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To cite this article: Hamidreza Hasheminasab, Sarfaraz Hashemkhani Zolfani, Edmundas Kazimieras Zavadskas, Mohammadreza Kharrazi & Marinko Skare (2022) A circular economy model for fossil fuel sustainable decisions based on MADM techniques, Economic Research-Ekonomiska Istraživanja, 35:1, 564-582, DOI: [10.1080/1331677X.2021.1926305](https://doi.org/10.1080/1331677X.2021.1926305)

To link to this article: <https://doi.org/10.1080/1331677X.2021.1926305>



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Published online: 18 Jun 2021.



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A circular economy model for fossil fuel sustainable decisions based on MADM techniques

Hamidreza Hasheminasab^a , Sarfaraz Hashemkhani Zolfani^b , Edmundas Kazimieras Zavadskas^c , Mohammadreza Kharrazi^d  and Marinko Skare^e 

^aSchool of Civil Engineering, College of Engineering, University of Tehran, Enghelab Square, Tehran, Iran; ^bSchool of Engineering, Catholic University of the North, Coquimbo, Chile; ^cInstitute of Sustainable Construction, Vilnius Gediminas Technical University, Vilnius, Lithuania; ^dOffice of Sustainable Development, Amirkabir University of Technology, Tehran, Iran; ^eFaculty of Economics and Tourism, Juraj Dobrila University of Pula, Pula, Croatia

ABSTRACT

Fossil fuels as the primary energy source create career opportunities, provide industries with vital raw material and energy resources, have harmful emissions to the environment and are also related to finite natural resources. They rely on them as the main source of energy supply is unsustainable. Sustainability assessment tools may be useful in developing a more sustainable scenario. However, the resiliency of nature is not taken into account in this linear assessment. The detrimental effect of these fuels on the environment during their life cycle would suggest transitioning from cradle-to-grave to the cradle-to-cradle lifecycle viewpoint. This study implements the Circular Economic (CE) in fossil fuel development to minimize the unsustainable effects and ensure the environment's resiliency. In this context, three different fossil fuels are assessed based on the CE model's proposed lifecycle phases to find out the most sustainable fossil fuel option. A case study is carried out in an industrial location with high-level decision-makers. CE criteria are evaluated based on the E-SWARA method to ensure the assessment's reliability at this critical step. Next, a novel MCDM method, MARCOS, is applied to this study. Based on the results, gas is the most sustainable energy generation plant in the intended region.

ARTICLE HISTORY

Received 9 February 2021
Accepted 30 April 2021

KEYWORDS

Circular economy; cradle-to-cradle; fossil fuel; sustainability; MCDM; Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS); extended stepwise weight assessment ratio analysis extended SWARA (E-SWARA)

JEL CLASSIFICATION:

Q56; C02; Q58

1. Introduction

Fossil fuels are coal, crude oil and natural gas supply 80% of the US (EIA, 2019) and global (Foster & Elzinga, 2015) energy demands. Also, global energy generation releases more than 65% of CO₂ emissions. Thus, these imperative energy industries are developed based on unsustainable settings concerning fossil fuels' finite resources. This inherent unsustainability in this strategic supply chain of global energy is an

CONTACT Edmundas Kazimieras Zavadskas  edmundas.zavadskas@vilniustech.lt

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important issue. Every reduction in the emissions and improvement in the energy efficiency and recycling processes in every step of the material lifecycle will result in a cleaner and more sustainable environment in the inevitable energy supply. Besides, they compromise nature's resiliency by emitting many pollutants into the air, water and soil. They increase our carbon footprint and cause many Green House Gas (GHG) emissions, resulting in various global environmental crises such as climate change, global warming and ocean acidification.

Every human being deserves to have a safe and comfortable living. People across the globe are working hard to improve their standard of living. Consequently, in a larger perspective, every country, regardless of development status, is trying to develop and satisfy more human needs and expectations. Thus, development is crucial for nations and inevitable to be facilitated; however, this fast-paced development is not sustainable. Economic growth cannot be steady in the process of take-make-use-dispose, and the resources and waste absorption capacity are limited (Bonviu, 2014).

Every industry and economic activity needs various resources such as materials and energy in order to produce value via their processes. As a result of these activities, air, water and soil pollutants are produced, including these industries' byproducts. Meanwhile, further development of enterprises, economies and societies will magnify the situation's complexity by converting every linear trend exponentially. In other words, industries consume finite resources for raw materials on the one hand. On the other, when they develop, they need more of such resources, which accelerates the depletion process for raw materials and other finite resources. Thus, development (enlarging the industry) in the shrinking system of resource consumption is unstable and will result in an unsustainability head collision (Korhonen et al., 2018).

Hence, it is required to consider the finite resources and the next generation's ability to fulfil their needs from nature (sustainability) and the environment's ability to react and treat the turbulences imposed by the emissions and pollutions (Resiliency) simultaneously. Consequently, a broader viewpoint needs to be followed at the strategic level, which would use a more comprehensive Life Cycle Assessment (LCA) approach, covering cradle-to-cradle. After the strategic level, the next crucial phase that would impact LCA's outcome is the design phase. During this phase, potential environmental impacts can be factored in, and a solution is found if the results are not satisfactory. It is shown that 80% of the product's environmental impacts are determined at the design phase (COM, 2020).

Based on the current literature and sustainability trends, this broader view of LCA, to consider and prepare for returning the resources to the environment at the end of the service life, upgrades the Linear Economic to a new approach called Circular Economy (CE). Apart from the variety of academic studies that have been carried out regarding CE, policymakers are also entering this field, which means major changes in strategic decisions. For instance, Europe (COM, 2020) and China (Lieder & Rashid, 2016) have developed their policies, instructions and promotions to boost CE implementation in their territories. Other countries such as Australia, Canada, India, Malaysia, South Korea, Thailand and the US have enacted legislations to support CE and the closed-loop concept (Ghosh, 2020). CE is regarded as a mean of economic development as the European Commission estimated that annually 600 billion

EUROs could be gained per annum, solely from the manufacturing sector in Europe (COM, 2014, 2015) while on the global scale, this can reach an annual gain of up to 1000 billion USD (EMAF, 2013; Finland's Independence Celebration Fund (FICF, Sitra) and McKinsey, Finland, 2014).

As sustainability is a high-level issue that targets the needs and expectations of coming generations to ensure, at least, a steady development line in the future, it is required to set and pursue inter-generational goals as well. Concerning the dependency of the global energy demand on non-renewable resources, quick and complete replacement of the resources would be an impossible option (Foster & Elzinga, 2015) and may cause unsustainable circumstances. Thus, developing the non-renewable resources with the least environmental footprint and gradual transition toward renewable energies may be the most sustainable route in line with the inter-generational goals. This strategic vision needs to have a broader and long-term decision to be implemented in the future (Korhonen et al., 2018).

The energy production industry and fossil fuel, in particular, are targeted in this study concerning the importance of their development and their inherent unsustainability, which makes it a highly important and sensitive industry to be under investigation. Besides, in the past, fossil fuels have been considered in the traditional linear development context of take-make-use-dispose which cannot be sustained as discussed before. As such, this study aims to develop a CE model for fossil fuels to address recycling the resources back to the environment as much as possible, both in terms of materials and energy produced. Furthermore, the environment's capacity to be subjected to turbulence is limited. This is more so in an industrial location, in which a great share of the environmental capacity might be already consumed. Thus, we performed the case study for a real industrial region, in which we developed our model to evaluate different types of non-renewable resources, that is, fossil fuels. This model was used for decision-making at a strategic level; during this study, a group of senior managers and policymakers contributed. The Multiple Criteria Decision Making (MCDM) methodology that was used for this study is the recently developed Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) method (Stević et al., 2020).

2. Literature review

Regardless of CE, researchers always hold sustainability of energy projects, particularly fossil fuels, in high regard. For instance, among the previous studies carried out addressing sustainability assessment of the fossil fuels, a research group focused on measuring the sustainability profile for a petroleum refinery project in a static decision environment (Hasheminasab et al., 2018a) and dynamic circumstances, the latter of which allowed the decision making framework to be modified based on the particular project conditions (Hasheminasab et al., 2020). This chain of studies on the sustainability of petroleum refinery projects performed research on scenario analysis (Gholipour et al., 2018) and fast-track decision making (Hasheminasab et al., 2018b) in the assessment process. A variety of other studies in the petrochemical (Heravi

et al., 2015, 2017) and upstream oil field projects (Poveda & Lipsett, 2014a, 2014b), have been published, which cover the sustainability assessment of fossil fuel projects.

There is no consensus in the literature review on how CE attends to sustainability's three pillars (Kirchherr et al., 2018). Some of the previous studies regard CE as focusing mostly on economic and ecological goals (Geissdoerfer et al., 2017; Sauvé et al., 2016), while others view CE's role broader, covering the complete lifecycle with economic as well as social, and environmental concerns considered in a balanced way (Kirchherr et al., 2017; Murray et al., 2017). Another study has adjusted the CE concept to cover all sustainability pillars and concluded that CE is related to the triple pillars' simultaneity and subscription of economic and environmental pillars of sustainability (Suárez-Eiroa et al., 2019). The present study will follow this broader view of the CE concept.

Currently, CE is widely used in the literature to follow this broader view. As the CE is the culmination of the cradle-to-cradle approach, it substitutes the linear economy approach (cradle-to-grave) (Braungart et al., 2007; McDonough & Braungart, 2002, 2003). CE covers the final step of returning to the environment in order to reuse, remanufacture and recycle. Regardless of CE, this circular concept and supply chain issues have been covered in some studies (Govindan et al., 2015; Stindt & Sahamie, 2014; Wells & Seitz, 2005). The environment's capacity to absorb the turbulence caused by different pollutants has been addressed in current CE studies. They have tried to measure social-ecological systems' resiliency (Crépin et al., 2012; Ferreira et al., 2018; Folke, 2006). In CE literature, one would also come across studies that have been carried out on zero-emissions to minimize the turbulence caused by pollutants (Liu et al., 2012; Pauli, 2010).

Regular and green energy production cases have been studied in various previous studies to assess sustainability and develop CE models. For instance, a structure for Chinese CE was created, and the government's policies and strategies for energy conservation were discussed and assessed in a previous study (Li et al., 2010). In this regard, another study focused mainly on the best practices in energy and environmental efficiency among OECD countries and developed a weighting based on a CE model (Mavi & Mavi, 2019). In particular, green energy and wind were targeted to assess with more investigation on the material and recycling procedure in the CE context (Hao et al., 2020). Also, CE was applied to renewable energies and their means of storage to create more reliable energy sources, and different case studies were included in another study (Olabi, 2019).

SWARA (Stepwise Weight Assessment Ratio Analysis) is a well-known and frequently used MCDM methodologies used in various studies (Kaya & Erginel, 2020; Hashemkhani Zolfani & Sapauskas, 2013). Since the methodology is mainly developed to evaluate the criteria sets in MCDM problems, some other studies are carried out by combining the SWARA with another methodology to cover both criteria weighting and alternative selection parts of the problem (Bitarafan et al., 2014; Ghorshi Nezhad et al., 2015; Singh & Modgil, 2020). Due to the criteria's pivotal role in developing the assessment framework, SWARA serves as the foundation of the weighted framework for evaluating various problems. Still, it is extended in another study to ensure the reliability of experts' opinions to be applied to other studies (Hashemkhani Zolfani et al., 2018). In the current study, due to its policy-level

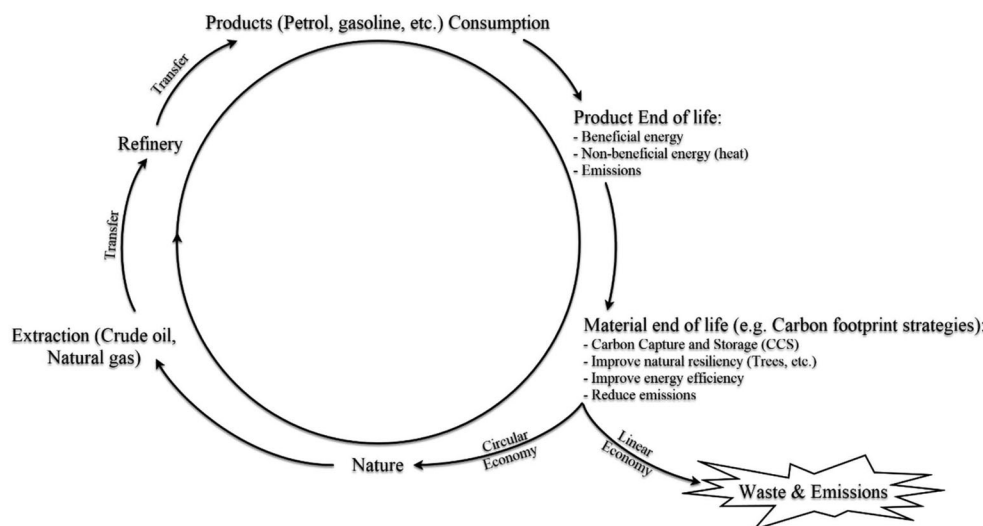


Figure 1. Circular Economy (CE) model for fossil fuel material lifecycle.
Source: The Authors.

evaluation, which would yield sensitive results, the criteria weighting is carried out by E-SWARA methodology.

MARCOS methodology has been recently developed to select a sustainable supply chain (Stević et al., 2020). Despite the novelty of this methodology, it is applied to different fields of science such as risk analysis in road traffic (Stanković et al., 2020), human resource evaluation in a transport company (Stević & Brković, 2020), supplier selection in the iron industry (Chakraborty et al., 2020) and a steelmaking company (Badi & Pamucar, 2020), and the best investment software selection (Puška et al., 2020). Among MARCOS's various applications, the current study seeks to apply the methodology at a strategic level for selecting the most sustainable alternative for energy generation using fossil fuels based on the CE life cycle model.

3. Methodology

3.1. CE Model for fossil fuels

CE is known to be a more resilient and sustainable alternative for the linear approach based on the existing literature. In reality, both of these approaches coincide. Without exception, the energy industry processes and fossil fuels are a combination of linear and circular processes throughout the entire material life cycle phases (Figure 1). Meanwhile, the goal should be to minimize the linear and maximize the circular processes in this industry.

Considering energy as the product of interest in this study, its life cycle's final step is energy consumption, which can be controlled and improved using more strict standards and more efficient engines. Using energy efficiency to reduce wasted energy can be a returning option for the product circular approach. Suppose fossil fuel is considered the product of interest, at the final step of the material's life cycle. In that case, different returning options can be proposed for the fossil fuel residuals as follows:

3.1.1. Carbon capture and storage (CCS)

This option is to capture the carbon emissions and safely store them, for example, at the bottom of the oceans, to be used in the future when the technology reaches the ability to use carbon emissions effectively. As a result, carbon is not spread to the environment, and energy can be produced more sustainably. However, this is an expensive option due to its dependency on advanced technologies, drilling and storing and maintaining the inventory.

3.1.2. Improve natural resiliency

The trees' breathing process consumes the CO₂ and releases oxygen to improve resiliency and reduce environmental turbulences. As a result, making policies on extensive use of vegetation in various development projects will improve the resiliency and be a long-term solution for recycling carbon emissions.

3.1.3. Improve energy efficiency

Fossil fuels are consumed to produce energy, which is to be used in various energy-consuming applications. Improving the energy efficiency in these applications can assist in reducing the energy demand and consumption rate.

3.1.4. Reduce emissions

Another CE strategy is reducing emissions in different ways, from using advanced technologies to producing fossil fuel products with the least potential for pollution. For instance, desulfurization is one of the refinery phases that will improve quality for final products.

Circular processes are derived from returning the used materials to the natural environment to use them again in other product lifecycles. Fossil fuels have a long lifecycle, and they are non-renewable sources of energy. However, the industry has lots of diverse phases from extraction to refinement and consumption, which are multidisciplinary and sometimes involve complex engineering work. This material lifecycle contains multiple projects, portfolios, programs and products regarding their lifecycle. The circular potential is undeniably high in this process. The returning process can be done for every work package, including manufacturing, supplying, construction, operation, and so on. Thus the goal is to build up a solution chain for this complex material lifecycle (see [Figure 2](#)).

There is a variety of returning options from 'reuse' to 'remanufacturing', 'recycling' and finally 'safe disposal'. Every choice requires a different amount of energy, time and cost. For instance, one of the frequently-used energy-efficient processes in the refinement of petroleum is preheating. In this process, the highly heated products need to be cooled, and the raw materials need to be heated. So, in the process of preheating, the products' released heat is used to warm up the raw materials, which can be interpreted as energy reuse.

Moreover, using the cooling towers to reuse the water in different processes is another example of reuse. However, water treatment plants that recycle wastewater are an example of 'recycling' which needs more energy, cost and time to make the water reusable compared to various treatment levels for different reuse options. If

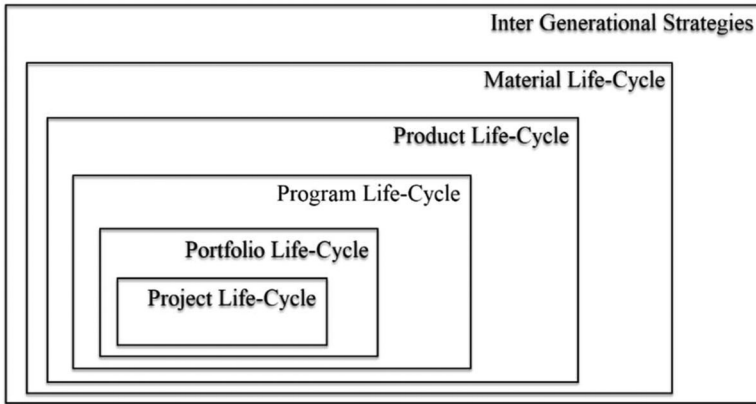


Figure 2. The lifecycle chain in the fossil fuel industry and the position of inter-generational goals in the meantime.
 Source: The Authors.

the treated water needs to be used as potable water or released to the river or used for agricultural purposes, the cost and energy requirement are steeply diverse.

3.2. Extended SWARA

As the criteria weighting exceeds all other decision-making processes in importance, the SWARA is developed to evaluate the criteria weighting based on evaluating the criteria ranking and weighing process (Karabasevic et al., 2016; Keršulienė et al., 2010; Stanujkic et al., 2015). However, the extended SWARA is an improved MCDM methodology that is primarily developed to enhance the original methodology’s quality and accuracy in the criteria weighting process by evaluating the reliability of the experts’ opinions regarding criteria weightings. Using the same procedure that was used in previous studies (Hashemkhani Zolfani et al., 2018) this methodology is applied to the current study with the following steps:

Step1: Criteria sorting

Based on the basic SWARA methodology, experts are asked to rank the criteria in the first step. Thus, t_{jk} represents the ranking assigned to the j^{th} criteria based on the k^{th} experts’ judgment (where $k \in \{1, 2, \dots, r\}$). The normalized criteria value is calculated in the following manner (\bar{t}_j) :

$$\bar{t}_j = \frac{\sum_k t_{jk}}{r}, \forall j \in \{1, 2, \dots, n\}$$

At the final step in the ranking process in this step, the variance and the coefficient of variance are calculated as follows:

$$\sigma^2 = \frac{\sum_k (t_{jk} - \bar{t}_j)^2}{r - 1}$$

$$\beta_j = \frac{\sigma}{\bar{t}_j}$$

Next, the level of experts' agreement is calculated as a representation of the reliability of the responses as follows (where the degree of freedom is 6 in this study ($v = n - 1$)):

$$W = \frac{12S}{r^2(n^3 - n) - r \sum_k T_k}$$

Where:

– S measures the deviation of the criteria $\left(S = \sum_j \left(\sum_k t_{jk} - \frac{\sum_j \sum_k t_{jk}}{n} \right)^2 \right)$.

– T_k is the reiterated ranks which is zero in this study since there is no iteration in the criteria weighting process.

The level of satisfaction with experts' responses is examined based on the X^2 value as follows (if $X^2 > X_{tbl}^2$, the weighting results are reliable):

$$X^2 = W \times r \times (n - 1)$$

Step2: Difference criteria weighting

Criteria are sorted in descending order, and experts have to evaluate the significant differences. Next, the importance coefficient is calculated by adding number one to the ratings (s_j) as follows:

$$k_1 = 1$$

$$k_j = s_j + 1, \forall j \in \{2, \dots, J\}$$

Step3: Recalculate weighting

Criteria weighting in this step is evaluated based on a recursive methodology as follows:

$$q_1 = 1$$

$$q_j = \frac{k_{j-1}}{k_j}, \forall j \in \{2, \dots, J\}$$

Step4: Criteria weights

Finally, the criteria weights are calculated from the following:

$$w_j = \frac{q_j}{\sum_j q_j}$$

3.3. Marcos Methodology

As discussed in the literature review, MARCOS is a novel methodology with a variety of applications. The methodology was developed based on both the ideal and anti-ideal solutions. Afterward, the utility of the alternatives is measured. Different utility functions are then calculated based on the alternative utilities' value to find the alternative weightings and their ranking finally. The methodology is applied to this study based on the following steps: (Stević et al., 2020).

3.3.1. Step 1: Extended initial decision matrix

It is assumed that the decision is made in 'm' alternatives and 'n' criteria. The extended matrix is a combination of the primary matrix and ideal as well as anti-ideal solutions as follows:

		Criteria (C _n) ... (C ₁)		
		x _{aa1}	...	x _{aan}
Alternatives	AAI	x ₁₁	...	x _{1n}
	(A ₁)	⋮	x _{ij}	⋮
	...	x _{m1}	...	x _{mn}
	(A _m)	x _{ai1}	...	x _{ain}
	AI			

Where x_{ij} refers to the decision value related to the assessment of the i^{th} alternative against the j^{th} criteria. The ideal and anti-ideal solutions are denoted as AI, AAI, respectively. The ideal solution is the minimum value among different alternatives concerning beneficial criteria (criteria in which an increase in value is desirable). If this is a cost criterion (a criterion in which a decrease in value is desirable), the ideal solution would be the maximum value. For the anti-ideal solution, the process is exactly the opposite. Maximum for beneficial and minimum value for the cost criteria.

3.3.2. Step 2: Normalization

The normalized matrix is calculated by the ideal solution as follows:

$$n_{ij} = \frac{x_{ij}}{x_{ai}}$$

for the beneficial and $n_{ij} = \frac{x_{ai}}{x_{ij}}$ for the cost criteria.

Normalization is practiced for the extended matrix and AAI, and AI is in the normalization process.

3.3.3. Step 3: Weighted matrix

$V = [v_{ij}]_{m \times n}$ is the weighted matrix, which is calculated concerning the criteria weights as follow:

$$v_{ij} = n_{ij} \times w_j$$

Weighted values are calculated for the extended matrix.

3.3.4. Step 4: Utility degree

Utility degrees are calculated for all the alternatives based on the ideal and anti-ideal solution values as follow:

$$S_i = \sum_j v_{ij} \Rightarrow K_i^- = \frac{S_i}{S_{aai}}, \quad K_i^+ = \frac{S_i}{S_{ai}}$$

3.3.5. Step 5: Utility function

Different utility positive and negative functions are calculated based on the utility values. However, the utility function is calculated based on the utility values and functions as follow:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad \text{and} \quad f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-}$$

$$f(K_i) = \frac{K_i^- + K_i^+}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}}$$

3.3.6. Step 6: Ranking

The alternative ranking is based on the utility function derived from step5 of the methodology.

4. Case study

Fossil fuels such as oil, gas and coal consumption are exacerbating the global environmental crisis. For instance, the coal-based energy generation industry is the source of 44% of mercury and two-third of sulfur dioxide emissions in the US (EPA, 2014). Also, fossil fuels are responsible for carbon emissions. This emission is absorbed by the oceans, increasing their acidity, which is harmful to biodiversity and, consequently, the food chain and the economies. From the beginning of the industrial revolution, seas have become 30% more acidic (NRDC, 2009). Although the ideal solution to these problems is to eliminate the use of fossil fuels in the long-term, the high dependence of the energy markets on fossil fuels would mean that the more realistic alternative in the short and mid-term is to reduce unsustainability.

In this study, an industrial region is selected as the case study. An energy generation plant is going to be built, which will use one type of fossil fuel as its source of energy. The problem is selecting the best alternative with the highest circuitry in the development process. Hence, the case study is carried out based on the developed CE

Table 1. Criteria ranking.

	Criteria						
	Nature (C ₁)	Extraction (C ₂)	Transfer (C ₃)	Refinement (C ₄)	Distribution (C ₅)	Consumption (C ₆)	Recycling (Material & Industry) (C ₇)
Experts	1	4	2	5	3	7	6
	2	4	2	5	1	6	7
	3	5	1	4	3	7	6
	4	5	2	6	3	7	4
	5	6	3	7	2	5	4
	6	5	2	7	2	6	4
	7	4	1	5	3	6	7
	8	5	1	4	1	7	6
	9	4	2	5	3	6	7
	10	5	3	6	2	7	4
	11	4	2	5	2	7	6

Source: The Authors.

Table 2. E-SWARA calculation process.

	Criteria						
	Nature (C ₁)	Extraction (C ₂)	Transfer (C ₃)	Refinement (C ₄)	Distribution (C ₅)	Consumption (C ₆)	Recycling (C ₇)
Sum t_{jk}	17	51	21	59	25	71	61
\bar{t}	1.55	4.64	1.91	5.36	2.27	6.45	5.55
Ranking	7	4	6	3	5	1	2
Q	0.06	0.17	0.07	0.19	0.08	0.23	0.20
σ^2	0.67	0.45	0.49	1.05	0.62	0.47	1.67
β	0.53	0.15	0.37	0.19	0.35	0.11	0.23
V				43.57			
S				2909.71			
W				0.86			
χ^2				56.68			
Degree of freedom				6			

Source: The Authors.

model. To achieve this goal, a group of high-level managers with related backgrounds working in this industrial region got involved in this study to select the best alternative.

The case study begins with the criteria weighting by the extended SWARA methodology as follows:

Experts are asked to rank the significance of the criteria, which is presented in Table 1:

The next steps based on the extended SWARA methodology are as follows (Table 2):

According to the statistical tables, the tabular value for the calculated degree of freedom (6) and considering 1% for the possibility of errors (or significance level of 0.01) is 16.8 (Fisher & Yates, 1963). Thus, the criteria weighting is converged, and the probability of the experts' agreement is 99%. Hence, based on the extended SWARA methodology:

$$\left. \begin{matrix} X_{tbl}^2 = 16.8 \\ X^2 = 56.68 \end{matrix} \right\} \rightarrow X^2 > X_{tbl}^2$$

The ranking and controlling the experts' decisions in the first step is continued to the next steps of the methodology to measure the criteria weights as follows (Table 3):

Table 3. Criteria weighting calculations.

	Average (s)	k	q	w
C6	–	1	1	0.24
C7	0.29	1.29	0.77	0.19
C4	0.15	1.15	0.67	0.16
C2	0.12	1.12	0.6	0.15
C5	0.43	1.43	0.42	0.1
C3	0.13	1.13	0.37	0.09
C1	0.24	1.24	0.3	0.07

Source: The Authors.

Table 4. Decision table for data entry (MARCOS methodology).

		CE life-cycle criteria						
		Nature (C ₁)	Extraction (C ₂)	Transfer (C ₃)	Refinement (C ₄)	Distribution (C ₅)	Consumption (C ₆)	Recycling (Material & Industry) (C ₇)
		Criteria weights						
		W ₁	W ₂	W ₃	W ₄	W ₅	W ₆	W ₇
Alternatives	Oil (A ₁)							
	Gas (A ₂)							
	Coal (A ₃)							

Source: The Authors.

Table 5. The expert panel for the MARCOS decision table.

Education	BSc	MSc	PhD
Number of experts	2	7	2
Years of experience	0–10	10–15	Over 15 years
Number of experts	0	3	8

Source: The Authors.

The criteria weighting is followed by the decision matrix, which is developed based on the CE and MARCOS methodology to evaluate the alternatives as follows (Table 4):

Since assessment is based on the turbulence level entering the life cycle phases (criteria), all of the criteria are cost criteria, except the recycling, which is a beneficial criterion. A panel of 11 senior managers working in the selected industrial site was formed to contribute to this case study. Panel member composition is shown in Table 5.

Experts are asked to enter their judgment based on their managerial experiences in the industrial region. Experts' opinions are gathered for criteria weight and alternative judgment concerning different criteria. Table 3 is the average value of expert judgments.

The weight vector is calculated based on the experts' preferences (see Table 3):

Criteria weight vector = {0.09, 0.14, 0.09, 0.18, 0.09, 0.23, 0.18}

Other calculation steps are based on the MARCOS methodology in Tables 6–10:

According to the case study results, if we want to develop an electricity generation plant based on fossil fuels, gas is the best alternative for the selected industrial region. The case study is evaluated through different cradle-to-cradle lifecycle phases developed as the CE for the fossil fuel development industry.

Table 6. Data entry.

		MARCOS data entry						
		Criteria						
		C1	C2	C3	C4	C5	C6	C7
Alternatives	Weight	0.07	0.15	0.09	0.16	0.10	0.24	0.19
	Status	Cost	Cost	Cost	Cost	Cost	Cost	Beneficial
	Oil (A1)	4	4	3	5	4	4	2
	Gas (A2)	3	3	4	4	4	3	3
	Coal (A3)	5	2	2	3	3	5	2

Source: The Authors.

Table 7. Ideal and anti-ideal solutions.

		Criteria						
AAI	3	2	2	3	3	3	3	3
AI	5	4	4	5	4	5	5	2

Source: The Authors.

Table 8. Normalization matrix.

		N						
Alternatives	AAI	1.667	2	2	1.667	1.333	1.667	1.5
	A1	1.25	1	1.333	1	1	1.25	1
	A2	1.667	1.333	1	1.25	1	1.667	1.5
	A3	1	2	2	1.667	1.333	1	1
	AI	1	1	1	1	1	1	1

Source: The Authors.

Table 9. Weighted matrix.

		V						
Alternatives	AAI	0.117	0.300	0.180	0.267	0.133	0.400	0.285
	A ₁	0.088	0.150	0.120	0.160	0.100	0.300	0.190
	A ₂	0.117	0.200	0.090	0.200	0.100	0.400	0.285
	A ₃	0.070	0.300	0.180	0.267	0.133	0.240	0.190
	AI	0.070	0.150	0.090	0.160	0.100	0.240	0.190

Source: The Authors.

Table 10. Utility values and functions.

		S	K ⁺	K ⁻	f(K ⁺)	f(K ⁻)	f(K)
Alternatives	AAI	1.682	-	-	-	-	-
	A ₁	1.108	1.108	0.659	0.373	0.627	0.539
	A ₂	1.392	1.392	0.828	0.373	0.627	0.677
	A ₃	1.380	1.380	0.821	0.373	0.627	0.672
	AI	1.000	-	-	-	-	-

Source: The Authors.

Environment and its capacity of dealing with development turbulences are limited and need to be protected. As such, the 'returning to the environment' option plays a pivotal role in ensuring the highest level of recycling and lowest environmental turbulences at the same time. Besides, fossil fuel positions in the energy supply chain and the desperate global energy demand make these industrial projects crucial for development. Hence, this study aims to minimize these projects' negative effects and enhance the positive ones simultaneously.

In the growing sustainability assessment literature, both in academia and practice, improved cases are always compared against a base case that reflects the status quo. This study follows a similar approach, aiming to improve the current fossil fuel energy infrastructural projects by introducing a better alternative with maximum return and minimum waste, emissions and pollutions. This in itself stands in contrast to the inherent unsustainability of this industry's projects, operations and products.

This study developed a CE model for the fossil fuel material lifecycle to be used for long-term assessment of this industry's projects and assist managers and researchers with strategic lifecycle decisions. The developed CE model is applied to a power generation project as a case study. The CE model stages are regarded as the decision criteria evaluated by the E-SWARA method to control the criteria weighting reliability. Different fossil fuel options are assessed using MARCOS as a novel MCDM methodology for solving the material selection problem.

5. Conclusion

Infrastructure and energy industry projects are necessary particularly for economic and societal development; however, thus far, they have commonly been associated with seemingly inevitable unsustainability, especially because most of them are done using fossil fuels. This is because fossil fuel resources are finite. The development has been accelerating, putting further pressure on these resources, let alone the pollution caused by burning fossil fuels to produce energy. Although the global energy supply is slowly shifting from fossil fuels to various renewable energy types, no one would anticipate a total elimination of fossil fuel use in energy production in the short-term. Thus, the intermediate target should be to develop relatively more sustainable ways to use fossil fuels for energy production.

The increasing pressure on the natural environment results from unsustainable development associated with the linear concept of take-make-use-dispose. Safe returning to the environment is one of the recent sustainability literature trends that contains reuse, remanufacture, recycling and safe disposal. The Circular Economy (CE) is developed to cover this returning concept and slow-down environmental deterioration. This study aims to develop a CE model for fossil fuel use in the energy generation industry. The target is not developing green fossil fuel generation plants but developing the best alternative that minimizes the turbulences caused by using fossil fuels in the natural environment.

The novel CE model can have various applications from policy-making to scenario analysis in this important development field. This study contributes to the body of knowledge by incorporating the cradle-to-cradle viewpoint of the oil and gas industry, which is multidisciplinary, high-tech and complicated by all accounts. In the developed CE model, four different returning options are proposed. However, there may be other options as well, depending on local circumstances. Further studies can be performed to improve the CE model's accuracy and its applicability to various conditions.

In this study, a policy-making problem was considered the case study with a re-allocation scenario; a group of experts was asked to contribute to the decision-making process. Three types of fossil fuels were considered as alternatives for a local project, which were evaluated using CE lifecycle criteria to select the most sustainable fuel for the power generation plant at the policy level. Based on the results, gas was found to

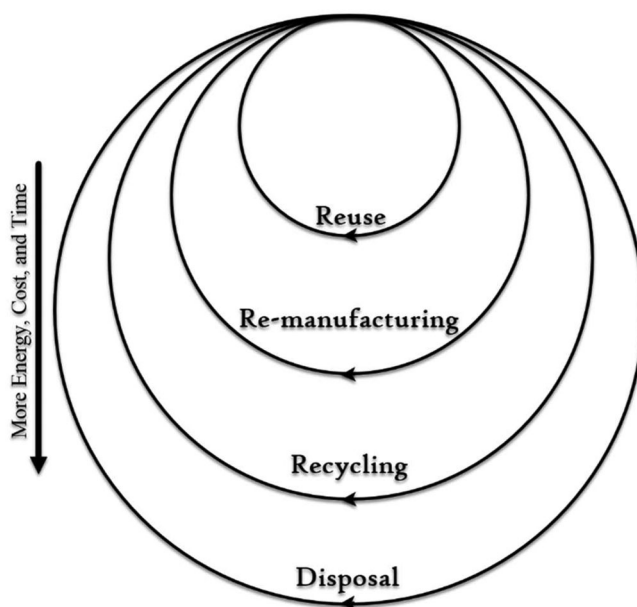


Figure 3. Returning to the environment options.

Source: The Authors.

be the most suitable alternative to be used in the particular industrial region considering local industries, various types of pollution, means of transportation, access to raw materials, final markets, and so on.

The circuitry in the development of fossil fuels as one of the most important energy infrastructure is a novel idea which needs to develop in the future studies. This study addressed the recycling options in the CE model of the fossil fuels (Figure 3) while developing a decision framework model to optimize the returning options would be an important issue for further studies.

Besides, despite the CE model's application in the policymaking and strategic levels in the long-term decisions, in the mid-term, the CE model can facilitate other development in the fossil fuel literature. For instance, selecting the best manufacturer, vendor, or contractor with the most suitability with the circuitry instead of linear approach represents a great achievement. Also, a combination of the CE and sustainability would be a future research line to ensure sustainability and local resiliency at the same time.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Hamidreza Hasheminasab  <http://orcid.org/0000-0003-0650-2733>

Sarfraz Hashemkhani Zolfani  <http://orcid.org/0000-0002-2602-3986>

Edmundas Kazimieras Zavadskas  <http://orcid.org/0000-0002-3201-949X>

Mohammadreza Kharrazi  <http://orcid.org/0000-0002-9575-8900>

Marinko Skare  <http://orcid.org/0000-0001-6426-3692>

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