MAGYAR AGRÁR- ÉS
ÉLETTUDOMÁNYI EGYETEM

METHANOL ECONOMY: A BRIDGE TO THE LOW CARBON ECONOMY, PROJECTS IN HUNGARY

JUDIT TÓTH

GÖDÖLLŐ

2021

Name of the doctoral school:	
	Hungarian University of Agriculture and Life Sciences, Doctoral School of Economic and Regional Sciences
discipline:	**management and organizational science**
leader:	**Prof. Dr. H.c. Popp, József**, **Full Professor** **Corresponding member of the Hungarian Academy of Sciences**, Hungarian University of Agriculture and Life Sciences, Gödöllő Institute of Economics
supervisor:	**Dr. habil Magda, Róbert PhD, Full Professor** Hungarian University of Agriculture and Life Sciences, Gödöllő Institute of Economics

....	....
Approval of the head of the school	Approval of the supervisor

Table of contents

1. BACKGROUND AND OBJECTIVES OF THE WORK ... 4

1.1. The topicality and significance of the subject ... 4

1.2. Objectives ... 6

1.3. Research hypotheses ... 7

2. MATERIAL AND METHOD ... 8

2.1. Life cycle analysis ... 8

2.1. Investigation of the possibility of a renewable methanol production plant in Hungary ... 11

3. RESULTS AND DISCUSSION ... 13

3.1. What impact does the methanol economy have on GHG emissions and whether its implementation have environmental benefits ... 13

3.1.1. Effects of methanol on fuel ... 13

3.1.2. Environmental impacts of CCU technologies ... 14

3.2. Hungary's raw material supply for the production of biomethanol and e-methanol ... 15

3.2.1. Possible locations for methanol plants based on point sources of carbon dioxide ... 17

3.2.2. Possible locations for biomethanol plants ... 19

3.3. Meeting the energy needs of methanol production ... 21

3.4. The perspective of economical biomethanol and e-methanol production 22

4. CONCLUSIONS AND RECOMMENDATIONS ... 25

4.1. Result of the Hypothesis Test ... 25

6.2. Recommendations ... 28

5. NEW SCIENTIFIC RESULTS ... 30

6. ANNEXES ... 31

6.1. References ... 31

6.2. **List of publications in relation with the dissertation** ... 36

1. BACKGROUND AND OBJECTIVES OF THE WORK

1.1. The topicality and significance of the subject

The history of humanity is extremely closely linked to energy carriers, and our dependence on them is for thousands of years. Of the resources, energy has always been one of the most important because it has contributed to the development and well-being of human societies. During the first about 4,000 years of human history, basically wood was used as an energy source, that is, the use of renewable energy was typical. The first significant change was the shift to the use of coal, which took place in some industries as early as the 18th century, while in the case of heating this can be traced back to the 19th century (FOUQUET 2011). The recognition of limited carbon sources and the emergence of internal combustion engines resulted in another change at the end of the 19th century when the era of oil use followed. There have always been two main drivers of change: on the one hand, the development of energy prices (for example, the price of wood fuel increased significantly between 1650 and 1740), and on the other hand, technological development. The transition to the use of coal and then crude oil went smoothly. However, the emergence of the use of natural gas led to fundamental changes: land transportation accelerated as well as the conquest of air began for transport purposes. Energy consumption increased explosively, and this trend has continued ever since. A further large increase in energy consumption is expected, as the key factors influencing this are working in this direction, I am thinking here of the increase in the population of the Earth as well as the rising living standards. It is generally true that as quality of life improves, so does energy consumption per capita. The latter can actually be interpreted as a combination of three factors: population, GDP per capita, and the energy intensity of the economy (that is the energy used per unit of GDP). By 2040, energy demand is projected to increase in absolute terms, although the growth rate will slow in percentage terms. It is a question of whether the energy transition that is taking place today will be as smooth as it has been so far. This is crucially influenced by the size of available oil and gas reserves, the impact of greenhouse gases on the Earth's climate, and whether access to alternative energy sources will be competitive. In 1980, depletion of oil stocks was predicted by 2010 at the latest, but in 2010 sufficient stocks were prognosticated for a further 45 years. Forecasts for natural gas are similar, with the rate of depletion rising from about 48 years to about 60 years from 1980 to

2010. Thus, the increase in consumption has been offset by the rapid discovery of new oil reserves in recent decades, as well as the mining of deposits that were not yet economically viable under previous conditions has meanwhile become economical thanks to technological advances and a changed environment. A typical example of this is that the US has become a natural gas exporter by exploiting “unconventional” natural gas fields. It can be assumed that oil and gas reserves will not be depleted in the next few decades as new deposits are discovered and new extraction technologies are used. The most difficult issue is predicting the price of oil and natural gas, as it is greatly influenced by political events (PÁPAY 2015). The energy crisis of the 1970s shocked the world at how vulnerable the economies of some countries were to oil-producing and oil-exporting states. Recognizing this fact, several countries have taken steps to accelerate experiments and research aimed at replacing oil. Experiments have been carried out in several places with government support since 1975, and the problem of oil substitution has been constantly appearing in experimental and research activities ever since. Nowadays, all this is justified not only by the intention to reduce economic dependence, but also by the fact that one of the biggest challenges of the XXI. century is to solve the problems attributable to climate change (SZLÁVIK 2007). The Kyoto Convention was concluded in 1997 within the framework of the United Nations Framework Convention on Climate Change (UNFCCC), which aimed to stabilize greenhouse gas concentrations in the atmosphere to mitigate the foreseeable effects of climate change and global warming (United Nations Framework Convention on Climate Change). One of the shortcomings of the convention is that it does not propose a technological solution to the problem and only imposed obligations - including those relating to emissions regulation -for developed countries until the end of 2012. Based on the data collected, it soon became apparent that, on a global scale, long-lived greenhouse gas (GHG) emissions continued to increase at a steady pace. Countries with developed economies have made significant progress in reducing CO_2 emissions, but this is being offset by emissions from emerging economies (mainly Asian), leading to continued increases in net CO_2 emissions.

The goals are clear, but the path to solving the problems is still controversial. Science helps to invent new raw materials and work out their use, to apply new technologies, but no clear professional solutions have yet been found. Technological developments are progressing in parallel in several areas:

- in the field of energy supply, the various renewable energies and nuclear fusion for energy production have significant research potential;
- the battery and the fuel cell compete in the power supply of electric vehicles;
- in the case of fuel cells, innovations related to hydrogen or methanol applications play a significant role.

Diversification of the energy sector is a solution and carbon dioxide can become a primary raw material, but this will require significant and ongoing research efforts. The concept of the methanol economy and its implementation is a promising opportunity to solve global problems (KOTHANDARAMAN et al. 2017). Future policies are responsible for ensuring that carbon dioxide can become an efficient and competitive raw material that can emerge in many industries. Last but not least, it is the responsibility of society that policy makers consider scientific results and build a strategy to create a more sustainable world (KESZI SZEREMLEI - MAGDA 2015).

1.2. Objectives

We will be able to replace a significant part of the use of fossil fuels with energy from alternative sources, but in some areas, there is still a need for carbon products, since it is enough to think about the objects that make up our immediate environment. The use of carbon raw materials will be present in both energy and plastics production for a long time to come, although new technological pathways will emerge. Assessing and understanding the risks involved and their environmental impact will help to spread new technologies. Life Cycle Impact Assessment (LCIA) seeks to identify the direct and indirect effects of interventions in the environment as accurately as possible. My research aims to determine the extent of the environmental impact associated with the technological processes of the methanol economy on the basis of the available literature with the help of life cycle impact analysis. My further research aim is to explore the links between the concept of the methanol economy and the European Union's energy strategy, the circular economy, and climate policy goals, as well as to present possible uses in the future economy and energy system based on the properties of methanol using the relevant literature. My further aim is to assess the potential raw materials for the production of renewable methanol in Hungary, as well as the conditions necessary for competitive methanol production.

1.3. Research hypotheses

Hypothesis H_1: The use of methanol has environmental benefits, and methanol produced using the right technology and energy sources can be used effectively to combat global warming.

Hypothesis H_2: Hungary has the raw materials needed for the production of renewable methanol, mainly in the field of municipal waste, wastewater and biomass.

Hypothesis H_3: Hungary's energy production does not provide the carbon-neutral electricity needed to produce renewable methanol.

Hypothesis H_4: In Hungary, renewable methanol production does not bring economic benefits under the current parameters, but this may change with the transformation of energy production.

2. MATERIAL AND METHOD

The following chapter presents the scientific methodologies required to test the assumptions in the order of the hypothesis of the dissertation.

2.1. Life cycle analysis

The concept of life cycle was introduced into economics by Schumpeter (1939) as a concept related to innovation, which lasts from the beginning of the production of a product or group of products or its appearance on the market to the end of production or its exit from the market. The concept of the life cycle used in environmental management appeared in the early 1990s and was already considered at the 1992 Rio Conference as a tool that can be applied to a wide range of environmental management tasks and emphasizes the essential elements of environmental sustainability (TÓTHNÉ SZITA 2008).

The basic principle of the EU's Integrated Product Policy (IPP) is that all products cause some form of environmental degradation, whether during production, use or disposal. Life cycles of products can be long and complex processes: from the extraction of natural resources through their design, manufacture, assembly, distribution, sale and use, to their final disposal as waste. Based on the decision of the European Commission, the Life Cycle Analysis (LCA) is the most suitable tool for examining the environmental impact of products, the methodological harmonization of which is facilitated by the establishment of the European LCA Platform (EUROPEAN COMMISSION 2016b). This analysis makes it possible to quantify and compare the effects of products, processes and models on the environment on the basis of metrics, according to the method defined by ISO standards.

Based on ISO 14040 standard, life cycle analysis can be defined as follows: „ a method of assessing product-related environmental factors and potential impacts that takes stock of the inputs and outputs of a system of product-related processes; assess the potential environmental impacts associated with them; interprets the results of the inventory analysis and impact assessment phases taking into account the objectives of the study." (MSZ EN ISO 14040)

The following ISO standards apply to life cycle analysis:

- ISO 14040:2006 Environmental management. Life cycle assessment. Principles and framework (ISO 14040:2006);

- ISO 14044:2006 Environmental management. Life cycle assessment. Requirements and guidelines (ISO 14044:2006).
  The life cycle assessment can be divided into four stages, as illustrated in Figure 1.

The four stages:

1. Designation of goal and scope: definition of the exact goal and object in accordance with the intended use.
2. Inventory analysis: a list of input/output data that applies to the system under study.
3. The impact assessment: provides additional information to establish the life cycle assessment of the production system.
4. Evaluation, interpretation: helps in decision making (BAKOSNÉ 2016).

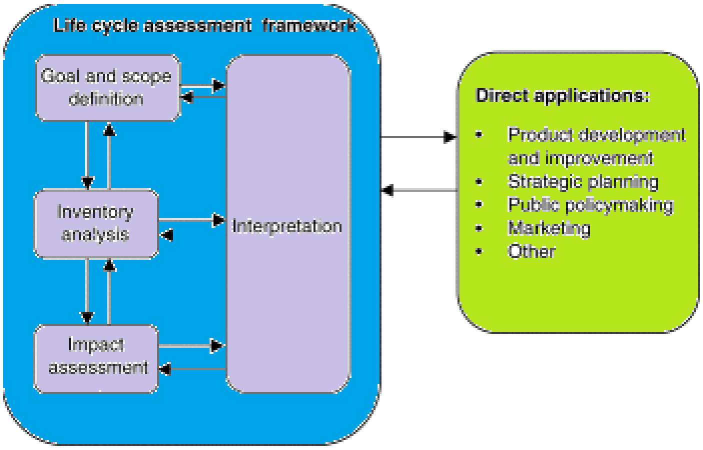

Figure 1: Phases of life cycle analysis

Source: KISS (2013)

One of the most commonly used impact assessment methods according to ISO 14040:2006 is CML 2001. Table 1 shows that the environmental impacts are divided into several impact categories, and the resulting environmental indicators can be aggregated into one indicator. (GUINÉE 2002).

Table 1: Impact categories for environmental impacts

Impact categories	Reference
Effects on global warming	kg CO_{2-} equivalent
Acidification potential	kg SO_2- equivalent
Eutrophication potential	kg Phosphate- equivalent
Human toxicity potential	kg DCB- equivalent
Photochemical ozone formation potential	kg Ethylene-equivalent
Ozone depletion	kg CFC11-equivalent
Depletion of resources	kg SB-equivalent
Terrestrial ecotoxicity	kg DCB-equivalent
Marine ecotoxicity	kg DCB-equivalent
Freshwater ecotoxicity	kg DCB-equivalent

Source: Based on GUINÉE (2002)

The strength of LCA is that it collects data on environmental impacts at all stages of a product’s life and then summarizes them. It interprets the aggregated results and then weights and evaluates them in terms of the significance of the environmental impacts. It presents the obtained results in simplified indicators in an easily transparent way.

Life cycle analysis is an essential part of fossil fuel substitution research and the introduction of new technologies. The use of CO_2 as a raw material can be a very effective tool in reducing global carbon dioxide concentrations and reducing dependence on fossil fuels, but it is necessary to take stock of the environmental impacts of the technologies developed in order to highlight that the technological path truly contributes to the achievement of sustainability goals. The strengths of the methanol economy make it difficult to carry out the analyses, as the raw materials for methanol production can come from numerous sources, and the energy used in the process can also be fossil, nuclear or some kind of renewable energy.

Analysis of a set of LCA results is suitable to make previous LCAs easier to interpret. The analysis allows the comparison of studies, helps to identify the main drivers of environmental impacts, and reduces the uncertainty of estimates (HEATH – MANN, 2012). The analysis of the set of LCA results is preceded by a harmonization process, which is illustrated in Figure 2. The first step is to define the goal of harmonization, and this provides a framework that defines the methods and processes used in later stages. The second step is to review and screen the relevant studies. The content of the studies to be harmonized largely determines the scope of the analysis and the application of appropriate screening criteria (WARNER et al.2010, PAKURÁR et al. 2020). This is followed by the extraction of the relevant parameters and then the harmonization.

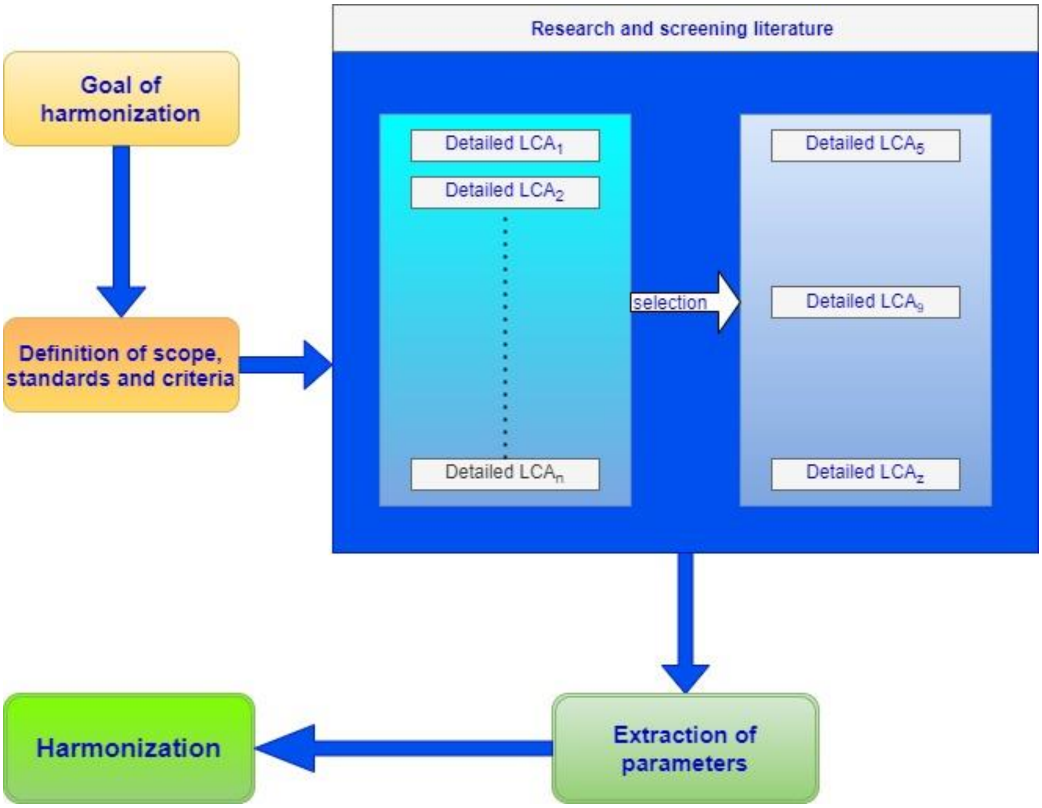

Figure 2: Harmonization process of life cycle analysis

Source: Own editing based on WARNER et al. (2010)

2.1. Investigation of the possibility of a renewable methanol production plant in Hungary

The issue of setting up a renewable methanol plant requires a complex approach. In addition to environmental sustainability, technical, economic and financial aspects must also be examined. Evaluation is hierarchical, technical feasibility is a prerequisite for economic feasibility, which eventually determines financial feasibility (TAKÁCS et al. 2012). The technical feasibility study is shown in Figure 3. The examination of the economic possibilities was done by adapting the parameters found in the international literature to the Hungarian conditions.

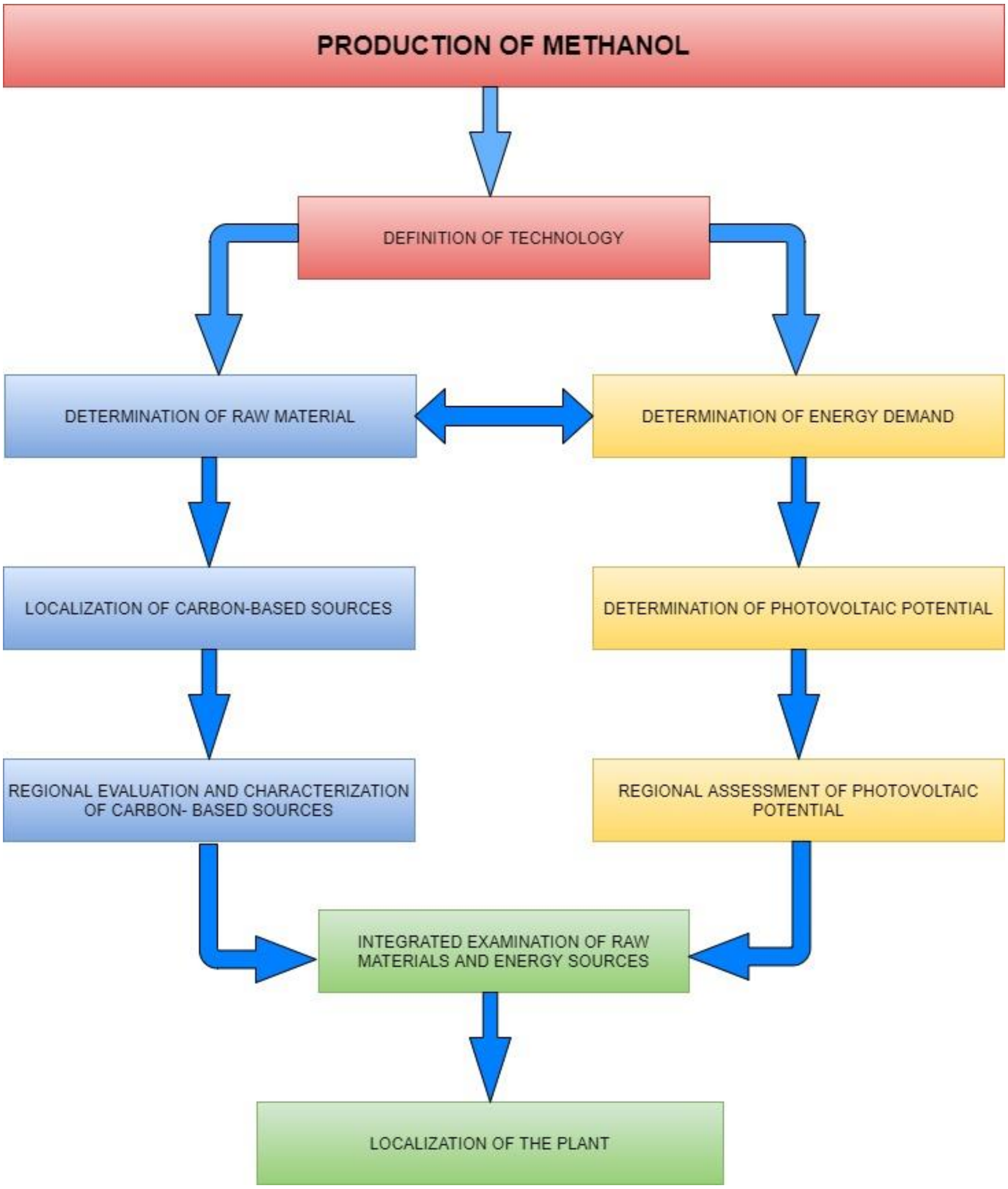

Figure 3: Determination of the methanol plant location

Source: Own editing

3. RESULTS AND DISCUSSION

The following chapter presents the results of the examination of the established hypotheses, which are based on the analysis of the collected data using the methods described in the previous chapter.

3.1. What impact does the methanol economy have on GHG emissions and whether its implementation have environmental benefits

A systematic study of global methanol supply chains and environmental impacts is needed to ensure that the realization of the methanol economy truly serves sustainability goals.

3.1.1. Effects of methanol on fuel

As the world's largest methanol producer, China has made much better progress in building its methanol economy than any other country, and this is aided by strong government support. In 2009, the Chinese government introduced a national standard for 85% methanol-gasoline (M85) fuel blend, thus promoting the use of methanol-powered vehicles. For the time being, China is not producing methanol for the purposes of the methanol economy, that is biomethanol, but from three fossil fuels: coal, coke oven gas (COG) and natural gas. The environmental impact of using methanol-based fuel has been investigated. The study used a method called "well-to-wheel" (WtW), which involved the production of methanol taking into account the use of the necessary catalysts, auxiliaries, the transport of methanol to fuel wells, as well as the use of M100 fuel. Methanol produced with the dominant carbon-based technology has been found to have higher environmental burdens than the use of gasoline. The environmental impact has been reflected in higher energy and water consumption, as well as in greenhouse gas and sulphur dioxide emissions. Coke gas-based technology, supported by the Chinese government, is more environmentally friendly than coal-based, but less favourable than gasoline. (YAO et al. 2017).

Analysing the studies of CHAPLIN (2013) and WINTHER (2019), it can be concluded that the use of biomethanol fuel has lower GHG emissions compared to the use of both fossil fuel methanol and bioethanol.

3.1.2. Environmental impacts of CCU technologies

CCU technologies can give the impression that the use of carbon dioxide from the atmosphere or from the flue gas of power plants as a raw material is clearly environmentally friendly, as it reduces the amount of carbon dioxide in the atmosphere. The development and application of CCU technologies shows intensive research activity. In order to identify the best solutions for sustainability, it is essential that the environmental impact of each path is comparable and that the benefits of new technologies are quantified in relation to existing processes. In the case of a product with the same chemical structure and composition throughout its life cycle, it is sufficient to compare the procurement routes of raw materials and the production process to determine the impact on the environment (ZIMMERMANN et al. 2018).

Based on the analysis of the studies of STERNBERG et al, (2017), HOPPE et al. (2017), MATZEN - DEMIREL, (2016), KIM et al. (2011), AL-KALBANI et al. (2016), MEUNIER et al. (2020), THONEMANN- MAGA, (2020) I conclude that for biomethanol and e-methanol production pathways, neither the carbon source nor the hydrogen source is determinant in terms of GHG emissions, and all processes may be more favourable in terms of effects on global warming than natural gas-based methanol production. GHG emissions from processes are determined by the source of electricity used in the production process. The use of fossil-based electricity does not represent an environmental advantage in methanol production compared to the reference, nor even the use of the EU-27 electricity mix. Hydrogen produced from renewable energy sources and carbon dioxide from any source results in a lower level of methanol production with an effect on global warming.

In order to reduce GHG emissions, the use of renewable energy sources is an essential requirement in the development and selection of technologies, but GONZALEZ-GARAY et al. (2019) argue that energy use, freshwater and land use must be taken into account if we want to express the real impact on the environment.

The result of my research is that biomethanol and e-methanol produced with the right technology are fuels for sustainability that can be delivered to consumers using the current transmission and distribution network, thus being able to change the structure of fuel consumption in a short time. There is no need to develop new transport technologies and new types of distribution stations, so it is suitable for rapid and effective intervention to reduce carbon dioxide emissions.

3.2. Hungary's raw material supply for the production of biomethanol and e-methanol

Nobel Prize-winning chemist György Oláh thought that if it was possible to produce methanol in Iceland, then Hungary would also have the environmental conditions necessary for production. According to his idea, this can be based on shale gas in the country, which is a fossil source, so its use has no environmental benefits (HVG 2013). In the followings, I will examine the raw materials used for the production of renewable methanol in Hungary.

Biogas, landfill gas

Disposal of waste by landfill has been considered the most widespread waste management solution in Hungary for decades, especially in municipal waste management. Material in the landfill is very heterogeneous in terms of both physical and chemical composition, and various processes, compaction and decomposition take place after disposal. Thus, during the so-called anaerobic biodegradation, landfill gas is formed from the landfilled waste, which is released into the atmosphere by diffusion.

In 2018, I formed a scaling-derived indicator of the ratio of the amount of landfill gas produced by the EU Member States to the amount of landfilled waste, in such a way that the value of the indicator for Hungary shall be 1. The values calculated for each country are illustrated in Figure 4. For the sake of clarity, the figure does not include the value of 119 for Finland as well as countries with a value of 0, including Romania, Bulgaria, Malta and Luxembourg.

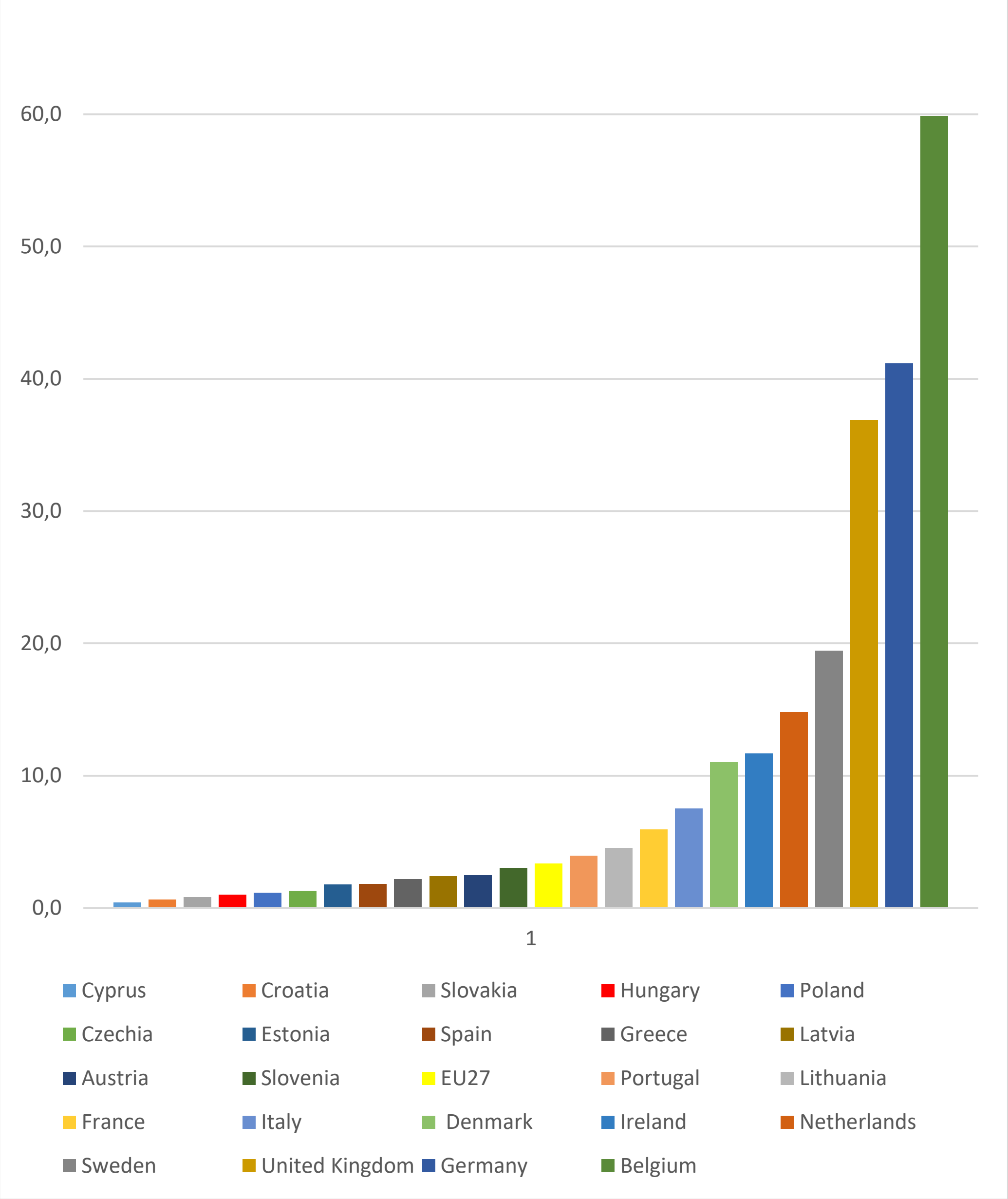

Figure 4: Ratio of landfill gas produced and landfilled municipal waste in EU countries

Source: Own editing based on EUROSTAT (2020a) and EUROBSER'ER (2020) data

My calculations show that the use of landfilled waste for landfill gas production is very high in Finland, almost twice as high as in Belgium, which has the second highest value. It is a particularly remarkable achievement, as 1% of municipal waste is landfilled in Finland. Romania, Bulgaria, Malta and Luxembourg are at the bottom of the ranking. These countries do not produce landfill gas, so the indicator is 0 for them, while the landfill rate for municipal waste is high, with the exception of Luxembourg: Malta 93%, Bulgaria 92%, Romania 71%, Luxembourg 7%. Hungary is at 20th place, far below the EU27 average, while 49% of municipal waste is landfilled. Based on the analysis of the data, I believe that Hungary has significant potential in the field of waste recovery development, a sustainable alternative to which is the production of methanol from waste.

3.2.1. Possible locations for methanol plants based on point sources of carbon dioxide

Pipeline transport is the only way to transport the large amount of carbon dioxide required for the operation of a methanol plant in Hungary. Compressors suitable for compressing gas are used at the site of CO_2 separation and capture. Carbon dioxide is transported in a supercritical state, so setting the right pressure and temperature is a requirement. During transport, the average distance between some compressor stations can be 160 km (TIHANYI- CSETE 2012). Pipeline transportation requires a significant investment and has a constant cost implication, so it is advisable to install the plant near the point sources. The capacity of existing or planned plants for the production of e-methanol is between 1,000 tonnes/year and 200,000 tonnes/year globally, which means between 1441 tonnes and 288,200 tonnes/year of carbon dioxide demand, thus, the size of methanol plants is/can be very wide.

Examining the territorial location, I identified the following major sources of carbon dioxide:

1. Mátrai Erőmű Zrt. has by far the largest annual carbon dioxide emissions. This means that the 5,770,000 tonnes of carbon dioxide emissions in 2017 will exceed the combined emissions of other power plants and thermal power plants operating in the country.
2. The ISD DUNAFERR group of companies located in Dunaújváros is one of the largest industrial production companies in Hungary, with an annual carbon dioxide emission of 1,323,000 tonnes.
3. Annual carbon dioxide emissions of power plants and plants in Baranya County: 1,271,000 tonnes
4. The annual carbon dioxide emissions of power plants and thermal power plants in Budapest are 1,267,000 tonnes, which is increased by 331,000

tonnes (2014 data) by FKF Nonprofit Zrt., thus it means a total of 1,598,000 tonnes. The plants of Vác and Százhalombatta could potentially join this group, thus increasing the value of annual carbon dioxide emissions to 2,675,000 tonnes.

Based on the supply of raw materials (carbon dioxide, water) and renewable energy, the following sites are suitable for the production of renewable methanol.

Based on its parameters, Pannónia Bio Zrt. would be one of the most suitable companies for the pioneering role of national renewable methanol production. The reasons for this are the followings:

- During the production of bioethanol, as a result of fermentation, a large amount and almost 100% of pure carbon dioxide is formed, i.e., no absorption, desorption or purification is required. In the case of biogas produced from waste in the plant, the concentration of carbon dioxide is also high, but in the case of its utilization, the capture and purification of carbon dioxide is necessary. Pannonia Solar Zrt. is a subsidiary of Pannonia Bio.
- The plant has an adequate water supply and is located on the banks of the Danube.
- Pannonia Bio Zrt. will soon have investments in the solar energy industry with a 35-megawatt solar power plant.

The largest emitter of carbon dioxide is the Mátrai Erőmű Zrt. (Mátra Power Plant), which uses a mixture of lignite, natural gas, waste, biomass and ATAMIX (refuse-derived fuel) in energy production. Lignite-based electricity generation is expected to decline at the plant, but it can utilize 300,000 tonnes of non-hazardous waste per year as fuel and biomass for energy. The capture and use of carbon dioxide produced in the power plant would significantly reduce domestic carbon dioxide emissions, as more than half of the power plant's and thermal power plant's emissions come from the Mátra Power Plant. Mátra Power Plant owns 3 power plants (Visonta, Bükkábrány, Halmajugra) which are currently among the largest photovoltaic power plants in the country, with a total capacity of 56 megawatts. Gradual phasing out of lignite units will be accompanied by the introduction of more modern and environmentally friendly technologies, and in addition to the existing photovoltaic power plants, an additional 200–220-megawatt solar park is planned in Visonta and Bükkábrány in the near future. Visonta is also a suitable location for a renewable methanol plant in terms of raw material and energy supply.

The second largest CO_2-emitting industrial complex in Hungary is located in Dunaújváros, which is shown in Table 2.

Table 2: Quantities of carbon dioxide emitted by the ISD DUNAFERR group of companies in 2017

Company	Activity	Annual carbon dioxide emissions (tonnes)
ISD DUNAFERR Zrt.	Iron and steel production	992 000
ISD POWER Kft.	Electricity and heat production	151 000
ISD Kokszoló Kft.	Manufacture of coke oven coke	180 000
In total		1 323 000

Source: Own editing based on THE EUROPEAN POLLUTANT RELEASE AND TRANSFER REGISTER (2017)

There is no significant photovoltaic power plant in the immediate vicinity of Dunaújváros, but Paks is located just over 40 km away, where a solar power plant is located.

In 2017, cement plants in Baranya County (Beremend and Királyegyháza) emitted 890 thousand tonnes of carbon dioxide. The concentration of carbon dioxide in the flue gas of cement plants is moderately high, so it is suitable for the application of carbon capture and utilization technology. In the case of cement plants, carbon dioxide emissions cannot be eliminated by providing non-fossil-based thermal energy, as carbon dioxide is formed during the production of cement after the decomposition of limestone. Globally, concrete is the second most widely used material, and it continuously induces large amounts of carbon dioxide production, thus contributing significantly to greenhouse gas emissions. Concrete is cheap, resistant and safe, there is currently no real alternative in the construction industry. In order to reduce environmental damage, it would be important to capture at least the carbon dioxide generated during cement production. A larger photovoltaic power plant can be found in Pécs and Pellérd near Beremend and by the end of 2020, MVM Zrt. placed 24 small power plants into operation (0.5 megawatts) in Southern Transdanubia.

3.2.2. Possible locations for biomethanol plants

In the analysis of DINYA (2018), based on the multifactor comparative assessment, the leading wind and solar energy projects are followed by bioenergy investments, in accordance with which biomass-based production is also of great importance for methanol production. The selection of the raw material should be guided by two principles: the utilization of the available biomass in a maximum added value way and the generation of zero waste. Instead of energy crops, production should be based on alternative substrates, such as biomass waste from different sectors.

Based on the study of SZALAY (2018), Szabolcs-Szatmár-Bereg county leads the ranking of the amount of dendromass-based by-products to be collected by county. The ranking of the other counties is: Bács-Kiskun, Pest, Zala, Somogy and Borsod-Abaúj-Zemplén. Taking into account the raw material consumption needs of major biomass power plants and heating plants, Bács-Kiskun, Pest, Zala, Somogy counties have a significant usable free raw material capacity.

In 2019, the production area, which makes up almost 79% of Hungary's land area, was 7 million 319 thousand hectares, with the following distribution by cultivation branch: 26.5% forest, 2.2% orchard and vineyard, 59% arable land, 10.8% grassland as well as vegetable garden, reeds and fishponds are all 0.5%. Cereals were grown on more than 2.5 million hectares in 2019, of which 1,048 thousand hectares were maize and 980 thousand hectares were winter wheat (KSH 2019b). Arable crop by-products, like straw and stalk residues, represent significant potential for biomethanol production, despite the fact that the vast majority of straw is used by livestock farming. According to the analysis of GYURICZA (2010), 2.2-3.7 million tonnes of straw, 5.0-6.5 million tonnes of maize stalks and cobs and 1.0-1.2 million tonnes of sunflower stalks can be used for energy utilization per year.

Although the use of straw in the sector is declining as a result of new technologies introduced in livestock breeding, maize stalks, sunflower stalks and disks have the greatest potential for herbaceous plant by-products. In the case of both maize and sunflower by-products, the method of utilization is ploughing, and other uses are hindered by the difficulty of collecting stalk residues. Mechanized collection and receipt of by-products at a stable, appropriate price would significantly increase the hitherto low energy recovery rate (YMERI et al. 2020). In the case of herbaceous plant by-products, Szabolcs-Szatmár-Bereg, Békés and Hajdú-Bihar counties have an outstanding potential, but Bács-Kiskun and Pest counties are also in the first half of the ranking. Based on the combined utilization of dendromass and herbaceous by-products, the implementation of a biomethanol plant in Bács-Kiskun or Pest county would be favourable.

3.3. Meeting the energy needs of methanol production

LCA studies have clearly demonstrated that the carbon dioxide emissions of the energy source used in the production of methanol determine whether the use of the methanol produced is beneficial in terms of the effects on global warming.

STENBERG et al. (2017) investigated the impact of the production of methanol and methane from carbon dioxide and fossil fuels on global warming. It was found that the use of the EU-27 electricity mix (2020) in the production process does not represent an environmental benefit. Examined separately, there are some European countries where the impact of global warming on carbon dioxide-based production is reduced when low-carbon electricity is used to produce the hydrogen feedstock. In the case of France and Belgium, nuclear energy, in the case of Norway and Iceland, renewable energy, and in the case of Sweden and Switzerland, the combined use of renewable and nuclear energy results or may lead to an environmentally friendly production method.

In the EU, 32% of electricity in 2018 and 34% in 2019 came from renewable sources, but there is a very significant difference between the Member States. In Austria and Sweden, the share of renewables is above 70%, while at the bottom of the ranking is Malta with an 8% share as well as Cyprus, Luxembourg and Hungary all with a 10% share (EUROSTAT 2020b). In the last two decades, the rate of coal-fired power generation in Hungary has decreased significantly, while that of nuclear and renewable energy has increased. In 2019, nuclear and renewable energy accounted for a total of 62% of electricity generation, while for 63% in 2020 (EMBER 2020).

The share of fossil fuels in the energy mix of the countries mentioned by Stenberg et al. is low. Iceland relies 100% on renewable sources for electricity generation, while Switzerland relies 1% on it. Norway uses less than 2% fossil fuels, Sweden 2%, while France uses less than 10% and Belgium 34.5% (EMBER 2020). The latter 2 countries may have the potential to produce methanol with environmental benefits. There is no gap between Hungary's current 38% fossil fuel share and Belgium's value, so I conclude that the production of renewable methanol has the potential to be established in Hungary as well. This is supported by the fact that, similarly to the EU countries, solar energy is the fastest growing source in electricity generation in Hungary. In 2012, it provided even less than 0.001 TWh of energy, compared to 1.625 TWh in 2020.

3.4. The perspective of economical biomethanol and e-methanol production

Change in costs related to electricity generation

The analysis of the investment costs of methanol plants clearly shows that the equipment required for the electrolysis of water is the most expensive element. In a study by PÉREZ-FORTES and TZIMAS (2016), of the EUR 270 million investment, electrification equipment cost EUR 147.7 million, which accounts for nearly 55%. According to RIVAROLO et al. (2015), an even larger share of investment costs is accounted for by the electrolysis equipment: 54% when using biogas feedstock (total capital cost EUR 3.8 million), and 86% when using feedstock from carbon dioxide point source (total capital cost EUR 2.5 million).

In the case of operating costs, an even higher proportion is related to the electrolysis of water, i.e., the production of hydrogen, as this value can be as high as 90%. It follows that the main determinant of the production price of biomethanol and e-methanol is the electrolysis, that is, the price of electricity used is a function of the production price of methanol. In contrast, in the case of methanol treated with conventional technology, the price of production is determined by the price of natural gas.

The production of a competitive biomethanol and e-methanol product requires a reduction in the cost of electricity, for which there are two options: the price of electricity used decreases and the efficiency of electrolysis increases.

According to the study of ZHANG et al. (2019), e-methanol production is economically feasible if the price of electricity is lower than 0.047 USD/kWh. In 2019, the average price of electricity generated by photovoltaic power plants was USD 0.068/kWh, so it is realistic that it will fall below USD 0.047/kWh in a short time.

On 9th May 2021, the solar power plants in Hungary reached the highest production peak ever, representing the largest slice of domestically produced electricity. The performance of the Paks power plant, on the other hand, fell by half, which was partly caused by the increased solar power plant performance. The consequence of the increase in solar power plant capacities is that the exchange price of electricity on the Hungarian Power Exchange (HUPX) market was 0 or negative on the next day. In the light of the data, I believe that in order to maximize profits during the operation of photovoltaic power plants, it may be worthwhile to utilize the electricity generated on two routes, that is to supplement the feed into the direct system with a methanol plant operating at a low purchase price.

Methanol as a hydrogen reservoir

Economic analysis related to renewable methanol production are based on a comparison of the costs and market prices of renewable methanol and methanol produced on the traditional production route. During the continuous transition to solar and wind energy, electricity storage is needed to balance supply and demand. Currently, the pumped water storage system (PHS) is the leading technology, accounting for 97% of global electricity storage (STOCKS et al. 2021), despite the fact that PHS can be used in specific geographical conditions, such as e.g., the right level difference, sufficient amount of water. KHAREL and SHABANI (2018) examined the cost of two pathways of large-scale energy storage: in the first case, battery storage, and in the second case, a hybrid (battery and hydrogen) storage were analysed. It has been found that a hybrid battery-hydrogen storage system is four times more cost-effective than the battery-only energy storage systems.

One way of storing hydrogen is chemical storage, in which methanol has a special role due to its favourable properties, e.g., 1 mole of methanol contains 4 moles of H atoms, which means that 1 m^3 of methanol stores 99 kg of hydrogen. Based on the role of hydrogen storage, it is worth examining the economy and price competitiveness of methanol production in comparison with other hydrogen storage options.

The size of hydrogen storage systems is determined by the mass of hydrogen that can be stored per unit volume. Ammonia has the highest storage density, followed by methanol. At the end of the ranking is the storage of pure hydrogen. The elemental hydrogen storage density is 2.5 times lower at 700 bars, 4 times lower at 200 bars, and more than 12 times lower at 100 bars than that of methanol (ANDERSSON and GRÖNKVIST 2019). The transport and distribution of hydrogen in elemental form requires the development of new technologies with significant research costs. For transport costs, DEMIR and DINCER (2017) obtained values of USD 2.73-2.86/kg hydrogen, depending on whether the hydrogen is transported by pipeline or tank truck from the plant to nearby cities. 1 m^3 of methanol stores 99 kg of hydrogen, thus the cost of transporting this amount of elemental hydrogen by tank truck is more than 280 USD.

DIAS et al. (2020) compared the costs of hydrogen storage and transportation in case of elemental hydrogen and chemical hydrogen storage. Their investigation included elements and costs of production, storage and transportation. The lowest cost is for the use of methanol with EUR 219 (transport by tank truck), while the use of elemental hydrogen is the most expensive with EUR 513 for tank truck transport and with EUR 492 for pipeline transport. The second lowest cost is the use of liquid hydrogen, followed only by the use of methane and ammonia. The costs are per unit of fuel per MWh and at a price of EUR 30/tonne carbon dioxide.

The above data show that, in terms of energy storage, storage in the form of hydrogen can be more economical than other modes and can be widely used as no special geographical conditions are required for its application. It is important to emphasize that the energy storage function of hydrogen is not the same as the production and use of elemental hydrogen. The safe use of hydrogen requires the use of chemical reservoirs, one of the materials of which may be methanol. Methanol is a liquid and stable compound, it is easy to store and can be solved in the long run without loss, and its storage cost is also negligible. Methanol logistics can be done using existing transmission and distribution facilities, thus providing a cost-effective transformation of energy systems in the short term.

4. CONCLUSIONS AND RECOMMENDATIONS

Climate change is one of the biggest challenges and threats today. We need to find and give an answer to this in a complex way so that we can slow down and reverse the negative processes. The European Union's energy policy strategy is based on the triad of security of supply, sustainability and economy. Unilateral movement in the direction of one element also affects the other two elements. Recent and present events, the coronavirus crisis, have clearly highlighted the importance of a reliable electricity supply as a prerequisite for working from home. At the same time, another pillar appears in energy policy, social acceptance, which results in an increase in the value of energy planning at the lower levels of the national economy. Increasing economic, social and political pressures due to ecosystem damage accompanying climate change have resulted in the development and expansion of renewable energy systems. If we examine the relative change in electricity production by source, it appears that in the future, renewable energy sources will be more widespread than ever. As a result, high-capacity storage systems will be needed to ensure a continuous flow of energy to offset the production of insufficient local renewable energy sources at a given time. Neither batteries nor elemental hydrogen are suitable for the task of storing strategic energy reserves, and Power-To-X technologies are indispensable in solving the problem.

Exploiting the technological link between renewable energy and CO_2 capture will lead to a positive change in reducing atmospheric carbon dioxide emissions and increasing independence from fossil fuels. This approach demonstrates the formation of a CO_2 loop as the material released during combustion is recycled and reused. There is a growing interest in Power-to-X technologies because they are actually able to convert renewable energy into chemicals and fuels that are easy to store and transport. Ideally, the use of fossil fuels can be exiled from all areas of life by using atmospheric CO_2.

In essence, the methanol economy means the creation of a circular economy, through which it is possible to capture and connect pollutants and waste generated during energy production and other industrial processes to the system with the help of carbon-neutral energy sources.

4.1. Result of the Hypothesis Test

Based on the literature review and my own research, the results of the examination of hypotheses described at the beginning of the dissertation are presented below.

Hypothesis H_1: The use of methanol has environmental benefits, and methanol produced using the right technology and energy sources can be used effectively to combat global warming.

I fully accept my first hypothesis because while analysing the literature on the environmental burden of the methanol economy, I found that the carbon intensity of energy used to meet the energy needs of the production process determines the impact on global warming, regardless of technology. Using carbon-neutral electricity sources, the impact on global warming is significantly lower than for conventionally produced methanol and also has better values than gasoline when used as a fuel for internal combustion engines. The concept of the methanol economy, if we mean the production and utilization of renewable methanol, serves the achievement of the goals of sustainable development, climate policy and the transition to a circular economy.

Hypothesis H_2: Hungary has the raw materials needed for the production of renewable methanol, mainly in the field of municipal waste, wastewater and biomass.

I consider my hypothesis to be confirmed, according to which the raw materials needed for the production of biomethanol, and e-methanol are available in Hungary. The raw material for e-methanol production is provided by carbon dioxide emitted by power plants, thermal power plants and plants related to the cement industry. The amount of carbon dioxide produced is sufficient, based on international experience and literature, to supply several methanol plants, so the plants can be installed close to point sources. Among the point sources, the bioethanol plant has an outstanding potential, because almost 100% pure carbon dioxide is formed as a by-product of the fermentation process, so the technology is simplified, i.e., gas purification and absorption steps are not necessary. Another advantage of using a bioethanol by-product is that methanol production and use emit zero carbon dioxide, which is not the case for power plants and other industrial point sources. The use of non-biomass power plants and other industrial point sources in methanol production significantly reduces carbon dioxide emissions compared to methanol obtained from fossil sources but cannot be considered as zero-emission routes. The production and use of methanol using biomass feedstock and DAC technology have zero carbon emissions. The use of biomass waste in Hungary has significant potential. The recovery of small amounts of dendromass and large amounts of by-products and waste from the cultivation of herbaceous plants does not take place at present, so they appear as free capacity for biomethanol production. Compared to international data, we also use domestic data at a low level in terms of the potential for the use of municipal waste, landfill gas and sewage sludge.

Hypothesis H$_3$: Hungary's energy production does not provide the carbon-neutral electricity needed to produce renewable methanol.

The main obstacle to the growth of the methanol economy is the high electricity demand for the production of hydrogen feedstock. In renewable methanol production, hydrogen is obtained by electrolysis of water using renewable energy, which is a much more energy-intensive route than natural gas-based methanol production. The member states of the European Union are net energy importers, in 2018 the energy dependency rate exceeded 50.0%. In the case of Hungary, in the period between 2015 and 2019, the share of electricity imports was between 27.6% and 31.6% on an annual basis, so the introduction of high-energy technology requires an increase in primary energy production. The government's goal is to reduce electricity imports to zero in the medium term.

Despite the dynamic growth of living standards (GDP per capita) in Hungary, the country's carbon dioxide emissions show a declining trend, as energy intensity and the carbon intensity of energy supply are constantly declining. In 2019, 56 percent of the electricity generated in Hungary came from carbon-free sources, but 90 percent of it was generated by the Paks Nuclear Power Plant. It is also a medium-term goal to include 50-50% of nuclear power and solar energy in the structure of electricity production, and this is supported by statistical data, the analysis of which highlighted that solar power is the most dynamically growing type of power plant in the Hungarian electricity production.

At present, neither the amount of collectively produced electricity nor the structure of its source is adequate for the production of renewable methanol, but government efforts and trends in energy production promise that this will change within 10 years. In order to maximize profits during the operation of photovoltaic power plants, it may be worthwhile to utilize the generated electricity on two routes in the near future, i.e., to supplement the feed into the direct system with a methanol plant operating at a low purchase price, which entails expanding storage capacities.

My hypothesis was confirmed, but the energy strategy and climate policy goals of the European Union and Hungary in line with them can positively change the perspective of the methanol economy within 10 years.

Hypothesis H_4: In Hungary, renewable methanol production does not bring economic benefits under the current parameters, but this may change with the transformation of energy production.

This hypothesis was confirmed. The economic efficiency of the methanol economy are determined by the price of energy needed to produce hydrogen. If the price of electricity needed to produce e-methanol falls below USD 0.047/kWh, then its production can also be economical compared to fossil source methanol. Currently, 5% of photovoltaic power plants are able to generate electricity at this price, but the use of off-peak electricity generation for methanol production is an opportunity for other power plants as well. Economical renewable methanol production is aided by the capture and sale of oxygen, which is currently in high demand as a by-product. Another possibility is the application of economic incentives and subsidies.

6.2. Recommendations

R_1: The methanol economy and its technological solutions are often associated with the term of "promising technology", which is not suitable for the service of environmental sustainability or the matter of economy. Subjective categories are not suitable for identifying the possibilities that best serve the goals of humanity among the solutions of the future technology. The accounting of environmental objectives requires an internationally accepted standard method of life cycle analysis, the basic elements of which are transparency and comparability. In this case, life cycle analysis provide a solid basis for decision-making processes.

R_2: In the European Union's strategy, hydrogen is the key to the decarbonisation of the integrated energy system. The storage and transport of elemental hydrogen is dangerous, it has no mature technology. Research has turned to the physical or chemical capture and then release of hydrogen. One such chemical capture is storage in methanol form. Methanol thus has a dual function: it stores carbon dioxide and is capable of storing large amounts of hydrogen (1 m^3 of methanol contains 99 kg of hydrogen). In the future, the question of the economic efficiency of the methanol economy cannot be examined in relation to fossil methanol alone. If methanol acts as a hydrogen storage, both economic aspects and environmental burdens should be compared with other hydrogen storage options.

R_3: In the case of Hungary, it is worth implementing a project for the production of methanol, which takes advantage of the opportunities inherent in the circular economy and industrial symbiosis, and utilizes the electricity produced during the operation of photovoltaic power plants in the event of a low purchase price.

5. NEW SCIENTIFIC RESULTS

Taking into account the objectives set out in the introduction, based on my research, I summarize my new and novel scientific results as follows:

1. I consider the complex and systematic summary of the concept of the methanol economy, the structured presentation of its connection to the energy strategy of the European Union and the circular economy, to the climate policy goals on the basis of the relevant literature, to be a novel result of the research.
2. Using the harmonization and subsequent analysis of the set of LCA results related to methanol production, I identified the main drivers of the environmental impacts of renewable methanol production.
3. I determined the occurrence of raw materials for renewable methanol production in Hungary, and I also proposed a location for a possible methanol plant based on the geographical location of the sources and technical parameters.
4. I determined the possibilities of methanol production, taking into account the use and production of Hungary's primary energy and electricity in particular, as well as the projected changes.
5. I have proved that the role of methanol energy storage through hydrogen determines the basics of economic calculations related to the methanol economy.

6. ANNEXES

6.1. References

1. AL-KALBANI, H., XUAN, J., GARCÍA, S., & WANG, H. (2016): Comparative energetic assessment of methanol production from CO_2: Chemical versus electrochemical process. In: *Applied Energy,* 165 1-13.p. https://doi.org/10.1016/j.apenergy.2015.12.027
2. ANDERSSON, J., & GRÖNKVIST, S. (2019): Large-scale storage of hydrogen. In: *International Journal of Hydrogen Energy,* 44(23) 11901-11919.p. https://doi.org/10.1016/j.ijhydene.2019.03.063
3. BAKOSNÉ BÖRÖCZ, M. (2016): Az életcikluslemzés módszerének használata és a karbonlábnyom számítás alapjai. Gödöllő: Szent István Egyetemi Kiadó. 40 p.
4. CHAPLIN, A. G. (2013): Renewable Methanol: An Analysis of Technological Potentials in Light of the EU Biofuels Policy Objectives of Greenhouse Gas Savings, Security of Supply and Employment, Aalborg University, 2013. https://projekter.aau.dk/projekter/files/77407997/Masters_Thesis_AGC.pdf. Lekérdezés időpontja: 2021.04.10.
5. DEMIR, M. E., & DINCER, I. (2018): Cost assessment and evaluation of various hydrogen delivery scenarios. In: *International Journal of Hydrogen Energy*, 43(22) 10420-10430p. https://doi.org/10.1016/j.ijhydene.2017.08.002
6. DIAS, V., POCHET, M., CONTINO, F., & JEANMART, H. (2020): Energy and Economic Costs of Chemical Storage. In: *Frontiers in Mechanical Engineering*, 6 21.p. https://doi.org/10.3389/fmech.2020.00021
7. DINYA, L. (2018): Biomassza-alapú energiatermelés és fenntartható energiagazdálkodás: a múlt és a jövő. In: *Magyar Tudomány*, 179(8) 1184–1196.p.
8. FOUQUET, R. (2011): A brief history of energy. In J. Evans & L. C. Hunt (Eds.), *International handbook on the economics of energy Cheltenham*, UK: Edward Elgar Publishing. 848 p.
9. GONZÁLEZ-GARAY, A., FREI, M. S., AL-QAHTANI, A., MONDELLI, C., GUILLÉN-GOSÁLBEZ, G., & PÉREZ-RAMÍREZ, J. (2019): Plant-to-planet analysis of CO_2-based methanol processes. In: *Energy and Environmental Science,* 12(12) 3425- 3436.p. https://doi.org/10.1039/c9ee01673b

10. GUINÉE, J.B. (2002): Handbook on life cycle assessment. Operational guide to the ISO standards. Kluwer Academic Publishers: Dordrecht, Boston. 692 p.
11. GYURICZA, CS. (2010): Energia biomasszából: esély vagy átok? In: *Agrofórum: a növényvédők és növénytermesztők havilapja*, 21(5) 68-72p.
12. HEATH, G. A., & MANN, M. K. (2012): Background and Reflections on the Life Cycle Assessment Harmonization Project. In: *Journal of Industrial Ecology*, 16. https://doi.org/10.1111/j.1530-9290.2012.00478.x
13. HOPPE, W., THONEMANN, N., & BRINGEZU, S. (2018): Life Cycle Assessment of Carbon Dioxide–Based Production of Methane and Methanol and Derived Polymers. In: *Journal of Industrial Ecology*, 22(2) 327-340.p. https://doi.org/10.1111/jiec.12583
14. KESZI SZEREMLEI, A., & MAGDA, R. (2015): Sustainable Production and Consumption. In: *Visegrad Journal on Bioeconomy and Sustainable Development*, 4 (2) 57–61.p
15. KHAREL, S., & SHABANI, B. (2018): Hydrogen as a long-term large-scale energy storage solution to support renewables. In: *Energies*, 11(10) 2825. https://doi.org/10.3390/en11102825
16. KIM, J.; HENAO, C. A.; JOHNSON, T. A.; DEDRICK, D. E.; MILLER, J.E.; STECHEL, E. B.; & MARAVELIAS, C. T (2011). Methanol Production from CO_2 Using Solar-Thermal Energy: Process Development and Techno- Economic Analysis. In: Energy & Environmental Science, 4 3122−3132.p.
17. KISS E. (2013): Környezetvédelem. .https://www.tankonyvtar.hu/hu/tartalom/tamop412A/2010-0013_kornyezetvedelem/9_1_az_eletciklus_elemzes_bemutatasa.html. Lekérdezés időpontja: 2018.05.20.
18. KOTHANDARAMAN, J., KAR, S., SEN, R., GOEPPERT, A., OLAH, G. A., & PRAKASH, G. K. S. (2017): Efficient Reversible Hydrogen Carrier System Based on Amine Reforming of Methanol. In: Journal of the American Chemical Society, 139(7) 2549−2552. p. https://doi.org/10.1021/jacs.6b11637
19. MATZEN, M., & DEMIREL, Y. (2016): Methanol and dimethyl ether from renewable hydrogen and carbon dioxide: Alternative fuels production and life-cycle assessment. In: *Journal of Cleaner Production*, 139 1068−1077. p. https://doi.org/10.1016/j.jclepro.2016.08.163
20. MEUNIER, N., CHAUVY, R., MOUHOUBI, S., THOMAS, D., & DE WEIRELD, G. (2020): Alternative production of methanol from

industrial CO_2. In: *Renewable Energy*, 146 1192–1203.p. https://doi.org/10.1016/j.renene.2019.07.010

21. PAKURÁR, M., KHAN, M. A., BENEDEK, A., & OLÁH, J. (2020): The impact of green practices, cooperation and innovation on the performance of supply chains using statistical method of meta-analysis. In: *Journal of International Studies*, 13(3) 111-128.p. https://doi.org/10.14254/2071-8330.2020/13-3/8
22. PÁPAY , J. (2015): Konvencionális és nem konvencionális kőolaj- és földgázkitermelő eljárások. In: *Magyar Tudomány*, 2015(11) 1285-1294.p.
23. PÉREZ-FORTES, M., & TZIMAS, E. (2016): Techno-economic and environmental evaluation of CO2 utilisation for fuel production. Synthesis of methanol and formic acid. In: *Scientific and Technical Research Series*.
24. RIVAROLO, M., BELLOTTI, D., MAGISTRI, L., & MASSARDO, A. F. (2016): Feasibility study of methanol production from different renewable sources and thermo-economic analysis. In: *International Journal of Hydrogen Energy*, 41(4) 2105–2116.p. https://doi.org/10.1016/j.ijhydene.2015.12.128
25. STERNBERG, A., JENS, C. M., & BARDOW, A. (2017): Life cycle assessment of CO2-based C1-chemicals. In: *Green Chemistry*, 19(9) 2244–2259.p. https://doi.org/10.1039/c6gc02852g
26. STOCKS, M., STOCKS, R., LU, B., CHENG, C., & BLAKERS, A. (2021): Global Atlas of Closed-Loop Pumped Hydro Energy Storage. In: *Joule*, *5*(1) 270–284.p. https://doi.org/10.1016/j.joule.2020.11.015
27. SZALAY, D. (2018): Energetikai célú dendromassza termesztés és hasznosítás lehetséges szerepe a lignocellulóz biohajtóanyag üzemek alapanyag ellátásában. Értekezés doktori (PhD) fokozat elnyerése érdekében, Soproni Egyetem Roth Gyula Erdészeti és Vadgazdálkodási Tudományok Doktori Iskola
28. SZLÁVIK, J. (2007): Környezet-gazdaságtan. Budapest: TYPOTEX. 260 p.
29. TAKÁCS, I., NAGY-KOVÁCS. E., & MARSELEK, S. (2012): A biomassza energiacélú felhasználásának energetikai és gazdasági kritériumai. In: Kis-Simon Tünde, Tóth Éva (szerk.). "A mezőgazdaságtól a vidékgazda(g)ságig" 54. Georgikon Napok. Keszthely. p. 465-475
30. THONEMANN, N., & MAGA, D. (2020): Life Cycle Assessment of Steel Mill Gas-Based Methanol Production within the Carbon2Chem® Project.In: *Chemie-Ingenieur-Technik*, 92(10) 1425–1430.p. https://doi.org/10.1002/cite.202000051

31. TIHANYI, L., & CSETE, J. (2012): A CO_2 lánc – CO_2 leválasztása, szállítása és tárolása. In: *Műszaki Földtudományi Közlemények*, 83 (1) 221–235.p.
32. TÓTHNÉ SZITA, K. (2008): ÉLETCIKLUS-ELEMZÉS, ÉLETCIKLUS HATÁSÉRTÉKELÉS. Miskolc: Miskolci Egyetemi Kiadó.
33. WARNER, E., HEATH, G.A., & O'DONOUGHUE, P., (2010): Harmonization of energy generation life cycle assessments (LCA). FY2010 LCA Milestone Report, Colorado.
34. WINTHER, K. (2019), Methanol as motor fuel, Danish Technological Institute Teknologiparken Kongsvang Allé 29 8000 Aarhus C Transport og Elektriske Systemer ISBN: J.nr. 64018-0719, p 59.
35. YAO, Y., CHANG, Y., HUANG, R., ZHANG, L., & MASANET, E. (2018): Environmental implications of the methanol economy in China: well-to-wheel comparison of energy and environmental emissions for different methanol fuel production pathways. In: *Journal of Cleaner Production*, 172. https://doi.org/10.1016/j.jclepro.2017.10.232
36. YMERI, P., GYURICZA, C., & FOGARASSY, C. (2020): Farmers' attitudes towards the use of biomass as renewable energy-A case study from Southeastern Europe. In: *Sustainability (Switzerland)*, 12(10) 4009 p. https://doi.org/10.3390/SU12104009
37. ZHANG, H., WANG, L., VAN HERLE, J., MARÉCHAL, F., & DESIDERI, U. (2019): Techno-economic optimization of CO2-to-methanol with solid-oxide electrolyzer. In: *Energies*, 12(19) 3742.p. https://doi.org/10.3390/en12193742.
38. ZIMMERMANN, A., MÜLLER, L. J., & MARXEN, A. (2018): Techno-Economic Assessment & Life-Cycle Assessment Guidelines for CO2 Utilization. CO2Chem Media and Publishing Ltd. ISBN 978-1-9164639-0-5 DOI: 10.3998/2027.42/145436.

Internetes források

39. EMBER (2020): https://ember-climate.org/project/eu-power-sector-2020/ Lekérdezés időpontja: 2021.02.22.
40. EUROBSER'Er (2020): Biogas barometer 2020 https://www.eurobserv-er.org/ Lekérdezés időpontja: 2021.04.05.
41. EURÓPAI BIZOTTSÁG (2016b): Integrált Termékpolitika, Integrated Product Policy 1.http://ec.europa.eu/environment/ipp/. Lekérdezés időpontja: 2018.05.20.

EUROSTAT (2020a): Waste statistics https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics Lekérdezés időpontja: 2021.01.22..

42. EUROSTAT (2020b): Renewable energy statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Share_of_renewable_energy_more_than_doubled_between_2004_and_2019 Lekérdezés időpontja: 2021.01.22.
43. EURÓPAI SZENNYEZŐANYAG-KIBOCSÁTÁSI ÉS -SZÁLLÍTÁSI NYILVÁNTARTÁS (2017): https://prtr.eea.europa.eu/#/home Lekérdezés időpontja: 2021.03.28.
44. HVG (2013): https://hvg.hu/cegauto/20131027_Nobeldijas_tipp_Magyarorszag_uj_uzemanya Lekérdezés időpontja: 2021.03.28.
45. KSH (2019b): A fontosabb növények vetésterülete, 2019. június 1. https://www.ksh.hu/docs/hun/xftp/gyor/vet/vet1906.pdf Lekérdezés időpontja: 2021.05.11.
46. MSZ EN ISO 14040:2006.

https://www.mszt.hu/mszt/portal/user/anon/page/default.psml/js_panename/msztStandardDetails?cikkszam=141792. Lekérdezés időpontja: 2018.05.18

6.2. List of publications in relation with the dissertation

Hungarian language peer-reviewed journal articles

1. SZLOVÁK, S. – TÓTH, J. (2018): A bioetanol közlekedési célú alkalmazásának kérdései a fenntartható fejlődés aspektusából. In: *A FALU*, 33 (1) 23-34. p.6. 5
2. TÓTH, J. – MAGDA, R. (2019): A „zöld” metanol szerepe a fenntartható energiagazdálkodásban. In: *INTERNATIONAL JOURNAL OF ENGINEERING AND MANAGEMENT SCIENCES / MŰSZAKI ÉS MENEDZSMENT TUDOMÁNYI KÖZLEMÉNYEK,* 4 (4) 249-258. p.

Foreign language peer-reviewed journal articles

3. TÓTH, J. – MAGDA, R. (2017): DIFFERENCES OF THE PRIMARY ENERGY CONSUMPTION OF THE COUNTRIES ALL OVER THE WORLD. In: APSTRACT - APPLIED STUDIES IN AGRIBUSINESS AND COMMERCE, 11 (3-4) 145-152. p.
4. TÓTH, J. – SZLOVÁK, S. – MAGDA, R. (2018): Innovations connected to methanol in the service of blue economy. In: VISEGRAD JOURNAL ON BIOECONOMY AND SUSTAINABLE DEVELOPMENT, 7 (1) 7-10. p.
5. MAGDA, R. – TÓTH, J. (2019): THE CONNECTION OF THE METHANOL ECONOMY TO THE CONCEPT OF THE CIRCULAR ECONOMY AND ITS IMPACT ON SUSTAINABILITY. In: VISEGRAD JOURNAL ON BIOECONOMY AND SUSTAINABLE DEVELOPMENT, 8 (2) 58-62. p.

Hungarian language publications in conference proceedings

6. TÓTH, J. – MAGDA, R. (2017): Metanol-kulcs a fennatrthatósághoz. In: LIX. GEORGIKON NAPOK (2017) (Keszthely). A múlt mérföldkövei és a jövő kihívásai: 220 éves a Georgikon. Pannon Egyetem Georgikon Mezőgazdaságtudományi Kar. p. 558-566.
7. CSAPÓ, I. – TÓTH, J. (2018): A fenntarthatóságot segítő innovációk támogatása menedzsment tanácsadással. In: KÖZGAZDÁSZ DOKTORANDUSZOK ÉS KUTATÓK TÉLI KONFERENCIÁJA (2018) (Gödöllő). Közgazdász Doktoranduszok és Kutatók IV. Téli Konferenciája: Konferenciakötet. Budapest: Doktoranduszok Országos Szövetsége. p. 41-50.
8. TÓTH, J. – MAGDA, R. (2018): Metanol – a fenntarthatóságot szolgáló üzleti modellek szereplője. In: XVI. NEMZETKÖZI TUDOMÁNYOS

NAPOK (2018) (Gyöngyös): „Fenntarthatósági kihívások és válaszok” - A Tudományos Napok Publikációi. Gyöngyös: EKE Líceum Kiadó p. 1779-1787.

9. TÓTH, J. (2019): A „hurok zárása” lehetőségek a szén- dioxid megkötésére. In: KÖZGAZDÁSZ DOKTORANDUSZOK ÉS KUTATÓK TÉLI KONFERENCIÁJA (2019) (Gödöllő). Közgazdász Doktoranduszok és Kutatók V. Téli Konferenciája: Konferenciakötet. Gödöllő: Doktoranduszok Országos Szövetsége. p. 662- 670.

Foreign language publications in conference proceedings

10. TÓTH, J. – MAGDA, R. (2018): The possibility of producing biomass-based methanol - hungarian projections. IN: BUSINESS AND MANAGEMENT SCIENCES: NEW CHALLENGES IN THEORY AND PRACTICE 25TH ANNIVERSARY OF THE DOCTORAL SCHOOL OF MANAGEMENT AND BUSINESS ADMINISTRATION (2018) (Gödöllő). Proceedings of the international conference “business and management sciences: new challenges in theory and practice” / "Gazdálkodás- és szervezéstudomány: Új kihívások az elméletben és gyakorlatban" nemzetközi tudományos konferencia tanulmánykötete. Gödöllő: Szent István Egyetemi Kiadó p. 131-139.
11. SZLOVÁK, S. – TÓTH, J. (2018): Potential of production of first and second generation bioethanol – Hungarian aspects In: XVI. NEMZETKÖZI TUDOMÁNYOS NAPOK (2018) (Gyöngyös): „Fenntarthatósági kihívások és válaszok” - A Tudományos Napok Publikációi. Gyöngyös: EKE Líceum Kiadó p. 1713-1721.
12. TÓTH, J. (2018): Innovations Connected to Methanol in the Service of Circular Economy. In: 14TH ANNUAL INTERNATIONAL CONFERENCE ON ECONOMICS AND BUSINESS: CHALLENGES IN THE CARPATHIAN BASIN (2018) (Csíkszereda). Konferenciakötet. Csíkszereda: Sapientia Hungarian University of Transylvania p. 308-317.

Book chapters

13. MAGDA, R. – SZLOVÁK, S. – TÓTH, J. (2021): The role of using bioalcohol fuels in sustainable development. 133- 146. p. In: BOCHTIS, D. – ACHILLAS, D. – BANIAS, G. – LAMPRIDI, M. (Editors): Bio-Economy and Agri-production.Academic Press, ISBN 9780128197745