Journal of Chemical and Petroleum Engineering (JChPE)
Print ISSN: 2423-673X Online ISSN: 2423-6721

Life Cycle Assessment of The Formalin Production Process Using Methods Eco-indicator 99, IMPACT 2002+, EDIP 2003

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ARTICLE INFO

Article History:

Received: 23 September 2023
Revised: 25 December 2023
Accepted: 01 January 2024

Article type: Research

Keywords:
Environmental Impacts, Formalin, Life Cycle Assessment, Modeling, SimaPro Software

ABSTRACT

Life cycle assessment is a suitable tool to examine and measure of the environmental aspects of the production of a product from the beginning to its formation. In this study, the environmental impacts of the production process of 1 ton of formalin in an industrial unit producing formalin with the approach of life cycle assessment and the requirements of the international standard ISO14040:2006, the use of SimaPro9 software and three evaluation methods Eco-indicator 99, IMPACT 2002+ and EDIP 2003 were investigated in the period of 2019-2020. In this research, the results of modeling with the Eco-indicator 99 method showed that the environmental impacts of using methanol is 86% of the total environmental impacts of the formalin production process. 80% of this impact comes from the consumption of fossil fuels in the production of methanol. The results obtained from the modeling of the formalin production process by applying the characteristic coefficients of the EDIP 2003 method indicate that the destruction of the ozone layer is the most important effect of the formalin production process and methanol has an 82% effect on the environmental impacts of the formalin production process. Among them, more than 28% of the harmful effect of methanol consumption is on the destruction of the ozone layer. The results of modeling with the IMPACT 2002+ method show that 83% of the environmental impacts of the life cycle of formalin production are caused by the consumption of methanol, and the consumption of non-renewable energy sources has an impact of 60% on this value.

Introduction

Population growth and the active interference of activities related to them, increased waste and energy consumption [1], resources [2], global warming/climate change and loss of biodiversity [3]. The issues directly affect the quality and sustainability of the ecosystem [4].

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Journal of Chemical and Petroleum Engineering, 2024, 58(1): 89- 102.
Publisher: University of Tehran, College of Engineering *DOI: 10.22059/JCHPE.2024.365743.1453*

This affects economic, social, and political issues among others [5]. To achieve sustainability goals such as carbon reduction, companies must first examine their supply chain and business activities to identify products and processes that have the greatest impact. This is to ensure that the most cost-effective measures are chosen to achieve the goal of sustainability [6]. Life cycle assessment is a method based on ISO 14040 and 14044 standards, which is developed by the United Nations environment Program and the Toxicology Association. American environmental science and chemistry is expanding. In order to standardize the way life cycle assessment is performed at the international level, the World Standard Organization (ISO) has assigned the ISO 14040 standard to this issue [7]. Life cycle assessment, which is also called cradle-to-grave analysis, determines the amount of environmental burden of a product during its life, from obtaining raw materials, through production, transportation, use, and final disposal. A man-made object begins its life cycle by harvesting and extracting resources, followed by production, use, and finally management of the object as waste. In this way, recycling or reuse can be considered as a "new beginning" for the life cycle of other man-made objects [8]. Life cycle assessment or life cycle assessment is a "cradle to grave" approach to evaluating industrial systems [9]. "Cradle to grave" begins with the collection of raw materials from the earth to produce a product and ends with the return of the consumed product to the earth [10]. Life cycle assessment provides the possibility to estimate the cumulative environmental effects of all stages of the product life cycle [11]. LCA is regularly used by a number of industries to prepare environmental performance reports and environmental monitoring [6]. One of the most important industries that plays a significant role in creating pollutants such as carbon dioxide and carbon monoxide in the environment is the petrochemical industry [12]. Life cycle assessment of chemical substances and products discusses the frameworks and concepts of chemical substances management, including risk assessment, green and sustainable chemistry, and evaluation of chemical options. A large number of LCA studies focus on the contrast of different raw materials or chemical synthesis processes, Therefore, often, cradle-to-gate (factory) assessments are performed, while typically a large share of potential environmental impacts occurs in the early stages of a product's life cycle. Potential impacts related to chemicals found as ingredients or residues directly in products can be affected by the stage of use of the products [13]. The number of chemical products is constantly increasing, and long-term analysis shows that the overall growth of chemical production and demand, as well as faster growth in emerging regions, is a behavior that is expected to continue in the future. Unfortunately, due to the lack of available information and the large number of material and energy flows, chemical inventories are usually one of the most challenging models [14].

Alizadeh Asanlu and Keinejad [15], studied the life cycle of processes and its application in the evaluation of the environmental effects of petrochemical industries. In this study, by introducing different techniques for evaluating environmental effects and stating the advantages and disadvantages of each, the evaluation of environmental effects based on the life cycle of a process has been examined more closely and by scrutinizing it, according to the process under study, it has been discussed and investigated. will be in the following, the implementation method of evaluation based on the life cycle of a process is presented and the problems of developing this method are discussed [15].

Formalin is an important chemical substance that is widely used in the industry to make building materials [16]. However, there is a lack of access to available scientific information about the environmental and interaction effects of the formalin production process [17]. Also, the local, regional and global effects of this chemical, including the effect on global warming, destruction of the ozone layer, and toxicity for humans are not known [18], The aim of the research is to evaluate the environmental impacts of the life cycle of the formalin production process with a gate-gate approach and the studied functional unit is functional unit. This research is the first research regarding the evaluation of the life cycle of formalin in the country. Considering the lack of studies on the environmental effects of the formalin production process, the evaluation of the life cycle of the production process of this product is of particular importance. In this research, the latest version of Simapro software is used, which has more updated and complete databases than the previous versions. This research is the first study conducted regarding the evaluation of the environmental consequences of the formalin production process using life cycle assessment software.

Materials and Methods

The mentioned company was put into operation in 2011-2012 and is active in the downstream petrochemical industries and produces three products: formalin, hexamine and urea-formaldehyde resin. The company's products are among the most widely used products in the field of petrochemical base materials, which are used as raw materials in the production of many products such as adhesives and resins, rubber and plastic materials, and various industries such as polymer industries, pharmaceutical and laboratory industries [19].

This research is in accordance with the methodological framework of ISO 14040 and ISO 14044 standards and has been carried out using SimaPro9 software in the period of 2019-2020. In order to evaluate the life cycle of the formalin production process in this industry, first define the purpose and scope of LCA and Then, the necessary data and information to prepare the list of the life cycle were collected through visits, interviews, library information collection, records review and sampling and physicochemical tests from the outputs to the environment.The boundary of the determination system and the list of the life cycle of the production process of formalin were prepared and after that, the data was entered into the software. Inventory analysis, effect evaluation and interpretation of the results were done.

Inputs and Outputs

Using the data inquired from the company, the life cycle log of the functional unit is in Table 1 [19].

Table 1. Production process life cycle log of functional unit

Output			Input		
Title		Value	Title		Value
Carbon Dioxide (gr)	Emissions to the air	0.29884	Water (m³)	Of Nature	5
Carbon Monoxide (gr)		4.71505	Air (ton)		0.850
Oxygen (gr)		0.64417	Methanol (ton)	Materials/ Fuel	0.5
Hydrocarbons (gr)		0.92973	Diesel (ton)	Materials/ Fuel	0.957
Nitrogen Oxides (gr)		5.24633	Electriity (kWhr)	Electricity	150
Sulfur Oxides (gr)		0.13282			

To evaluate the Environmental impacts of the life cycle of the formalin production process, three methods Eco-indicator 99, EDIP 2003 and IMPACT 2002 + were used [20].

Table 2. Category of impacts in the Eco-indicator 99 method

Category of Impacts	Unit	Category of Impacts	Unit
Ecotoxicity	.yr²PDF.m	Carcinogens	DALY
Acidification/ Eutrophication	.yr²PDF.m	Resp. organics	DALY
Land use	.yr²PDF.m	Resp. inorganics	DALY
Minerals	MJ surplus	Climate change	DALY
Fossil fuels	MJ surplus	Radiation	DALY
Ecotoxicity	.yr²PDF.m	Ozone layer	DALY
Carcinogens	DALY		

Table 3. Category of impacts in the EDIP 2003 method

Category of Impacts	Unit	Category of Impacts	Unit
Global warming	Kg CO_2 eq	Human toxicity soil	m^3
Ozone depletion	Kg CFC_{11} eq	Ecotoxicity water chronic	m^3
Ozone formation (Vegetation)	m^2.ppm.h	Ecotoxicity water acute	m^3
Ozone formation (Human)	Person.ppm.h	Ecotoxicity soil chronic	m^3
Acidification	m^2	Hazardous waste	kg
Terrestrial eutrophication	m^2	Slags/ashes	kg
Aquatic eutrophication EP(N)	Kg N	Bulk waste	kg
Aquatic eutrophication EP(P)	Kg P	Radioactive waste	kg
Human toxicity air	Person	Resources (all)	PR2004
Human toxicity water	m^3		

Table 4. Category of impacts in the IMPACT 2002+ method

Category of Impacts	Unit	Category of Impacts	Unit
Carcinogens	kg C_2H_3Cl eq	Terrestrial acid/nutri	kg SO_2 eq
Non-carcinogens	kg C_2H_3Cl eq	Land occupation	m^2
Resp. inorganics	kg $PM_{2.5}$ eq	Aquatic acidification	kg SO_2 eq
Ionizing radiation	Bq C-14 eq	Aquatic eutrophication	kg PO_4 P-lim
Ozone layer depletion	kg CFC-11 eq	Global warming	kg CO_2 eq
Resp. organics	kg C_2H_4 eq	Non-renewable energy	MJ primary
Aquatic ecotoxicity	kg TEG water	Mineral extraction	MJ superplus
Terrestrial ecotoxicity	kg TEG soil		

Results and Discussion

The assessment of the Environmental impacts of the life cycle of the formalin production process was carried out using three methods: Eco-indicator99, IMPACT2002 and EDIP2003, and applying coefficients to determine characteristics, impact category, normalization, weighting and single environmental score, and the results are as described in the tables. And the following Figs are:

In Figs 1 to 4, the results of modeling are displayed with the Eco-indicator 99 method, respectively, by applying coefficients for defining characteristics, impact category, normalization and weighting.

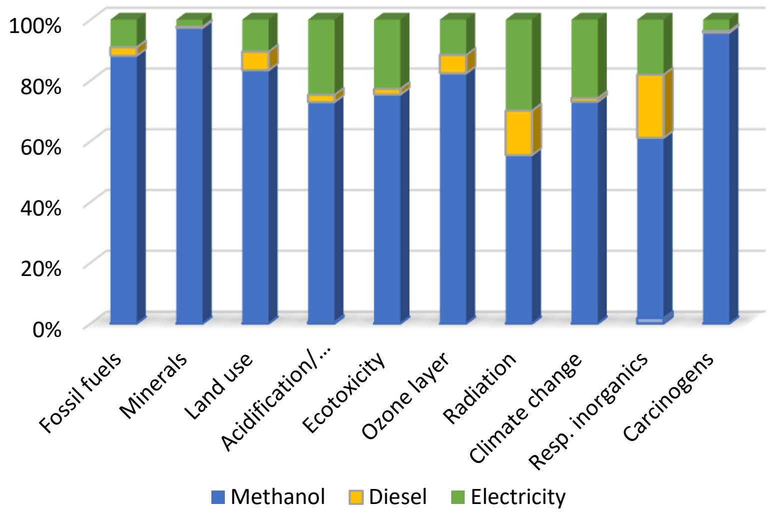

Fig .1. The results of applying the characteristic coefficients of the Eco-indicator 99 method

After applying the characteristic determination factors, the materials in each of the work categories are calculated and aggregated with each other based on the equivalent unit of that category. In order to display the values of all the impact categories in one Fig, the relative contribution of each input in creating each impact category is shown in Fig. 1. It can be seen that methanol has the largest contribution in creating all the effects in the 99 Eco-indicator method. After methanol, the electricity consumed in the formalin production process has the greatest impact on the formation of all effects.

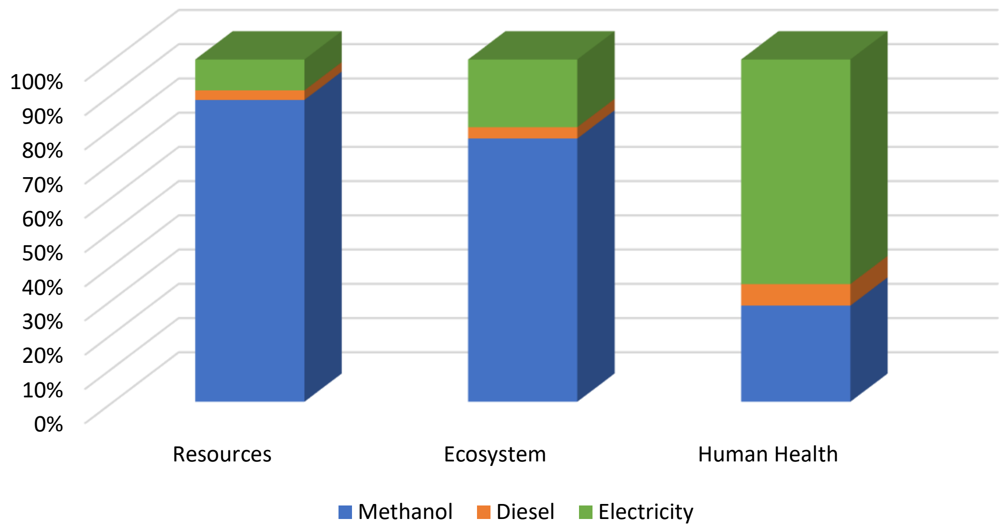

Fig. 2. The results of applying the Eco-indicator 99 method

The Environmental impacts of methanol in the formalin production process is also evident in the impact categories (Fig. 2). The relative share of methanol (compared to all inputs) in the categories of human health effect, ecosystem quality and resources is 79, 77 and 88%, respectively. The overall values of the impact categories are 0.000396 DALY, 17.20559 PDF.m². year, and 2620.413 MJ surplus, respectively.

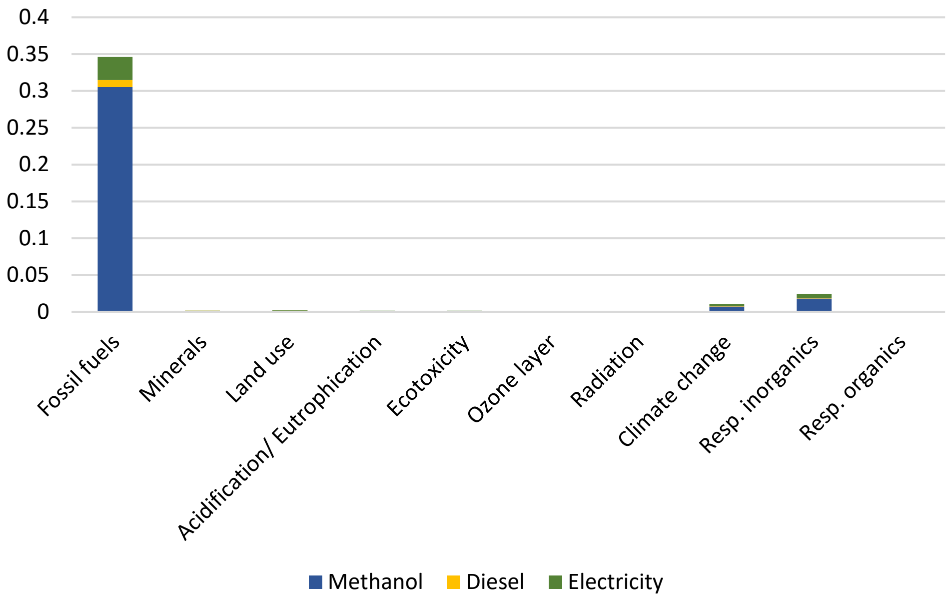

Fig. 3. The results of applying the normalization coefficients of the Eco-indicator 99 method

According to the different dimensions of the parameters, in order to compare the impact categories, it is necessary to make all of them the same dimension. For this purpose, normalization coefficients are used and shown in Fig. 3. Among all impact categories, the consumption and reduction of fossil fuels, with a significant difference (more than 14 times the second effect), has received the greatest impact from the formalin production process. The effects of respiratory problems caused by inorganic substances, carcinogenicity and climate changes are in the next categories and the effect of the process on other effects is insignificant.

In Fig. 4, the weighted score of each impact category can be compared with each other. Considering the environmental importance of each impact category in the final environmental score of the process, each of the normalized values have been weighted using the available values. The weighted score shows the effect of fossil fuel consumption (from the resource impact category) and the effect of respiratory problems caused by inorganic substances (from the human health impact category).

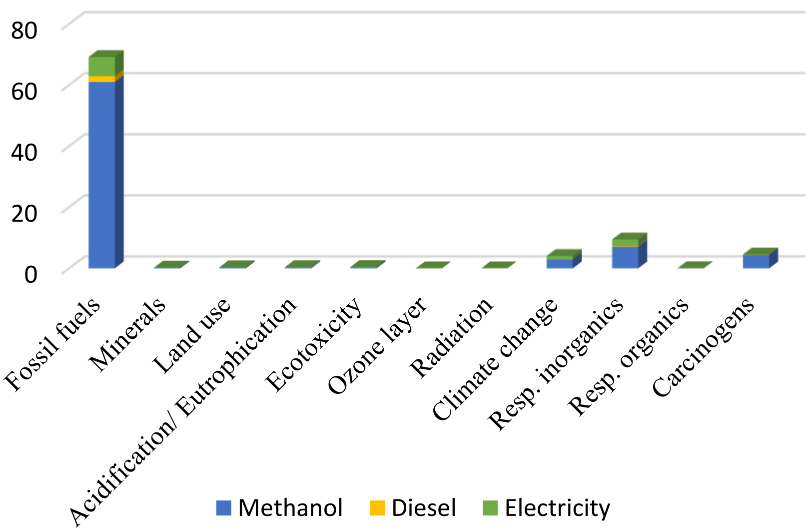

Fig. 4. The results of applying the weighting coefficients of the Eco-indicator 99 method

A comparison has been made on the entries of the life cycle list. By re-examining the weighted values from the perspective of process inputs, it can be seen that the overall Environmental impacts of the use of methanol is 86% of the total Environmental impacts of the formalin production process. 80% of this impact comes from the consumption of fossil fuels. After methanol, the consumption of electricity and diesel fuel have an effect of 11 and 2.5% in the process, respectively.

In Figs 5 to 7, the results of modeling with the EDIP 2003 BetterTib method by applying characteristic determination coefficients, normalization, weighting are displayed.

The results obtained from the modeling of the formalin production process by applying the coefficients of the EDIP 2003 method in Fig. 5, show that in creating all the effects (except radioactive waste), methanol has a share of more than 70% among all process inputs. This share in the use of resources reaches more than 93%.

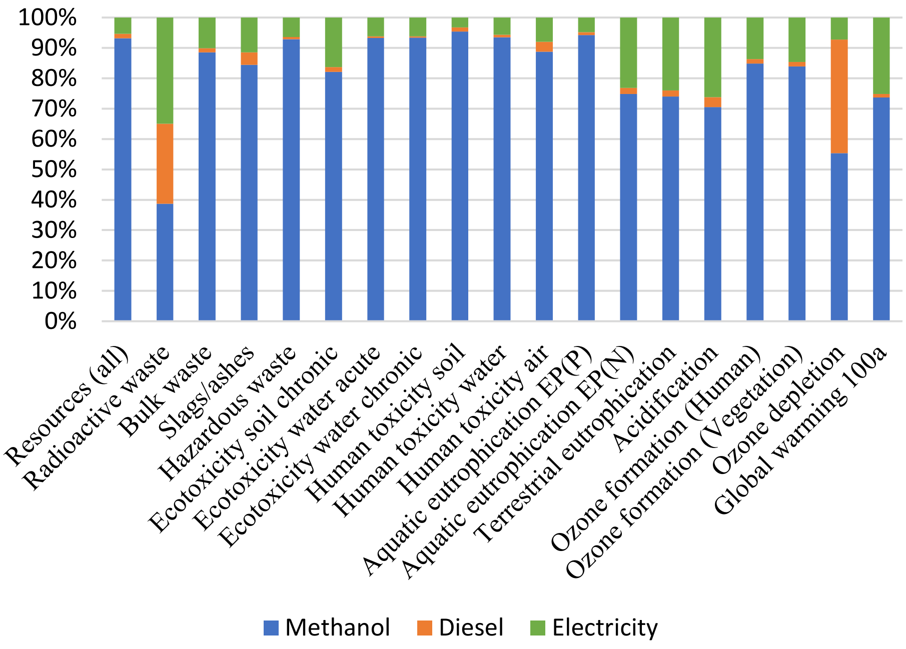

Fig. 5. The results of applying the characteristic coefficients of the EDIP 2003 method

The normalized values of impact categories are shown in Fig. 6. It can be seen that without applying weighting factors, overnutrition and water toxicity are the two main effects of this process. By applying the introduced factors and by looking at Fig. 6, it is clear that according to the management and control of waste water and the absence of release into the water environment, the destruction of the ozone layer will be the most important effect caused by the formalin production process.

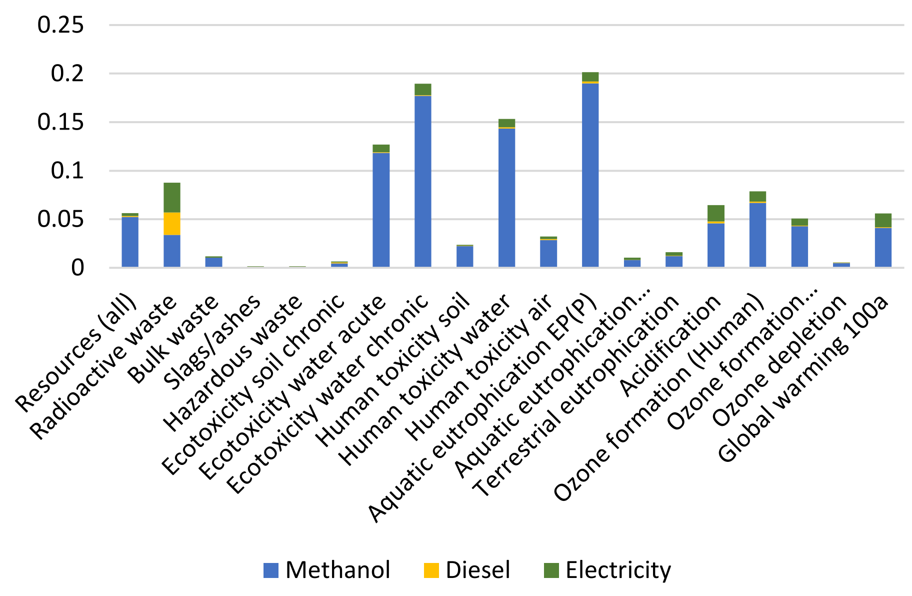

Fig. 6. The results of applying the normalization coefficients of the EDIP 2003 method

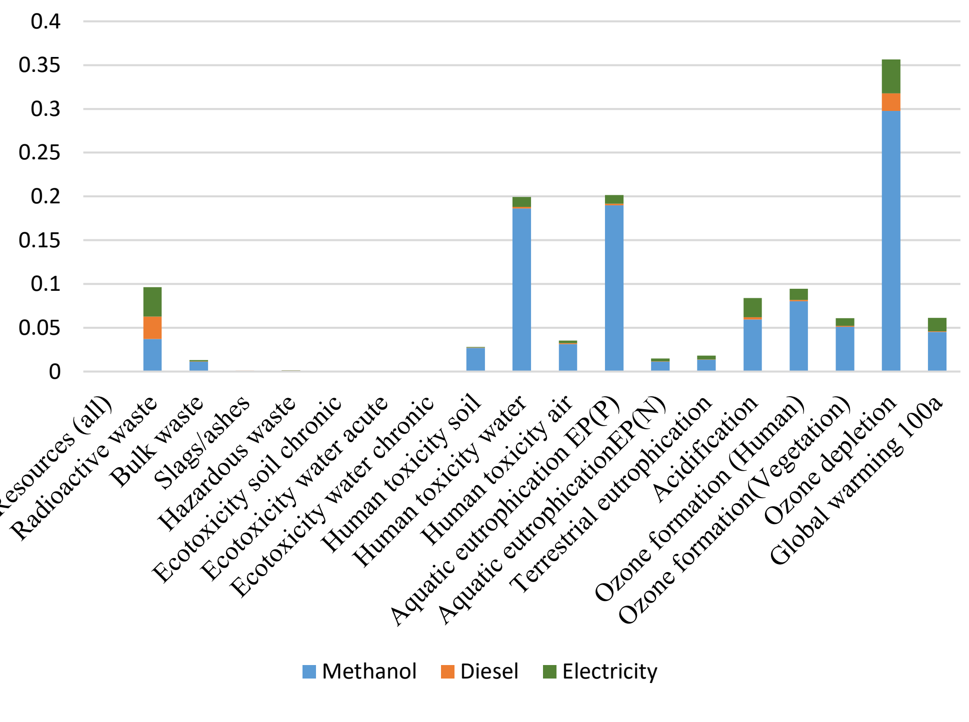

Fig.7. The results of applying the weighting coefficients of the EDIP 2003 method

In Fig. 7, the weighted environmental score of each impact category can be compared with each other. Examining the Fig shows that 82% of methanol has an effect on the environmental effects of the formalin production process. Meanwhile, more than 28% of the harmful effect of methanol consumption is due to the destruction of the ozone layer.

In Figs 8 to 11, the results of modeling with the IMPACT 2002+ method, BetterTib, by applying coefficients to determine the characteristic, impact category, normalization, weighting and single environmental score are displayed.

As in Figs. 1 and 4, in Fig.8, the dominant influence of methanol consumption among all inputs is evident. This article shows the existing correlation between different methods. Methanol's effect on impact categories is between 71% (climate change) and 88% (resource depletion). Also, Fig. 8 shows that the environmental effects of formalin production (apparent emissions during the production stage) are significant in the category of human health effects (2.5% effect), which originates from the carcinogenic effect. The overall values of the impact categories by applying the IMPACT 2002+ method is 0.000386 DALY, 54.4493 PDF.m². year, 386.256 Kg CO2 equivalents and 19846.2 MJ surplus.

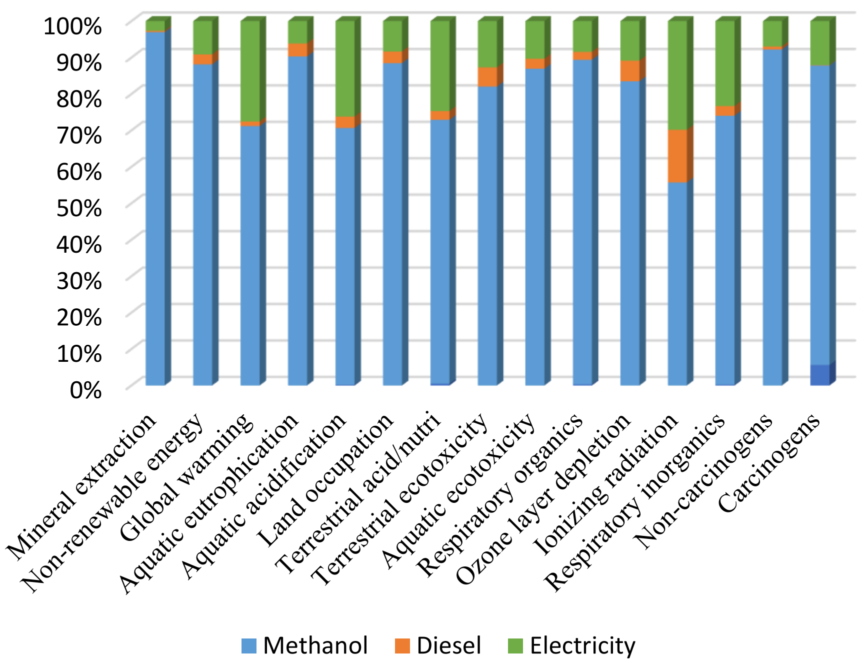

Fig. 8. The results of applying the coefficients for determining the characteristics of the IMPACT2002+ method

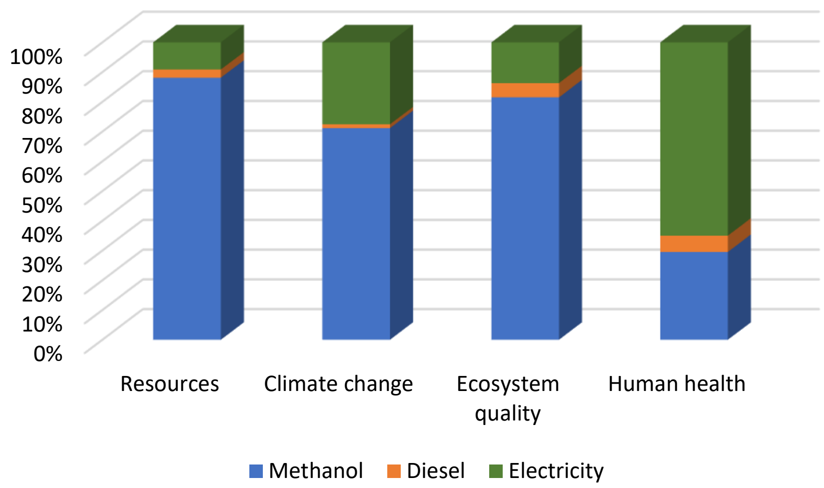

Fig. 9. The results of applying the IMPACT 2002+ method

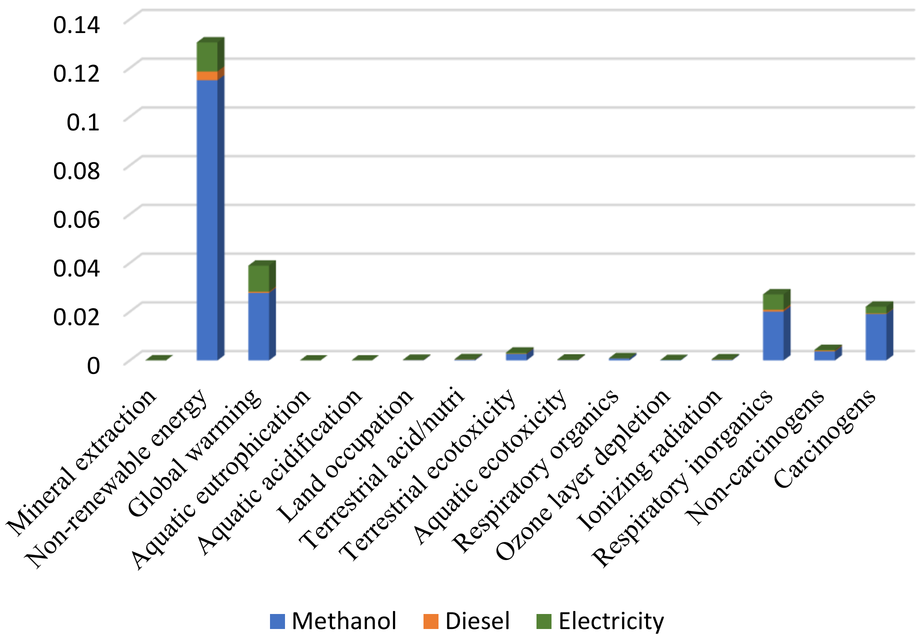

Fig. 10. The results of applying the normalization coefficients of the IMPACT 2002+ method

The normalized and weighted values of the effects are shown in Figs 10 and 11. It is observed that 57% of the overall Environmental impacts of this process originates from the consumption of non-renewable energy sources. Global warming (17 %), respiratory problems caused by inorganic substances (12 %), and carcinogenicity (10 %) are the dominant effects from the life cycle of formalin production.

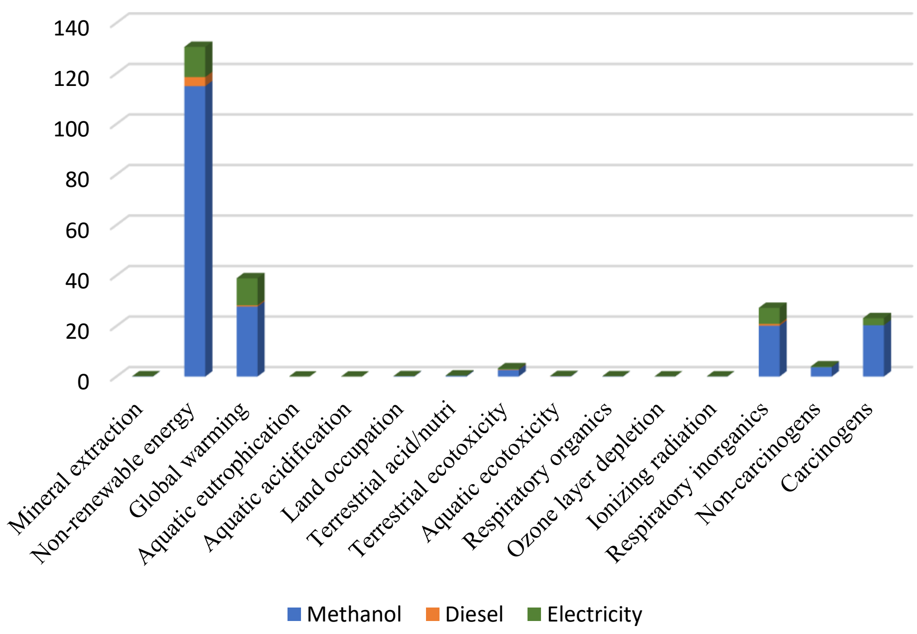

Fig. 11. The results of applying the weighting coefficients of the IMPACT 2002+ method

In Fig. 11, the weighted environmental score of each impact category can be compared with each other.

Conclusion

The comparison is made on the entries of the life cycle list. 83% of the Environmental impacts of the life cycle of formalin production are caused by the consumption of methanol, and the consumption of non-renewable energy sources has an impact of 60% on this amount. In this research, the production life cycle of functional unit in a petrochemical industry was evaluated. The results of modeling after applying the characteristics determination factors with the Eco-indicator 99 method showed that methanol has the largest contribution in creating all the existing effects. After methanol, the electricity consumed in the formalin production process has the greatest impact on the formation of all effects. The relative share of methanol (relative to all inputs) in the categories of human health effect, ecosystem quality and resource depletion is 79, 77 and 88%, respectively. After applying the normalization coefficients, the results showed that among all impact categories, fossil fuel consumption, with a significant difference (more than 14 times the second effect), has received the greatest impact from the formalin production process. The effects of respiratory problems caused by inorganic substances, carcinogenicity and climate changes are in the next categories and the effect of the process on other effects is insignificant. By examining the weighted values from the perspective of process inputs, it was observed that the overall Environmental impacts of using methanol is 86% of the total Environmental impacts of the formalin production process. 80% of this impact comes from the consumption of fossil fuels in the production of methanol.

After methanol, the consumption of electricity and diesel fuel have an effect of 11 and 2.5% in the process, respectively. The use of natural gas in the process of methanol production causes depletion of fossil fuel resources and respiratory problems caused by the synthesis of natural gas. Also, the emission of carbon monoxide, carbon dioxide and nitrogen oxides affect the destruction of the ozone layer, the creation of the greenhouse effect, global warming and climate change and human health.

In the results of modeling with the IMPACT 2002+ method, the dominant effect of methanol consumption among all inputs is also evident. This article shows the existing correlation between different methods. The influence of methanol on the impact categories is between 71% (climate change) and 88% (resource consumption). Also, the environmental effects of formalin production (apparent emissions during the production stage) are significant in the category of human health effects (2.5%), which originates from the carcinogenic effect. The normalized values of the effects show that 57% of the overall Environmental impacts of this process originates from the consumption of non-renewable energy sources. Global warming (17 %), respiratory problems caused by inorganic substances (12 %), and carcinogenicity (10 %) are the dominant effects from the life cycle of formalin production. Also, the application of weighting coefficients shows that 83% of the Environmental impacts of the life cycle of formalin production are caused by the consumption of methanol, and the consumption of non-renewable energy sources has an impact of 60% on this value.

The results of the modeling by applying the weighting coefficients in the EDIP 2003 method showed that the destruction of the ozone layer is the most important effect caused by the formalin production process, and methanol has an 82% effect on creating the environmental effects of the formalin production process. Meanwhile, more than 28% of the harmful effect of methanol consumption is due to the destruction of the ozone layer. Considering that the methanol required in the process is produced and supplied outside the industrial unit and the consumption of fossil fuels is also very small considering the Environmental performance of the mentioned industrial unit, therefore, the reduction and discharge of fossil fuel resources and respiratory problems caused by Inorganic substances resulting from the methanol production process, with the current production capacity in this company, will not affect the evaluation of the Environmental performance of this industrial unit. Although this industrial unit has taken appropriate measures to reduce the consumption of fossil fuels. The use of the Off Gas compressor aims to recover the gases sent to the burner and zero flaring and use the output gases in steam production to reduce the emission of environmental pollutants, control greenhouse gases, global warming and climate change. Reducing the consumption of fossil fuels and replacing excess gases in the production process, installing and improving thermal insulation of pipelines with the aim of reducing energy consumption and thermal pollution, using process flows for heating or cooling in different points of the production process with the aim of optimizing energy consumption, among the measures of this The industrial unit aims to save as much energy as possible and preserve fossil fuel resources.

The results obtained from the modeling of the formalin production process by applying the characteristic coefficients in the EDIP 2003 method, show that in creating all effects (except for radioactive waste), methanol has a share of more than 70% among all process inputs. This share in the use of resources reaches more than 93%. The normalized values of the impact categories showed that overnutrition and water toxicity are two indicative effects of this process. According to the production products of this industry, the possibility of the presence of water polluting parameters has been predicted and guidelines and test methods have been developed. In this way, different types of used and circulating water are sampled and the results of relevant analyzes are monitored.

At the end of the water operating cycle, the rate of increase of each of the ions is re-examined and according to the rate of increase of the key and influential parameters and comparison with the standards of various types of industrial effluents, wastewater management decisions are made. The use of electronic antifouling, the use of antifouling chemicals in the cooling tower system to remove phosphates and organic substances in the tower bed are other measures of this industrial unit. It should be noted that removing the acid washing process and installing electronic anti-sediment, both dredging and preventing sediment formation at the same time, and it also has a great effect on reducing the consumption of water resources.

Dioga et al. [21], investigated the life cycle effects of urea-formaldehyde resin in wood panel production. This study was conducted with the cradle-gate approach of the life cycle of medium-density wooden boards produced in Brazil. To evaluate the environmental effects, the potential effects were quantified using the CML2001 method. In the classification of environmental effects, the indicators of "biological degradation, global warming, acidification, overnutrition, creation of photochemical ozone, toxicity for marine and fresh water, biological poisoning, and toxicity for humans" were selected. The results showed that the sensitive and important points environmental pollution arise from the production of methanol and urea, which are the raw materials for the production of urea-formaldehyde resin, and the release of formaldehyde into the air is caused by the production of medium-density panels. Also, the results of this study showed that the main environmental effects of urea-formaldehyde resin range from 2.5% to 43.3% for marine aquatic toxicity and creation of photochemical ozone, respectively. In order to improve the environmental efficiency of urea-formaldehyde resin produced in Brazil. And reducing the molar ratio of urea-formaldehyde resin, which is 25-30% higher than the amount of production in Europe, it is suggested to use favorable and quality sources of urea and methanol. The results of this research correctly confirm the results of the current research [21].

The research done by Barazandeh [22], under the title "Formaldehyde: environmental bio-pollutant found in wooden products" shows that formaldehyde is one of the environmental bio-pollutants and can even be harmful under certain conditions. Although in short periods of time, the harmful effects caused by the release of formaldehyde will not appear, but with the passage of time and the influence of environmental factors such as heat and humidity, the rate of its release will increase and the negative effects will become visible. In wood products, the source of formaldehyde emission is wood material, formaldehyde-based resins include urea formaldehyde, phenol formaldehyde, melamine formaldehyde, etc. Advantages such as urea-formaldehyde resins being cheaper compared to other resins, have encouraged producers to use it more, and this is while the release of formaldehyde is much higher than this resin [22]. Hussain et al. [23], conducted the study "Analysis of the environmental characteristics of particle board production with a life cycle assessment approach in Pakistan. In this study, energy consumption and Environmental impacts of raw materials and processes in the production of particle board were investigated. In 2015-2016, the cradle-to-gate life cycle assessment method, CML 2000 v.2.05 method was used in SimaPro v.8.3 software for modeling. The results show that urea-formaldehyde resin, transportation of raw materials and the final stage of product distribution have the largest share in all amounts of environmental effects. Consumption of heavy fuel and natural gas leads to biological degradation, photochemical oxidation, destruction of ozone layer and environmental effects on marine aquatic life [23]. The results of this research also confirm the presence of formaldehyde and the use of fossil fuels as influential inputs in creating environmental effects caused by petrochemical products.

The lack of studies on formalin life cycle assessment, the unknown environmental and cumulative effects of the production process of this product, and the tortuousness of the research path due to its innovative nature have been some of the limitations of this research.

In the end, considering that the effective inputs in the production of formalin (methanol) in the production process of various products of this industrial unit have been identified in this research, it is suggested to study alternative solutions for the production of this substance as well as alternative materials.

Acknowledgements

Authors gratefully acknowledge for supporting the Department of Environmental Science, Faculty of Natural Resources, Bandar Abbas Branch of Islamic Azad University. Also, we would like to express our gratitude for cooperation of the Gameron Petro Industry complex.

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How to cite: Taghizadeh Isini L, Dehghani Ghanatghestani M, Kargari N, Ghasemi S. Life Cycle Assessment of The Formalin Production Process Using Methods Eco-indicator 99, IMPACT 2002+, EDIP 2003. Journal of Chemical and Petroleum Engineering 2024; 58(1): 89-102.