THE CONNECTION OF THE METHANOL ECONOMY TO THE CONCEPT OF THE CIRCULAR ECONOMY AND ITS IMPACT ON SUSTAINABILITY

Robert Magda*, Judit Toth

Szent Istvan University, Gödöllő, Hungary; North-West university, South Africa

The idea of the circular economy is gaining ground as one of the means to realize a sustainable future. The concept of a circular economy is an innovative alternative model to society's current "linear" mode of operation. An alternative to fossil fuels is a cycle in which carbon and methanol play a major role. Carbon use plays a major role in mitigating global climate change, while methanol as a renewable fuel can also mitigate the negative effects of climate change and bridge the problems of scarcity of ecosystem resources and rising levels of consumption. Despite the fact that a circular economy reduces the environmental burden while providing business benefits, not all circular solutions have a positive impact on sustainability. The use of CO_2 as a feedstock can be a very effective tool for reducing global carbon dioxide concentration as well as reducing dependence on fossil fuels. At the same time, the environmental impacts of the technologies developed need to be accounted for in order to highlight that the technology pathway actually contributes to the sustainability goals.

Keywords: circular economy; sustainability; methanol; indicators

Introduction

According to the United Nations (UN), the amount of raw material extracted from the earth has tripled in the last four decades, primarily as a result of the rapid growth of per capita income and consumption, i.e. the middle class (UNEP, 2017). Several initiatives aim at putting the concept of sustainable development into practice, such as the Green Economy and Green Growth Concept (OECD, 2016) and the increasingly important circular economy (CE) concept. CE represents a business strategy that is capable of creating an economy with a strong and competitive industry where resources are not exploited at a rate exceeding the Earth's capacity (MacArthur Foundation 2014). The governments of China, Japan and the European Union (EU) have been at the forefront of adopting circular economic policies. The Europe 2020 Strategy underlines the Union's primary objective of becoming a sustainable economy and sets ambitious targets for climate policy and energy efficiency. According to the European Commission, "the transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy" (European Commission, 2015).

The Circular Economy

CE is a term that, unlike the concept of linear economy, is commonly used to describe traditional economic business processes. The term CE is widely used by researchers, stakeholders in the industry, policy makers, and thus it has a wide variety of definitions in the literature, as 114 definitions have been collected by Kirchherr et al. (2017). The large number of definitions is explained by the complex and transdisciplinary nature of CE (Lieder et al., 2017; Sauvé et al., 2015). The CE is one of the tools of a sustainable society, with the aim of generating economic value (increasing economic value of materials or products), creating social value (minimizing the destruction of social value throughout the system, such as unhealthy working conditions for raw material extraction and reuse) and value creation from the environmental point of view (resilience of natural resources) (Van Buren et al., 2016). The CE basically covers all stages of a product's life cycle, from product design through production and marketing, to consumption, waste management, recycling, and reuse. The main principles of CE are to significantly reduce the production and consumption of raw materials, in combination with a strategy to recover and reuse waste resources. Figure 1 illustrates that the CE means more than recycling or recovering materials.

The recycling economy still involves the use of raw materials and waste production, while in a fully CE, loops are closed. In addition, in the first two models, energy consumption is predominantly related to the widespread use of scarce raw materials (oil and gas), while the CE model uses renewable energy production and use (Rli, 2015).

In the literature regarding the CE there are various degrees and possibilities of the cycle. Cramer (2014) describes the nine degrees of circularity:

1. Refuse: preventing the use of raw materials.
2. Reduce: reducing the use of raw materials.
3. Reuse: product reuse (second-hand, sharing of products).

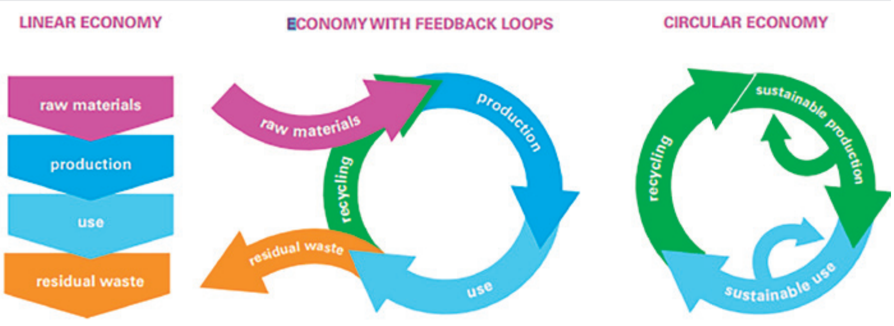

Figure 1 Differences between linear economy, economy with feedback loops and CE
Source: RLi, 2015

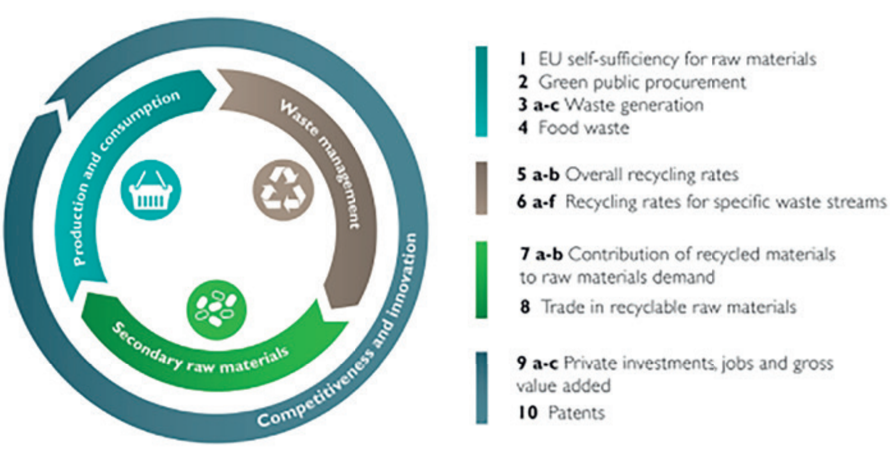

Figure 2 Circular economy monitoring framework
Source: European Commission, 2018

4. Repair: maintenance and repair.
5. Refurbish: refurbishing a product.
6. Remanufacture: creating new products from (parts of) old products.
7. Repurpose: product reuse for a different purpose.
8. Recycle: processing and reuse of materials.
9. Recover energy: incineration of residual flows.

Of the degrees of circularity, the lowest level is "energy recovery" because energy recovery actually "ends" the cycle.

Indicators of the circular economy

Due to the complex and transdisciplinary nature of CE, monitoring is a challenge. The development of measurable indicators and methodologies is still at an early stage of research. The concept of environmental life cycle was introduced in the early 1990s and was already considered at the 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). According to the decision of the European Commission, Life Cycle Assessment (LCA) is the most suitable tool for assessing the environmental impact of products, of which methodological harmonization will be helped by the creation of the European LCA Platform (European Commission, 2016). Lifecycle analysis enables to quantify and compare the environmental impacts of products, processes, and models based on metrics, using a method defined by ISO standards. The strength of LCA is that it collects and summarizes environmental impact data at every stage of the product's life. It also interprets the aggregate results and then weights and evaluates them in terms of the significance of environmental impacts. It displays results in a simplified, easy-to-understand format. According to many researchers, the LCA method, or a system based on it, is best suited for monitoring CE, due to the variety of indicators used and their detailed analysis, although the interpretation of the results requires expertise (Elia et al., 2017; Lonca et al., 2018). The indicators developed so far for CE monitoring depend on not only the sectors, the geographical location, but also the purpose of the organization or government applying for it and the target audience (Fogarassy et al., 2017). As part of its ongoing efforts to transform the European economy into more sustainable and to implement the CE action plan, the European Commission adopted a new package of measures in January 2018, including the implementation of monitoring system that should reflect efforts to build the CE. The monitoring system includes 10 indicators to cover all life cycle stages of resources, products, and services and to show four aspects of the CE: production and consumption; waste management; secondary raw materials; competitiveness and innovation, as illustrated in Figure 2.

The role of methanol in the circular economy

The philosophy of CE is based on the principle of natural processes. Ecosystems are interconnected by creating networks of networks, circulating energy and nutrients through cycles, so nothing is wasted (Pauli, 2015). Non-recyclable materials still hold significant energy, and our goal is to extract and store that energy. Ashes and gaseous materials generated during energy recovery should become secondary raw materials. The circulation and recycling of the carbon dioxide (CO_2) produced by power plants, which has so far been the only example in nature, is a major area of the research and innovation that contributes to the net emission of greenhouse gases. CO_2 and hydrogen are the raw materials for the production of the simplest alcohol, methanol, based on Fischer-Tropsch synthesis, so the idea of the carbon capture by methanol production came simply. Figure 3 illustrates the closure of the carbon loop by producing renewable and sustainable methanol through capturing the carbon dioxide of the power plants, which can efficiently recycle the CO_2 released (Goeppert et

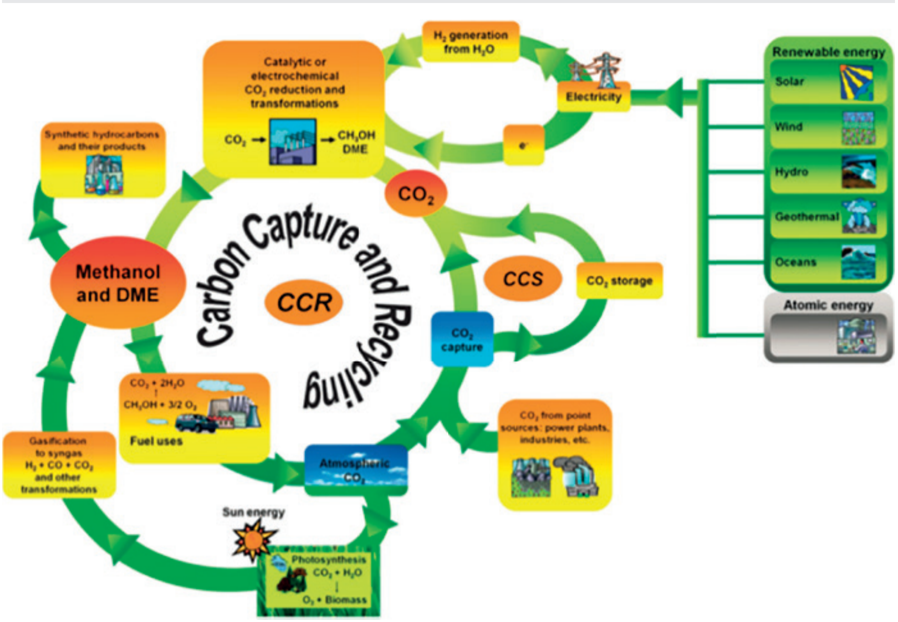

Figure 3 Anthropogenic carbon cycle within the Methanol Economy.
Source: Goeppert et al., 2014

al., 2014). The essence of the methanol economy is to use methanol as an intermediate energy source in areas where it is not possible to draw electricity directly from the electricity grid during use.

Material and methods

The purpose of the study is to present the relationship between the concept of the methanol economy and the CE as well as the benefits of the methanol economy using indicators of the CE. In addition, a comparison of the environmental impact analysis of methanol produced from different starting materials and technology pathways is performed. The analysis is based on relevant statistical data from secondary sources of national and international literature.

Results and discussion

The use of CO_2 as a feedstock can be a very effective means of reducing global carbon concentration and reducing dependence on fossil fuels, but it is necessary to consider the environmental impact of the technologies developed in order to highlight that the particular technology pathway actually contributes to achieve sustainability goals. The strength of the methanol economy, i.e. that the raw materials used to produce methanol can come from a variety of sources, make the analysis difficult, and the energy used in the process can also be fossil, nuclear or some form of renewable energy.

Studies based on life cycle analysis

China

As the world's largest producer of methanol, China is far more advanced than any other country in developing a methanol economy, assisted by strong government support. In 2009, the Chinese government introduced a national standard for the 85% methanol-gasoline (M85) fuel blend, thus promoting the spread of methanol-powered vehicles. China is not producing methanol for the purposes of the methanol economy, i.e. biomethanol production, but is produced from three fossil feedstocks: coal, coke oven gas (COG) and natural gas. The environmental impact of using methanol from different feedstocks as fuel has been investigated. The result is illustrated in Figure 4.

It has been found that methanol produced by dominant carbon-based technology entails higher environmental burdens than gasoline.

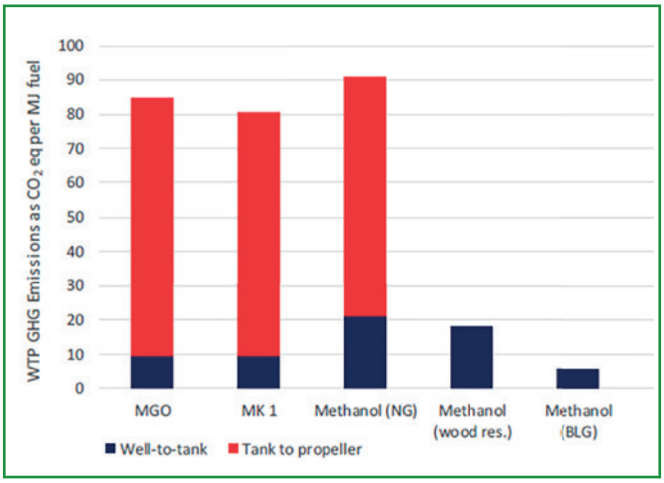

Figure 5 GHG emissions per MJ fuel for methanol from natural gas (NG), wood residues, and black liquor gasification (BLG) as compared to marine gasoil and MK 1 diesel
Source: Ellis and Svanberg, 2018

Environmental burdens have been reflected in higher energy and water consumption and in the release of greenhouse gases and sulphur dioxide. Coke oven gas-based technology supported by the Chinese government is more environmentally friendly than coal-based but less favourable than gasoline (Yao et al., 2017).

Europe

Joint efforts to reduce emissions of sulphur dioxide, nitrogen oxides and greenhouse gases require significant changes in sea freight. One of the options for shipping companies is to change the fuel used. The environmental impacts of liquefied natural gas (LNG), liquid biogas (LBG), methanol and biomethanol have been studied in Sweden as fuels for larger ships. LCA has shown that natural gas and methanol produced from natural gas are no more favourable to climate change than diesel fuel, only reducing the environmental impact during transport. The use of methane and methanol produced from biomass can equally reduce the impact of shipping on climate change (Brynolf et al., 2014). The operators of smaller ships, for example, state-owned road ferries, pilot boats, and work boats already have targets to reduce GHG emissions. The Sustainable Marine Methanol (SUMMETH) project, which develops the use of renewable methanol fuel, is helping to achieve

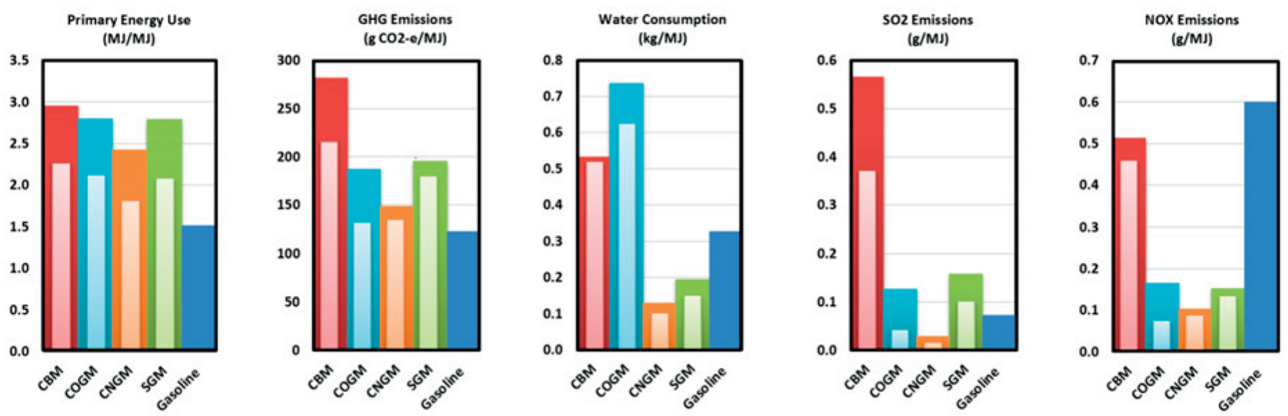

Figure 4 Life-cycle environmental burdens of methanol produced from four feedstock and conventional gasoline
Source: Yao et al., 2017
CBM – coal-based methanol; COGM – coke-oven-gas based methanol; CNGM – conventional natural gas-based methanol; SGM – shale gas-based methanol

Table 1 Impact of the energy source used to produce hydrogen on the environmental performance of CO_2-based methanol production

H2 SUPPLY	Global warming	Fossil depletion
Wind electricity	+	+
Solar electricity	+	+
EU-27 electricity mix (2050)	o	o
EU-27 electricity mix (2020)	-	-
EU-27 electricity mix (2012)	-	-

Source: Sternberg et al., 2017

+ environmentally beneficial CO_2-based process; o potentially environmentally beneficial CO_2-based process; - not environmentally beneficial CO_2-based process

Table 2 Indicators on the circular economy included in the monitoring framework – Waste management

Indicator	Sub-indicator	Relevance
Overall recycling rates	Recycling rate of municipal waste	Increasing recycling is part of the transition to CE
	Recycling rate of all waste	
Recycling/recovery for specific waste streams	Recycling rate of overall packaging	This reflects the progress in recycling key waste streams.
	Recycling rate of packaging waste by type	
	Recycling rate of wooden packaging	
	Recycling rate of e-waste	
	Recycling of biowaste	
	Recovery rate of construction and demolition waste	

Source: European Commission, 2018

these goals. The result of the SUMMETH fuel LCA for GHG emissions is shown in Figure 5. Methanol produced from renewable raw materials, such as wood residues and black liquor from a pulp mill, can result in a 75–90% reduction in greenhouse gas emissions. Methanol produced from fossil fuels produces slightly higher greenhouse gas emissions than conventional petroleum fuels.

CO_2 emissions from the combustion of methanol (wood residues and BLG) from renewable raw materials are zero, since the amount of CO_2 released by combustion is equal to the amount of CO_2 absorbed by plants during photosynthesis. This is in line with the EU Renewable Energy Directive (2009/28/EC) on the calculation of greenhouse gases or biofuels. There is GHG emissions in the "Well to tank" process, which is due to the production process, the shipping. A further environmental benefit of using methanol fuels is that they significantly reduce particulate emissions and NOx emissions (Ellis and Svanberg, 2018).

The environmental impact of European CO_2-based methanol production is greatly influenced by the source of the CO_2 used as a feedstock and the electricity demand for the most energy-intensive part of the production process, hydrogen. Studies by Hoppe et al. (2017) have shown that the use of CO_2 from cement production and waste incineration is a promising option for reducing GHG emissions, but the extent of this depends largely on local conditions. The use of renewable energy sources for hydrogen production contributes significantly to reducing the environmental impact of methanol production, with wind and solar energy being of paramount importance, as shown in Table 1.

The usage of EU-27 electricity mix (2012) and EU-27 electricity mix (2020) for hydrogen production does not favour CO_2-based methanol production over fossil-based processes in terms of global warming and fossil depletion, but it is worth to separately examine each country. Countries such as Sweden, Norway, Iceland, France, Switzerland, and Belgium, which have a high share of renewable energy and nuclear energy, have significant environmental benefits from CO_2-based methanol production (Sternberg et al., 2017). Carbon Recycling International is the world's first renewable methanol producing commercial plant, which is based in Iceland and has two biomethanol production projects (VärmlandsMetanol Ltd., Chemrec) in Sweden.

Application of the EU Circular economy monitoring framework

The first step in implementing the CE is more efficient waste management. In this spirit, one of the four aspects of the monitoring system proposed by the European Commission is waste management which has 2 indicators. Table 2 shows the structure of the indicators.

The EU has set new common EU targets for municipal waste: 55% of municipal waste need to be recycled by 2025, 60% by 2030 and 65% by 2035. Up to 10% of municipal waste can be landfilled by 2035 (European Parliament, 2018). The achievement of the objectives is helped by energy recovery and chemical transformation of waste to e.g. fuel, while respecting the waste hierarchy as well.

By 2022, the city of Edmonton in Canada, has set a target of recycling 90% of household waste rather than to put them into landfill. To this end, a partnership has been established between the city and Enerkem Alberta Biofuels. Enerkem Alberta Biofuels converts non-recyclable, non-compostable municipal solid waste into liquid biofuel. The plant produces methanol and ethanol, which can be used directly as a fuel or blended with petrol and serve as a feedstock for the chemical industry.

Figure 6 Transitioning to a circular economy with Enerkem's MSW to methanol model
Source: Enerkem

The W2C project in Rotterdam also uses Enerkem technology to convert non-recyclable, non-compostable municipal solid waste into methanol, thus providing a sustainable alternative for the production of renewable chemicals. The project will help to achieve the Netherlands' ambitious plan to become carbon neutral by 2050. Figure 6 illustrates the Enerkem CE model (Enerkem.com).

Conclusion

Methanol is a versatile chemical feedstock, fuel. Aside from fossil sources, a variety of raw materials can be involved in methanol production, from biomass through municipal waste to CO_2 from flue gases. LCA have clearly highlighted the environmental benefits of using methanol from renewable raw materials as a fuel. It can be stated that methanol production technologies that use H2 as a feedstock in addition to CO_2 require a large amount of electric content, so the contribution of the resulting methanol to sustainability depends on the energy source used. The use of renewable energy sources is beneficial both in terms of sustainability and CE. The methanol economy contributes to the CE objectives by, inter alia, turning flue gas from energy recovery into a secondary raw material. The transition to the CE can be achieved through the use of new innovative methods and technologies as well as effective political action.

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Contact address

Róbert Magda, professor, Szent István University, Institute of Economics, Law and Methodology, Faculty of Economics and Social Sciences H-2100 Gödöllő, Páter Károly street 1, Hungary, e-mail: rmagda72@gmail.com