts mentioned above. The obligatory rules and goals for Hungary's usage of renewable energy will be examined in the sections that follow. By 2020, the European Member States must contribute 20% of their gross energy consumption to renewable energy, according to Directive 2009/28/EC of the European Parliament and Council on the promotion of the use of energy from renewable sources. Hungary has pledged to use 13% of its energy from renewable sources.

Additionally, according to the Directive, every Member State must make sure that at least 10% of the energy used in transportation comes from renewable sources. In order to achieve this, the proportion of biocomponents in fuels was raised starting on January 1, 2020.⁹

(percentage, %)										
Denomination	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Final gross electricity consumption	7,0	7,1	6,4	6,1	6,6	7,3	7,3	7,3	7,5	8,3
Heating and cooling	17,0	18,1	20,0	23,3	23,7	21,3	21,3	21,0	19,9	18,1
Transport	5,8	6,1	6,1	5,9	6,2	6,9	7,1	7,6	7,6	7,7
Final gross energy consumption	11,7	12,7	14,0	15,5	16,2	14,6	14,5	14,3	13,5	12,5

Table 1: Proportion of renewable energy distribution in final gross energy consumption¹⁰

(terajoule, TJ)					
Generation	2014	2015	2016	2017	2018
Domestic waste, renewable	1 845	2 756	2 766	1 930	1 626
Biomass	98 928	105 221	100 570	98 952	89 262
Biogas	3 323	3 335	3 708	4 141	3 850
Biofuels	12 823	16 030	17 187	17 629	18 699
Solar	647	956	1 346	1 749	2 759
Geothermal	3 800	4 426	5 026	5 590	5 866
Hydropower	1 084	842	932	792	799
Wind	2 365	2 495	2 462	2 729	2 185

Table 2: Generation of primary renewable energy sources¹¹

3. Power plant performance today

The installed capacity has decreased from 10,000 MW to 8,500 MW during the last ten years, according to Hungary's power plant performance statistics. The decommissioning of outdated power plants and the absence of new power plant units may be used to explain this occurrence.

9 Bodnár (2017). 10 Hungarian Authority for Energy and Public Utility Regulation (2020). The production capacity of power plants that don't often run, including the Tisza II Power Plant, the Debrecen and Nyíregyháza Combined Cycle Plants, and the Dunamenti Erőműge Power Plant, is included in this performance statistics. Twelve

This indicates that the 1,200 MW of spare capacity that existed in 2012 has almost vanished. Since 5% of the installed capacity must function as reserve power capacity for the electrical system to run safely, imports are presently the only way to guaranty this in Hungary. Given the current patterns of electricity use, peak daily consumption often surpasses 6,500 MW of power demand; thus, our nation's

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electricity supply cannot be met without the use of imported energy. Hungary now has 17 big power plants with a gross installed capacity of 7,415 MW (net capacity of 6,916 MW). However, because to the power plants' self-consumption and the so-called persistent deficit, this electricity cannot be completely used. Power plants that are active but not in use cause a permanent deficit. 5,964 MW of power plant capacity is available due to the constant shortfall of 1,222 MW, plus 1,524 MW of net electricity from minor power plants.

(GWh)					
Energy source	2014	2015	2016	2017	2018
Nuclear	15 649	15 834	16 054	16 098	15 733
Coal	6 114	5 908	5 758	5 098	4 834
Natural gas	4 240	5 108	6 479	7 838	7 234
Oil	76	77	63	85	90
Biomass	1 702	1 660	1 493	1 646	1 799
Biogas	287	293	333	348	331
Domestic waste, renewable	137	208	245	160	162
Hydropower	301	234	259	220	222
Wind	657	693	684	758	607
Solar	67	141	244	349	620
Geothermal	0	0	0	1	12
Other	173	204	290	284	360
Sum-total	29 403	30 360	31 902	32 885	32 004

Table 3: Gross electric energy generation

Bodnár 12 (2017). 13 The Energy and Public Utility Regulation Authority of Hungary (2020).

4. Power plant performance in the future

By 2030, the total domestic peak load would exceed 7,500 MW due to the rising trend in consumption. These requirements must be met by future power plant layouts. In the near future, we'll observe how power plant capacity changes. The Paks Nuclear Power Plant's current units are around 35 years old. Their decommissioning is slated to begin in 2032. The majority of power plants constructed in the 1950s and 1960s have already been shut down and rebuilt in more recent decades. Similar-aged power plants are nearing the end of their design lifespan, including the oldest units of the Mafra Power Plant and the power plants at Oroszló and Bakony. The Quick-start Reserve Power Plants (Lópezzinci, Litér, and Sajószöged) will eventually also need replacements. Consequently, by 2025, the capacity of the existing power plant will be decreased to around 5,300 MW, which will also not be completely used. However, Hungary's reliance on imports will increase significantly as demand continues to climb and peak loads are expected to surpass 7,000 MW by that time.¹⁴ Power plant construction projects that are now in progress will be completed in the medium future. Older power stations are still being decommissioned. The greatest power producing unit's capacity will rise to 1,200 MW with the building of Paks II Nuclear Power Plant, necessitating an extra 800 MW of tertiary system reserve. A workable method of energy storage is also needed to offset the varying system demands because of the notable rise in the percentage of renewable power. Investing in renewable technologies won't need financial backing since they will be so inexpensive.¹⁵

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The cost of biomass power plants has not changed, but the cost of solar and wind power plants has been steadily declining and will continue to do so, according to research on the particular investment costs of renewable energy. Open-cycle gas turbine power plants now have the lowest investment costs among conventional power plants and will continue to do so in the future. Bituminous coal and lignite power facilities will continue to be expensive. The issue with gas-fired power plants is that their operational expenses are heavily reliant on gas prices, which are still a significant issue in Hungary today. In Hungary, the total capacity of household-scale (distributed) solar power plants—that is, solar power plants with an integrated peak output of less than 50 kW—is increasing at an exponential rate. Solar power plant construction has advanced at the fastest pace of any form of power plant. In 2016, the percentage of domestic power produced by renewable energy reached 14.19%, surpassing the 2020 goal of 13%. Biomass fuel accounts for 47% of Hungary's electricity output, followed by wind energy (22%), biogas (10%), hydropower (7%), solar energy (6%), and other sources (8%). It is evident that biomass, a combustion-based energy source, plays a significant role in the production of renewable energy. Let's look at the current capacity and explore our options.¹⁶

Since 2010, the use of wind energy has stagnated. Currently, the nation has 37 wind farms with about 170 wind turbines. Establishing new farms is challenging due to the present rules. This is made worse by the fact that some wind turbines have been temporarily shut down as a result of improper maintenance.

There is a significant potential associated with solar power plants' increased peak capacity. Recent years have seen notable advancements in photovoltaic power plants. In 2010, the total capacity was only 2 MW; in 2014, it was 77 MW; in 2018, it was 640 MW; and in 2019, it was 960 MW. Both high-capacity solar farms and distributed solar power plants are responsible for the exponential increase. With 20.6 MW, Paks is now the biggest solar power facility. Recent years have seen the development of solar power plants with very large capacities at Visonta, Százhalombatta, Felsőzsolca, and Škkábrück. A number of power plants are now under construction.

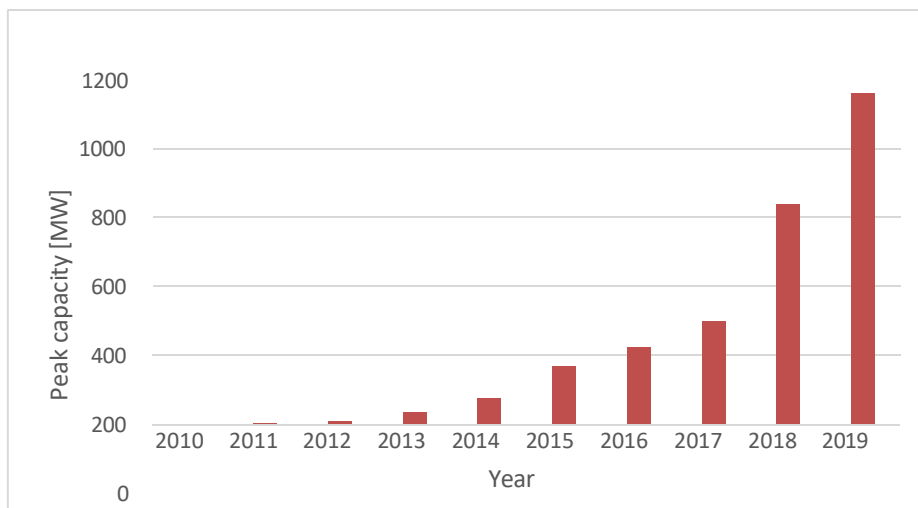


Figure 2: Peak capacity of the Hungarian solar electric power generation in the last

Hungary only has one geothermal power station with a 3 MW installed capacity. It was founded in Tura in 2017. Although there is a lot of room for growth and the development of new geothermal power plants, the process is dangerous and time-consuming, both financially and ecologically. The low water temperature implies that only poor-efficiency (6–10%) ORC (Organic Rankine Cycle) power plants can be constructed, which further taints the notion of geothermal energy. A combined heat and power plant, also known as a cogeneration plant, is much more economical when it comes to geothermal power plants. Like the Tura plant, a combined heat and power plant generates electricity as well as useable heat for district heating. Twenty About 15% of Hungary's biomass potential is presently being used. A new power plant with a total capacity of around 2,800 MW may be constructed if a biomass-fired power plant were to reach its full potential. It goes without saying that we must consider expanding solar and wind power plants, but we also need to consider using municipal solid waste and refuse-derived fuels (also known as secondary fuels) in power plants.²¹ The anticipated composition of Hungary's total power plant output by 2030 is shown in Figure 3. Gas and oil-fired power plants, as well as the Paks II Nuclear Power Plant, will take over if the Mafra Power Plant and the Paks I Nuclear Power Plant are shut down and no further renewable power plants are constructed. The nuclear power plant will continue to exist. The most potent base load power plant in Hungary is the Paks II Nuclear Power Plant. But because none of these facilities run on homegrown fuel, our country would become heavily reliant on imports.^{22, 23, and 24}

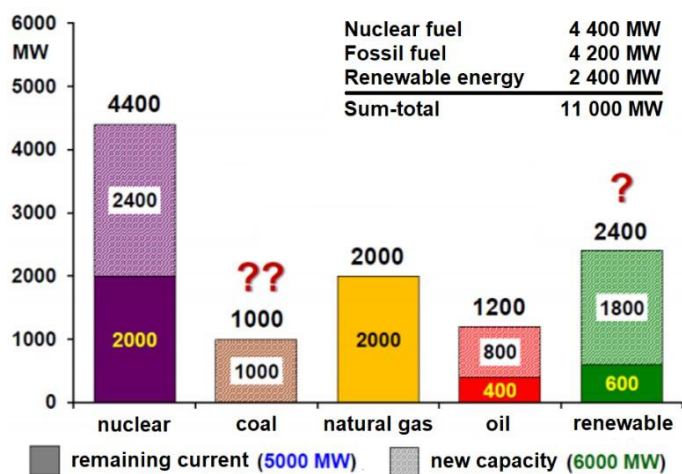


Figure 3: Prognosis of installed power plant capacities by 2030²⁵

While freshly constructed lignite power plants have the potential to attain 43% efficiency, the Mafra Power Plant's present efficiency is just 29%. Because of this, it is both essential and justified to construct a new power plant in the Mafra. Who will build the two 500 MW units is the crucial issue. The main issue is that there will be 5,400 MW of base load power plants (coal and atomic) with rigid regulations.²⁶

The fuel mix of all domestic power production by 2030 is shown in Figure 3. It is evident that, with its 40% share, nuclear energy will take the lead in comparison to 2020. Hungary's reliance on natural gas will drastically decline when the overall capacity of gas-fired power stations is reduced by 900

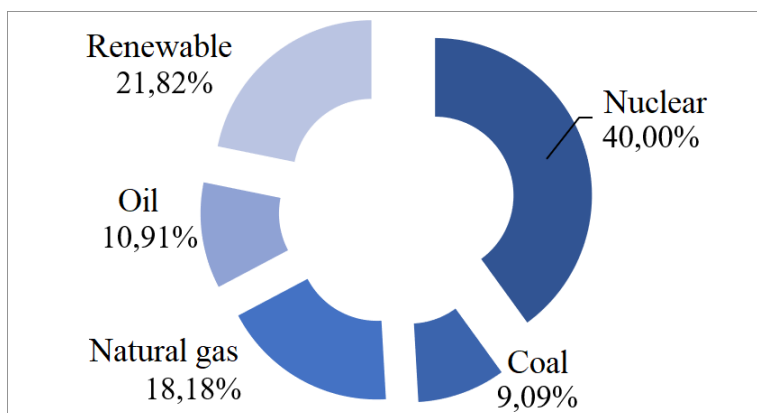


Figure 4: Prognosis of total domestic power generation by fuel by 2030³⁰

By 2030, Hungary's power plant layout might be designed such that imports are completely unnecessary. Since we anticipate that by 2020, certain energy storage facilities will be integrated into the electrical grid, load fluctuations will be less than in 2020. A fictitious average daily gross output for 2030 is around 5,600 MW. The two units of Paks II are in addition to the existing units of the Paks Nuclear Power Plant. By 2030, each nuclear power plant will have a capacity of 1,200 MW. Gas-fired power plants will need to operate even less than they do now thanks to renewable energy and a much-needed lignite-fired power plant. Even the capacity of Paks II units may need to be lowered at dawn when the system demand is at its lowest, which is far from cost-effective for a base load power plant. If any of the neighboring nations are prepared to purchase the extra energy, exporting it might be one way to fix the issue.^{31, 32, and 33}

In conclusion, in order to replace outdated base load and load-following power plants that are now in operation but will eventually be decommissioned, new power plants will need to be constructed. Replacements are also required for highly flexible peaking power plants. In addition to nuclear energy, Hungary's electric system may be made much more secure by building lignite and biomass-fired power plants, as well as solar and wind power facilities, the costs of which are fast declining.

5. Solar and biomass power plants in Hungary

Hungary's primary renewable energy source is biomass. However, solar power plants have been expanding quickly in recent years, and their construction will probably continue to be crucial in the near future. In 2019, Hungary's installed solar power plants had a peak capacity of 960 MW. This capacity is identical to the Mafra Power Plant's installed capacity. In spite of this, solar power plants produce around 10% less energy annually than the Mafra Power Plant. The yearly peak power utilization rate is more than 90% since the Mafra Power Plant is a base load power plant that can operate continuously at rated capacity (apart from maintenance breaks). Conversely, since they are only exposed to optimal conditions during the day, solar power plants may run at their rated capacity for one to two hours each day. They are unable to generate without sunshine. This implies a 12-hour loss every day. A Gaussian distribution may be used

to characterize the solar energy flow during the intermediate period. Their yearly peak power use rate thus averages around 10%. This rate is typically 8–9% in Northern Hungary, but it may reach 12–14% in Southern Hungary. The active surface area of the solar power plants that are now in operation in Hungary is 6 km², while the kind of installation requires an area of more than 15 km². There are around 4 million solar panels. We would need to travel more than 6,200 kilometers from one solar panel to the next if we were to arrange them in a row.

6. Life Cycle Assessment

These days, one of the most popular methods for environmental management is Life Cycle Assessment (LCA, often called Life Cycle Analysis). It is especially useful for researching goods, services, and technology that may be substituted for one another. Through the study, we are able to evaluate and estimate the environmental consequences that a product produces over its whole life cycle (manufacturing, distribution, consumption, and disposal), including energy costs and resource needs.³⁴

The ISO 14040 standard defines life cycle assessment as "a technique for assessing the environmental aspects and potential impacts associated with a product, by (a) compiling an inventory of relevant inputs and outputs of a product system; (b) evaluating the potential environmental impacts associated with those inputs and outputs; (c) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study."

The life-cycle approach is the outcome of ethical business practices. Without environmental management, no business can succeed over the long term in a market that is always changing. To improve the effectiveness of managing environmental challenges, a variety of environmental management tools and techniques are available. Selecting the best approach is a challenging undertaking that depends on a number of variables, including environmental laws and regulations. A commitment to reduce the negative environmental impacts of production, technology, and service activities and emissions is known as environmental policy. Opportunities to use cleaner manufacturing methods and eco-friendly goods across the whole production and waste management life cycle should be highlighted in order to accomplish this. In the traditional sense, a product or technology may only be deemed environmentally friendly if neither the product nor the waste produced during its manufacture and use have any negative effects on the environment, either directly or indirectly. In this way, a product's ecological balance from "cradle to grave" is favorable to the environment, if not neutral. Since a waste-free manufacturing and consumption process is unthinkable in reality, the use of a positive signal in this instance suggests that the items and technology in question have less negative environmental effects. It is difficult to determine if a product or technology is ecologically friendly, because there are several inconsistencies in reality. Although the importance and value of life cycle assessment (LCA) are undeniable, the approach is often criticized for being time-consuming, expensive, and sometimes inadequate due to the lack or deficiency of data for each life cycle phase. Incorporating LCA findings into product design or the dynamic corporate environmental management system is often challenging or impossible. Life Cycle Assessment was first created as a tool to aid in decision-making by differentiating goods and services from an environmental perspective. It is feasible to focus on certain affects or stages of the product life cycle in order to streamline the entire study.³⁵

A product, process, service, or activity's environmental burdens are assessed through life cycle assessment (LCA), which involves the following steps: (1) identifying and quantifying the energy and materials used and the wastes released to the environment; (2) assessing the impacts of those energy and material uses and releases to the environment; and (3) identifying and evaluating opportunities

for environmental improvements. These days, these applications include marketing, consumer education, government policy, strategic planning, process improvement, and product design. Additionally, they serve as the foundation for consumer education initiatives and eco-labeling around the globe. "A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle" is what ISO 14040:2006 states. The Life Cycle

There are four primary stages of an assessment study (Figure 5): (1) The aim and scope defining phase: the topic and intended purpose of the research determine the scope of an LCA, including the system boundary and degree of detail. Depending on the purpose of a given LCA, its width and depth might vary significantly. (2) The second stage of LCA is the inventory analysis phase, or LCI phase. It is a list of

input/output information related to the system under study. It entails gathering the information required to fulfill the objectives of the specified research. (3) The third stage of the LCA is the effect assessment phase, also known as the LCIA phase. In order to better grasp the environmental importance of a product system's LCI findings, LCIA aims to give further information. (4) The interpretation phase: The last stage of the Life Cycle Assessment (LCA) process involves summarizing and discussing the findings of an LCI, an LCIA, or both in order to draw conclusions, make suggestions, and make decisions that are in line with the aim and scope description.

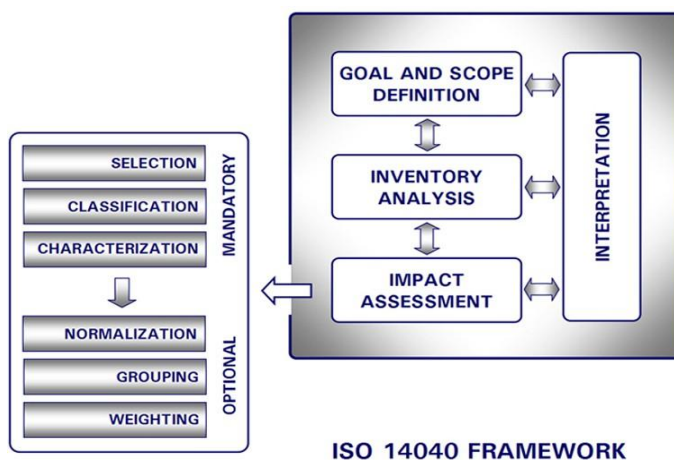


Figure 5: The Life Cycle Assessment framework³⁶

7. Environmental emissions from electricity generation

To ascertain power plants' environmental emissions, life cycle assessments were carried out. For the analysis, the most popular CML evaluation technique was used. One kWh of power produced using a life cycle method is the functional unit. The values of the seven environmental effect categories that are most typical were analyzed. The details of these impact categories are shown in Table 4.

Global Warming Potential	GWP	kg CO₂ equivalent
Acidification Potential	AP	kg SO₂ equivalent
Eutrophication Potential	EP	kg Phosphate equivalent
Ozone Layer Depletion Potential	ODP	kg R11 equivalent
Abiotic Depletion Potential elements	ADP elements	kg Sb equivalent
Abiotic Depletion Potential fossils	ADP fossil	MJ
Human Toxicity Potential	HTP	kg DCB equivalent

Table 4: The most common environmental impact categories

³⁶ Product Design for the Environment (2020).

The environmental effect categories of Slovakia, Hungary, Switzerland, Romania, and the EU-28 are contrasted in the next section. Let's start by looking at the possibilities for global warming independently. Romania has the greatest CO₂ emissions per kWh of power generated, according to the statistics. All three EU member states have GWPs that are greater than the average of the EU's 28 member states, according to statistics from 2019. Switzerland's carbon footprint from energy production is around one-third that of the EU-28.

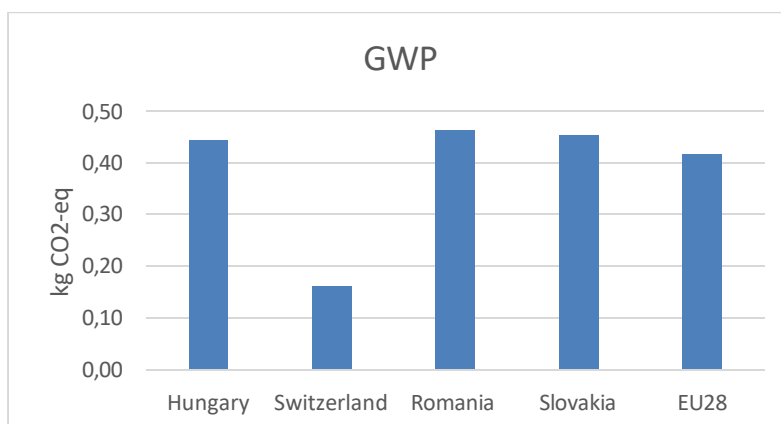
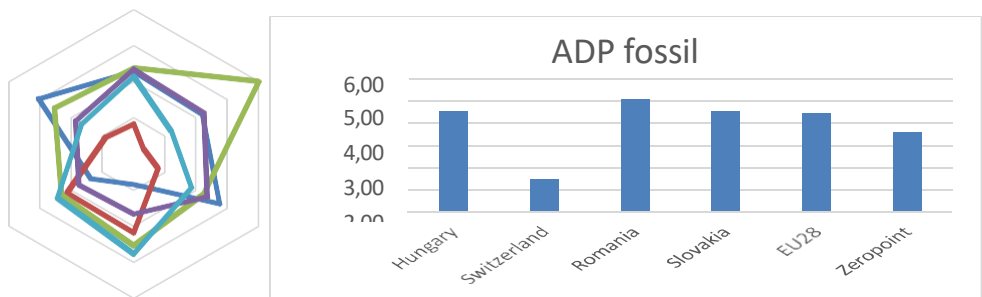


Figure 6: Normalized carbon-dioxide emissions of Hungary, Switzerland, Romania, Slovakia and EU-28

The normalized environmental effect categories for various nations are shown in Figure 7. As may be shown, Switzerland produces one kWh of power with the least environmental effect. Slovakia's performance is precisely average for the EU-28. Hungary is only 1% higher than this figure. Compared to the other nations under investigation, Romania is in a less favorable situation for the majority of environmental effect categories.

The diminishing abiotic fossil sources are seen in figure 8. This category displays the normalized depletion of abiotic fossil fuels by calculating the amount of fossil fuels used for



each unit of energy generated. It is evident that the output of power generation is negative in every country except Switzerland and the EU28. This indicates that we use more fossil fuels than we can generate. Fossil fuel depletion is slower in Switzerland due to the country's high percentage of renewable energy sources.

Lastly, let's examine how Hungary's environmental emissions would change by 2030 if the planned power plant construction were completed and the current power plants were put back into service. We can mostly rely on the substantial building of solar power plants as a source of renewable energy. The carbon footprint of producing power will be lowered by more than 23%, as Figure 9 illustrates. Fossil fuel depletion is predicted to improve by around 10%, even though it will still be negative.

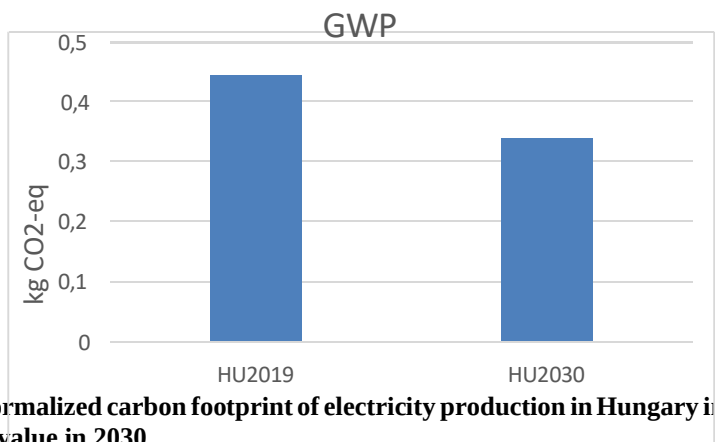


Figure 9: Normalized carbon footprint of electricity production in Hungary in 2019 and its anticipated value in 2030

8. Classification of environmental emissions of power plants

Based on their emissions and effects on the environment, power plants may be divided into two categories. Power plants that enable fuel-to-energy conversion constitute one kind. There are direct emissions from these power plants. Indirect environmental emissions are associated with the other type, which consists of power plants that enable energy-to-energy conversion to produce electric power. Fuel is often burned to extract energy in power plants with direct environmental emissions. Fossil fuels (coal, petroleum, or natural gas), municipal solid waste, fuels obtained from trash, biomass, biofuels, etc. are used in these power plants. Power plants

that use nuclear energy or conventional renewable energy sources, such as hydro, solar, or wind energy, are considered to have indirect environmental emissions. Compared to other power plants with direct environmental emissions, biomass power plants are distinct. Biomass power plants may be regarded as carbon neutral since biomass is a renewable energy source and produces the same amount of carbon dioxide when burned as it absorbs during its lifespan. But the only way to reach a net zero carbon footprint is to cultivate at least as much biomass as we have consumed. But that's also not really accurate. Biofuel manufacturing has advanced dramatically in the last few years. Before being sold in certain nations, biofuels must be mixed with conventional fuels in a specific ratio. Additionally, there are instances when the alternative renewable fuels themselves may be bought at gas stations. However, using and selling biofuels is specifically forbidden and sanctioned in several nations.³⁷ The most popular biofuel is bioethanol, sometimes referred to as E85, a drop-in biofuel that may take the place of fossil fuels. Biodiesel, which is mostly made from vegetable or animal fat, is another popular alternative to gasoline. In 1901, wood gas's potential as a substitute fuel was identified. The military, as well as the civilian and agricultural sectors, utilized it as fuel for cars and machines during the World War II oil scarcity. Over a million wood-gas-powered cars were in use globally by the beginning of the 1940s. This fuel has been almost forgotten by now. Lastly, biogas is a biofuel that may take the place of autogas derived from natural gas. The most crucial need for energy recovery is that a greater percentage of combustible components than non-combustible components must be present in the trash that is released.³⁸ Slag and ash, which need further processing, are the non-combustible components that are still in the solid phase. Landfills and vitrification (slag smelting) are two possible post-treatment methods where metals may be recovered and the remaining inorganic components can be turned into glass. Another need is that the system's energy balance must be positive in order for the energy recovery to be implemented in reality. The waste's energetic use must provide more energy than it requires for processing, which is another crucial component.

Carbon neutrality can only be really attained by taking into account the energy and raw material requirements of power plant construction, operation, and end-of-life decommissioning when calculating the carbon footprint. Accordingly, we may need to cultivate up to 1.5 times more biomass than the power plant utilizes in order to reach net zero carbon footprint. Therefore, in order to maintain a constant capacity, we would need to either grow an increasing number of plants to meet the power plant's consumption or gradually reduce the amount of burned fuel (and thus the power plants' total net capacity) by continuing to grow biomass. When these factors are taken into consideration, the carbon dioxide emissions from energy generated by biomass power plants can potentially be negative.

For various kinds of power plants, the environmental effects of building, operation, and decommissioning should also be taken into account. As a result, indirect emissions from every power plant harm the ecosystem. A power plant's total environmental effect is the sum of its direct and indirect emissions. The majority of emissions from fossil fuel power plants are usually direct (up to 90–95% of total emissions). For biomass power facilities, where indirect emissions predominate, the opposite is true. Only indirect emissions are produced by solar, wind, and hydropower installations. The design lifespan of a power plant is the basis for calculating indirect emissions. The value of the particular indirect emissions per unit of electricity production is calculated by dividing the environmental emissions from power plant construction, operation, and decommissioning by the total quantity of energy produced throughout the design lifespan. Different and diverse main resource needs might be attributed to individual power plants. In essence, the primary resource demand may be divided into raw

needs for energy and materials. Although they are still measured in energy units, the latter may also be stated in terms of material demand since the energies utilized are usually fossil-based and so reflect fossil material needs. The building of renewable energy sources (such as sun, wind, and water) takes a lot of energy and raw materials since their energy density is much lower than that of conventional and biomass power plants. They also need a lot more area. These indicate that their indirect environmental emissions are also greater than those of biomass and conventional power plants.

Aging-related declines in a power plant's efficiency should therefore not be disregarded. This primarily impacts solar power plants because, as solar cells age, they experience more severe deterioration than other kinds of power plants since they are semiconductor devices. The efficiency of solar power plants is further reduced by environmental factors including dust, bird droppings, and other surface contaminants. Consequently, an extra efficiency decrease factor has to be taken into account when it comes to solar power plants.

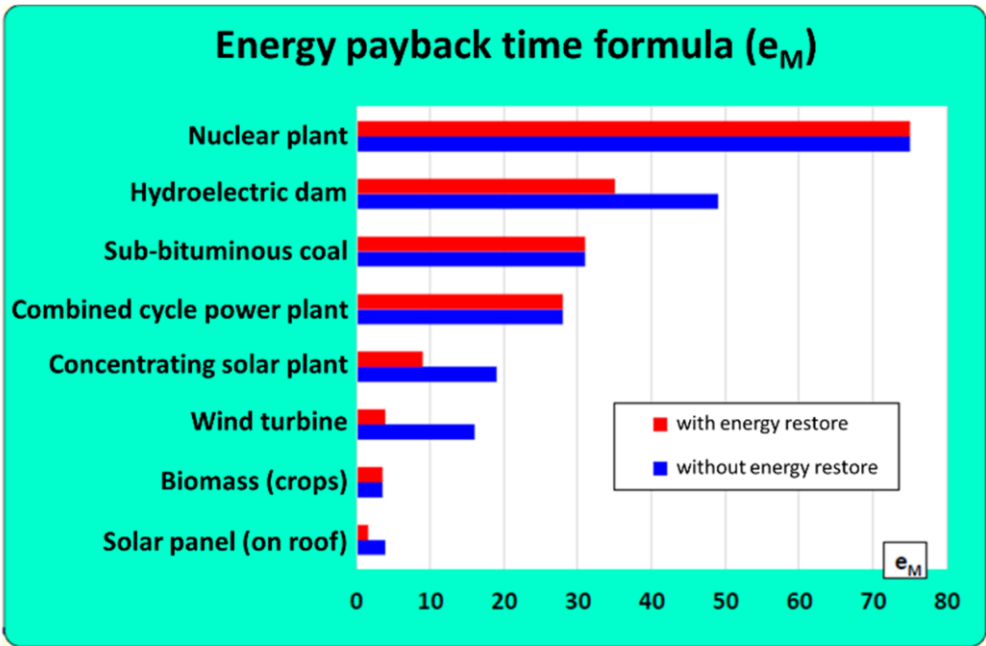


Figure 11: Energy payback time diagram⁴⁰

9. Energy recovery from municipal solid waste

Around the globe, there is debate about how trash is handled. The waste hierarchy, which asserts that prevention and reduction are the best attitudes, is intended to mitigate these conflicts. In addition to technological requirements, recycling and reuse also need for a positive social mindset.

Beyond the issue of waste separation, there are other elements that make the situation worse, such how food-contaminated garbage is handled. Energy recovery, which is effectively a fuel replacement, is a less desirable alternative at the upper level of the hierarchy. The environmental impact of energy recovery is higher, but waste preparation and workflow design are more

simpler. Energy may be recovered from garbage in a variety of methods, including gasification, pyrolysis, traditional incineration, and plasma technology. Waste may be used in power plants to generate electricity, cogeneration power plants to generate electricity and usable heat, or heating plants to provide useful heat for district heating, depending on the technology. In addition to producing solid leftovers and flue gas, burning the trash yields thermal energy. The primary issue and drawback of this process is the flue gas released, which includes greenhouse gasses and potentially dangerous substances. Another drawback is the ash produced throughout the process. Only after cleaning may such byproducts be discharged into the environment. Fermentation is the best method for producing biogas from biodegradable waste. There are several known techniques that use heat therapy. In a more precise sense, energy recovery refers to the generation of heat and electricity in power plants. However, as biofuels are becoming more and more significant, the generation of mechanical energy as a work-related energy type may also be included here. Conventional incineration, gasification and plasma technology, cracking pyrolysis, or flow incineration (in pieces of equipment) may all be used for potential energy use. The most popular thermochemical processes for Waste to Energy are covered in the sections that follow. The most well-known thermic treatment methods are: (1) full oxidative combustion in conventional incineration; (2) partial oxidation in gasification; (3) partial oxidation in gasification; and (4) partial oxidation in plasma technology, which combines (plasma-assisted) gasification and pyrolysis of the organic fraction with plasma vitrification of the inorganic fraction of waste feed.

It is possible to combine these technologies. On some smaller-scale waste streams, additional thermochemical techniques like pyrolysis, gasification, and plasma technologies have been used in an effort to regulate process temperatures and pressures. Gasification is appropriate for all burnable materials, but pyrolysis at low, mid, and high temperatures may be used primarily for garbage. In relation to plasma technology, oxidation is used to remove hazardous waste, and the objective of this reduction process is raw material extraction. The least well-known method is plasma technology. Since even PCBs break down at temperatures over 5,000 °C, this method is ideal for treating organic waste.⁴² The unintentional inclusion of garbage will have an impact on the emission levels. The cleanup of synthesis gas is the primary problem. Methane, carbon dioxide, carbon monoxide, and hydrogen are the primary components of synthesis gas. Large amounts of carbon dioxide are produced by gasification facilities, and if the synthesis gas is just utilized to generate electricity, the amount of carbon dioxide produced is several times more than that of a normal power plant. Generally speaking, gas engines and turbines are not very tolerant to contaminants in the synthesis gas.

Because there is less oxygen during pyrolysis, heavy metal emissions are reduced. However, using pyro oil comes with a number of drawbacks. In addition, pyrolysis produces a significant amount of pyro coke with a high concentration of heavy metals in the cinders. In contrast to conventional incineration methods, the new technologies recover chemical energy from the trash. In some situations, the resulting chemical compounds may be used as secondary fuel or as feedstock for other operations. In order to generate heat and/or power, the waste is transformed into a secondary energy source (a combustible liquid, gas, or solid fuel) and used in a steam turbine, gas turbine, or gas engine. The synthetic gas has a lower calorific value than natural gas.⁴³ Table 5 displays the tested technologies and test data.

Tested Technology	T [°C]	Oxidation factor	Atmosphere	Product	Engine
Pyrolysis	500 1200	$\lambda = 0$ endothermic	-	pyrolysis-gas, coke and oil	gas engine, steam turbine
Conventional incineration	1150	$\lambda = 1,5$ exothermic	natural gas additional firing, air	flue gas (<5% burnable), slag and ash	steam turbine
Gasification	1200 1600	$\lambda = 0,55$ partial oxidation	air	synthesis gas, slag and ash	gas engine
Plasma-gasification	1200 2000	$\lambda = 0,5$ partial oxidation	air, steam	synthesis gas, vitreous slag	gas engine
Plasma technology	3000 5000	$\lambda = 0,5$ partial oxidation	steam, O ₂ and CO ₂ blend	synthesis gas, vitreous slag	gas engine
Natural- and Biogas in cogeneration	650	$\lambda = 0,99$ exothermic	air	flue gas (<3% CH ₄ content)	gas engine
Coal-fired power plant	500	$\lambda = 0,99$ exothermic	air	flue gas (<5% burnable), slag and ash	steam turbine

Table 5: The technologies and the data of the tested

Eleven methods have been examined in relation to the thermic treatment of organic industrial waste. Natural gas cogeneration using gas engines served as the reference amount. Since my primary objective is to identify carbon-dioxide-saving technology, I highlighted Global Warming Potential (GWP) from the environmental categories. Of all the gasses that contribute to the greenhouse effect, carbon dioxide is the most important of these technologies. One kWh of power produced was selected as the functional unit, or the foundation for the treatment comparison. This functional unit (Table 6) refers to all emissions, materials, and energy consumption.⁴⁴

System boundary	Applied methods and functional unit
From the waste charging until the burning of the generated synthetic gas in a gas engine. Normal, steady operating condition.	Applied methods: CML 2001 (November, 2010.) Functional unit: 1 kWh electricity (CHP)
Operating Condition and exploitation of the power plant	
Operating Condition: Normal, steady-state condition	Exploitation: 75,34 % power exploitation per year

Environmental category	Measure
Global Warming Potential (GWP)	kg CO ₂ - equivalent
Environmental category definition	
GWP is a relative measure of how much heat a greenhouse gas (for example: CO ₂ , CH ₄ , N ₂ O and FCKW) traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon- dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years.	

Table 6: System boundary, and the main parameters of the analysis

We may conclude from the data that the plasma technologies produced the most noteworthy numbers (Figure 6). These numbers are less than the Hungarian average and the natural gas used in cogeneration. Pyrolysis (500 °C) has the most unfavorable rate. In certain temperatures, this number is more than that of Hungary's coal-fired power plant. By 2016, this power station hopes to cut its CO₂ emissions from 1.22 kg per kWh to 0.9 kg. At certain temperatures, the higher temperature pyrolysis (1200 °C) is superior than gasification and plasma gasification. Due to the greater calorific rate of the synthesis gas, rising temperatures have decreased carbon dioxide emissions per kWh of power. Conventional incineration rates fall between those of plasma-gasification (1200 °C) and lower temperature gasification (1200 °C).

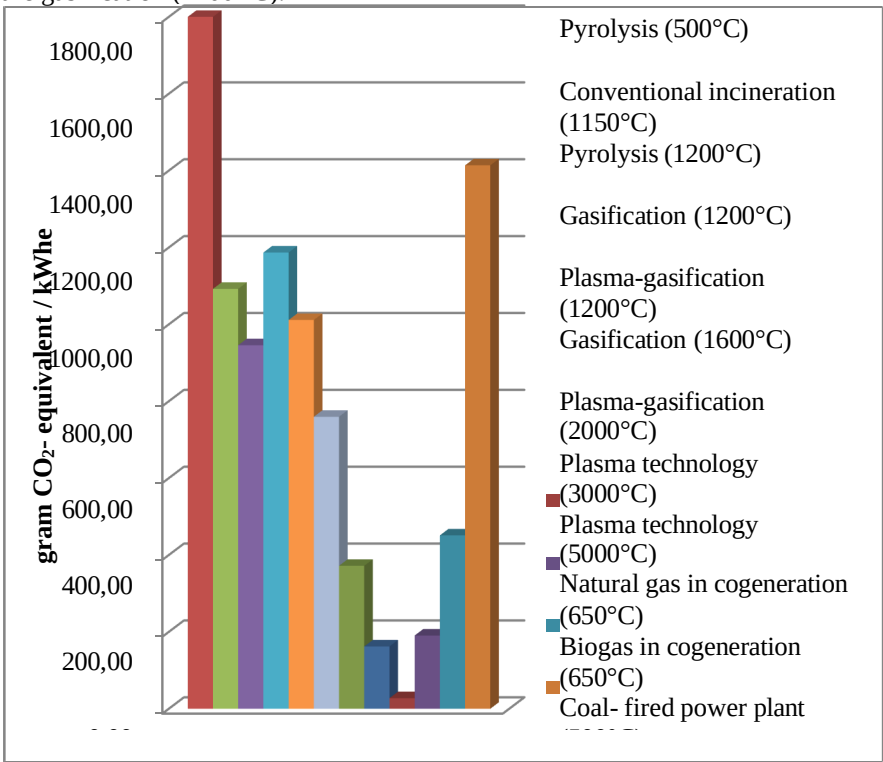


Figure 12: Carbon-dioxide equivalent per kWh electricity emission of the tested technologies

10. Conclusions

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All things considered, it can be said that the home electrical sector is undergoing a substantial transition. A lengthy procedure is just getting started. As expected, there is still a long way to go before residential power production is sustainable and favorable to the environment. In addition to the home circumstances, we think it is possible to further expand the usage of biomass and solar energy. It is encouraging that many investments in solar energy have been made, which will enable us to anticipate a further sharp rise in current capacity.

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