Research Paper

Environmental Impacts of Formalin and Hexamine Production Units Using Life Cycle Assessment: A Case Study in the Gameron Petro Industry Complex, Iran

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ABSTRACT

Background: Formalin and hexamine as important chemicals are widely used in industry that their pollution effect is often taken into account. The aim of this study was to investigate environmental effects of formalin and hexamine production process in Gameron Petro Industry Complex using the life cycle assessment method.

Methods: This study was conducted according to ISO 14040, using the life cycle assessment (LCA) method and SimaPro software 9, as well as Eco-indicator99, IMPACT2002+ and EDIP2003. The functional unit studied was 1 ton of product (800 kg hexamine plus 200kg formalin) in this complex.

Results: It was found that ammonia was the most influential input material in creating the consequences of climate change, radiation and toxicity. In respiratory inorganics, the contribution of ammonia and methanol was the same. Methanol was the dominant input of other outcome. It was determined that the effect of methanol and ammonia on human health was approximately equal. Ammonia and methanol had effect on ecosystem toxicity and creating the category of resource consumption, respectively. The total values of the effect classes were 0.001636 DALY, 2038.305 PDF.m² yr, 2091.536 kg CO_2 equivalents and 61.87139MJ surplus.

Conclusion: The results showed that in the life cycle of formalin production, and hexamine, methanol is the dominant input in creating environmental impacts. After that, ammonia, diesel and electricity were the effective inputs in the production life cycle of these products.

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1. Introduction

Increasing population and their widespread activities have resulted in increasing waste and prevalence of pollution [1], lack of resources [2], global warming/climate change and biodiversity loss [3]. These issues have directly affected the quality and sustainability of ecosystems [4]. Awareness of environmental issues are the most important factors affecting global decision making in a way that affects other effective components in this matter such as economy, society and politics [5].

Formalin and hexamine are an important chemical used widely in industry to manufacture building materials [6]. As a result, the issue of their pollution have often been taken into account and have always been considered as research topics, over the past few years [7]. There is, however, lack of access to existing scientific information regarding the environmental and reciprocal effects of formalin and hexamine production process [8]. The local, regional and global effects of these compounds, including global warming, ozone layer destruction, toxicity for humans, are not well known as well [9].

The life cycle assessment (LCA), which is a method to evaluate environmental impacts, is gaining increasing attention all over the world due to the urgent need for the preservation and sustainability of the environment. Since LCA is commonly utilized in the environmental analysis of businesses, industries, products, and services, this assessment method promoted by the United Nations Environment Programme (UNEP), Society of Environmental Toxicology and Chemistry (SETAC), Life Cycle Initiative, the Forum for Sustainability through Life Cycle Assessment (FSLCI), International Reference Life Cycle Database System (ILCD), and the European Reference Life Cycle Database system (ELCD); also, it benefits from others advantages in improving environmental performance towards the achievement of economically viable, safe, and sustainable societies. The LCA is an important technique to identify the environmental impacts of products or services throughout their entire life cycle stages [10].

It is important to recognize the main life cycle stages or hotspots to part in the environmental impacts of the production process of formalin and hexamine, and etc. [11]. The LCA deals with environmental aspects throughout the life cycle of a product from processed raw material to production, consumption, end of biological acts, recycling and final disposal [12].

Evaluation of life cycle is a "cradle to grave" approach for evaluating industrial systems [13]. "Cradle to Grave" starts by collecting raw materials from the ground to produce the product and ends with the return of the consumed product to the ground [14]. LCA allows the estimation of the cumulative environmental impacts of all stages of the crop's life cycle [15]. According to ISO 14040, life cycle evaluation is carried out in four stages including goal and scope definition, inventory analysis, impact assessment, and interpretation [16]. Some of the studies conducted in the country and abroad in the field of chemical life cycle assessment are as follows:

Marbaix et al., studied the subject of life cycle evaluation of CO_2 methane activated by magnetic heating [17]. On the others hand, Toniolo et al., examined the subject of international standards with a life cycle perspective. The purpose of this study was to investigate the dimensions of sustainability that have received the most attention in international standards [18]. Alsaleh and Sattler researched on the comprehensive LCA of large wind turbines in the United States; the aim of this study was to conduct a comprehensive life cycle assessment for large onshore wind turbines in the United States [19]. Moreover, Dal Pozzo et al. investigated the geopolymer mixed life cycle assessment for insulation programs [20]. Kalberlah et al. studied the performance index for the analysis of potential health effects using LCA and environmental product announcement [21]. Pastore et al. conducted a case study on reducing N-methyl-2-pyrrolidone solvent wastes in the production of polyamide and polyangsazole precursors [22]. Costa et al., studied the LCA of a military explosive production unit and the chemical industry in general has great potential for producing environmental impacts and health risks [23]. Moreover, researches of formaldehyde in wood products shows that formaldehyde is one of the environmental pollutants and can lead to cancer even under conditions [24]. Also, Rashidi et al. studied the life cycle evaluation of the process of producing18 oxygen isotope by the water distillation method using SimaPro software with cradle-to-gate approach [25]. The investigations of Kargari et al., were about environmental pollution emissions, specially the emission of greenhouse gases from electricity generation investigated in Bushehr Nuclear Power plant [26]. Finally, Moini studied the application of life cycle evaluation in the management of sulfur wastes and waste oils of Tehran Oil Refinery using SimaPro software [27].

This research is the first study to the LCA of formalin in Iran and hexamine both inside and outside Iran. Due to the lack of study on the environmental effects of formalin and hexamine production process, life cycle evaluation of the production process of these two products is of particular importance. Therefore, this study can help to produce new information in the field of environmental management of these two products and be a model for other industries producing formalin and hexamine. This research used the latest version of SimaPro software, which had a more up-to-date and complete database than previous versions. This research is the first study conducted to evaluate the environmental performance of an industry in the country using life cycle assessment software. This is an important innovation in the study and evaluation of environmental performance of industries.

2. Materials and Methods

This study was conducted at Gameron Petro Industry Complex, located in Hormozgan province, north of Bandar Abbas City: 27° 22′ 30″ N, 56° 20′ 24″ E (Figure 1) [28]. In this study, in order to evaluate the environmental impacts of the life cycle of formalin and hexamine production process, version 9 of SimaPro software was used which had more up-to-the-latest and complete databases than previous versions. SimaPro is an economic software provided by PRe' consultants in the Netherlands [29]. The software provides professional tools for collecting, evaluating and monitoring the environmental efficiency of products, processes and services [30]. After brief introduction of the concept of life cycle evaluation, the evaluation stages are expressed according to ISO standards as well as analytical steps to obtain the results of the analysis. It should be noted that there are different methods for evaluating life cycle in SimaPro software. The difference between these methods is in the number of materials analyzed, midpoint outputs, endpoint injuries and coefficients of characteristic determination, weighting and normalization. In this study, the environmental impacts of process life cycle were evaluated using three methods: Eco-indicator, +2002IMPACT and 2003 EDIP.

LCA is a "cradle to grave" approach for evaluating industrial systems. "Cradle to Grave" starts by collecting raw materials from the ground to produce the product and ends with the return of the consumed product to the ground. LCA allows estimating the cumulative environmental impacts of all stages of the crop's life cycle [31].

Overall structure of life cycle evaluation methods in this study included the following: 1. Characterization, 2. Damage assessment, 3. Normalization, 4. Weighting and 5. Addition. In the following, each of these steps will be briefly introduced.

Characterization

Cases that are influential in an effect class are multiplied by a property determination coefficient indicating the relative impact of that material on that environmental effect. For example, the characteristic factor in CO_2 in the climate change impact category is considered to be 1, while this factor for methane is equal to 29. This means that the effect of 1 kg of methane on climate change is equivalent to the impact of 29 kg of CO_2. The overall result is expressed as indicators of the effect class [31].

Damage assessment

Degradation assessment is a relatively new step in environmental impact assessment. This step has been added to use endpoint methods such as Eco-indicator 99 and EPS2000. The purpose of degradation assessment is to combine a number of outputs indicators in a degradation class. In the degradation assessment step, the effect class indicators are combined with a common unit. For example, in the Eco-indicator 99 method, all categories of effect become human health indicators with DALY unit (years of life lost). In this method, DALYs caused by carcinogens can be aggregated with DALYs created by climate change using appropriate coefficients [31].

Normalization

Many methods have made it possible to compare the effect class index with a reference value. This means dividing the effect class by a reference value. The common reference used is the average annual environmental burden in a country or continent, divided by the number of residents in that region. But the reference can be chosen differently. The environmental load generated by a 60-watt lamp can be chosen within an hour, the displacement of a car with a distance of 100 km, and the like as the reference value. This can be useful in expressing the results for people unfamiliar with the LCA, as the results are introduced based on a criterion that are familiar to everyone. After the normalization process, all the indicators of the effect class will have one dimension, which makes it easier to compare them. Normalization can be applied on the results of injury assessment and characteristic determination [31].

Figure 1. The locality of Gameron petro industry complex

Weighting

Finally, in some methods, it is possible to weigh the impact categories. This means that the results of the impact/damage category index in the multiplied weighting factor, and their aggregation, result in the creation of a comprehensive/individual environmental score. Weighting can be applied to normalize or un-normalized scores. For example, the EPS method lacks the normalization step. In this study, three methods of Eco-indicator 99, EDIP 2003 and IMPACT 2002+ were used [31].

Inputs and outputs

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

3. Results and Discussion

Eco-indicator 99 modeling results in Figures 2-6, the results of modeling by Eco-indicator 99 method are better illustrated by applying specificity determination coefficients, degradation category, normalization, weighting and environmental single score. In Figure 5, the weighted environmental score of each impacts category is comparable. Figure 6 is another representation of the weighted values. In this figure, this analogy is performed on the inputs of the life cycle inventory.

It is taken from Figure 2 that none of the inputs is the absolute dominant input in creating impacts. In creating the impacts of climate change, radiation and toxicity, ammonia with a share of 48, 49 and 73 percent is the most influential input. In respiratory inorganics, the share of ammonia and methanol is the same. In other impacts, methanol is the dominant input. By examining the damage categories in Figure 3, it is found that the effect of methanol and ammonia on human health is approximately equal (44% ammonia and 48% methanol). Ammonia consumption has a 56% effect on ecosystem quality and methanol consumption, with a 64% share among all inputs, in causing damage to resource consumption.

Normalized and weighted results were shown in Figures 3 and 4. Fossil fuels consumption is the dominant impacts of life cycle (74% of the overall environmental score of the process). Methanol, ammonia, diesel and electricity are the four inputs with the greatest effect on creating this impacts (they have a share of 65%, 25%, 8% and 2%, respectively). The impacts of respiratory inorganics (Pt 50), carcinogenicity (Pt 23) and climate change (Pt 21) are other important impacts in the life cycle of this functional unit.

Figure 6 is another expression of the weighted values. Methanol (Pt 245), Ammonia (Pt 123), Diesel (Pt 29) and Electricity (Pt 10), four main inputs in creating environmental impacts and damages of life cycle are, with a share of 60%, 30%, 7% and 2%, respectively.

EDIP 2003 modeling results

In Figures 7-10 the results of modeling by EDIP 2003 method are, respectively, represented by applying characteristic determination coefficients, normalization, weighting and individual environmental score.

The results of EDIP 2003 characteristic determination coefficients indicate that methanol is the determinant input in 16 impacts of 19 impacts. Global warm-

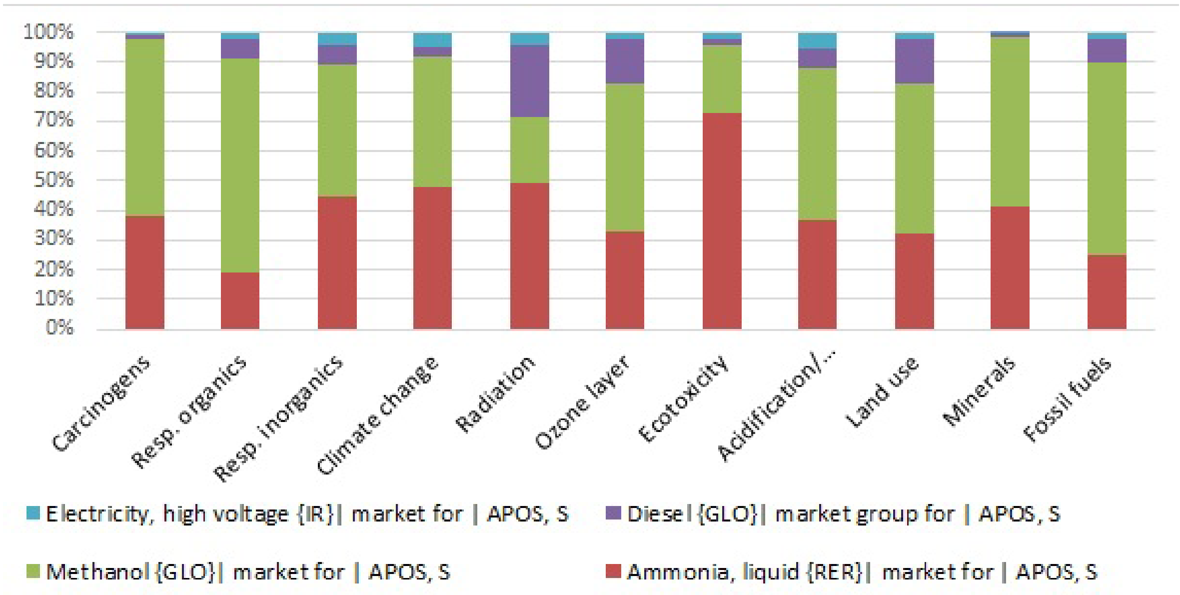

Figure 2. Results of applying the coefficients of determining the characteristics of the Eco-indicator 99 method in calculating the impacts

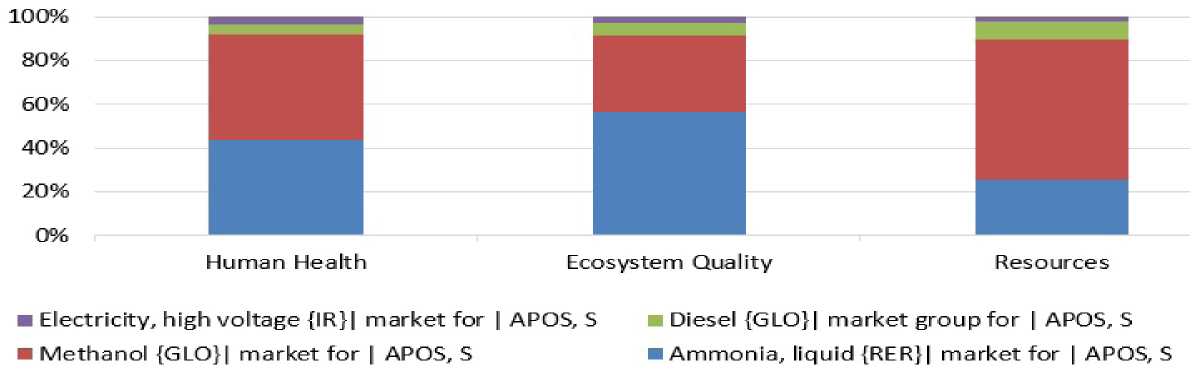

Figure 3. Results of applying the Eco-indicator 99 method in damage calculation

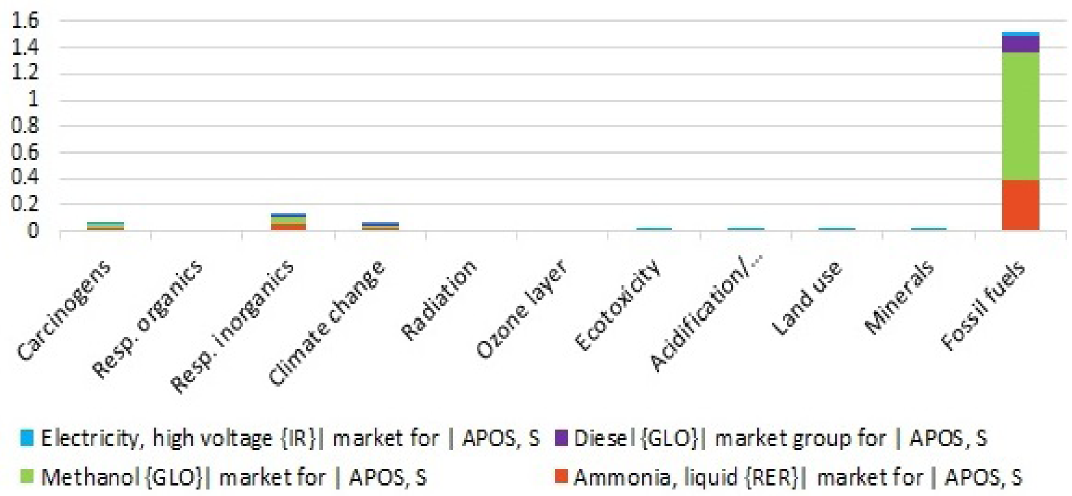

Figure 4. Results of applying normalization coefficients of the Eco-indicator 99 method in calculating impacts

Table 1. Production process life cycle log of 800 kg hexamine and 200 kg formalin [28]

Inputs			Outputs		
Title		Value	Title		Value
Water (m^3)		1.5	Carbon Dioxide (gr)		0.29884
Cooling Water (m^3)	Of Nature	150	Carbon Monoxide (gr)		4.71505
Air (ton)		3.5	Oxygen (gr)		0.64417
Ammonia (ton)		0.53	Hydrocarbons (gr)	Emissions to the air	0.92973
Methanol (ton)	Materials/ Fuel	1.6	Nitrogen Oxides (gr)		5.24633
Diesel (ton)		0.1248			
Electricity (kWhr)	Electricity/ Heat	150	Sulfur Oxides (gr)		0.13282

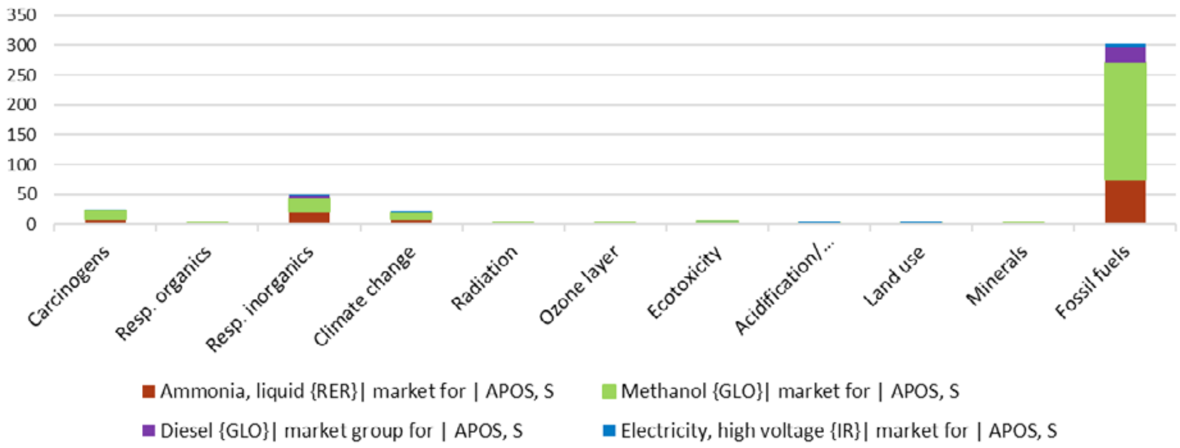

Figure 5. Results of applying weighting coefficients of the Eco-indicator 99 method in calculating impacts

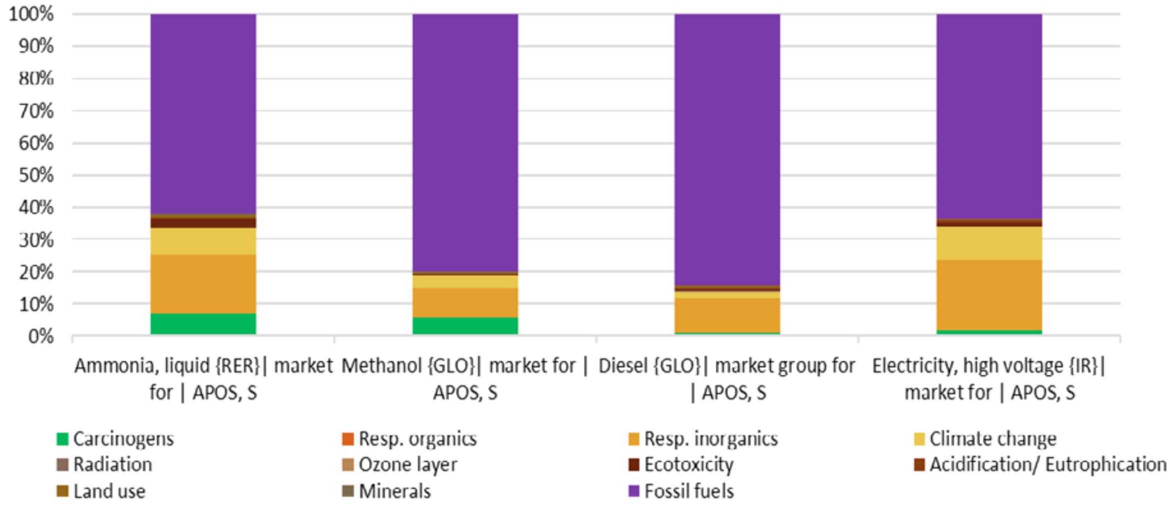

Figure 6. Final environmental points (single score) of life cycle using the eco-indicator 99 method

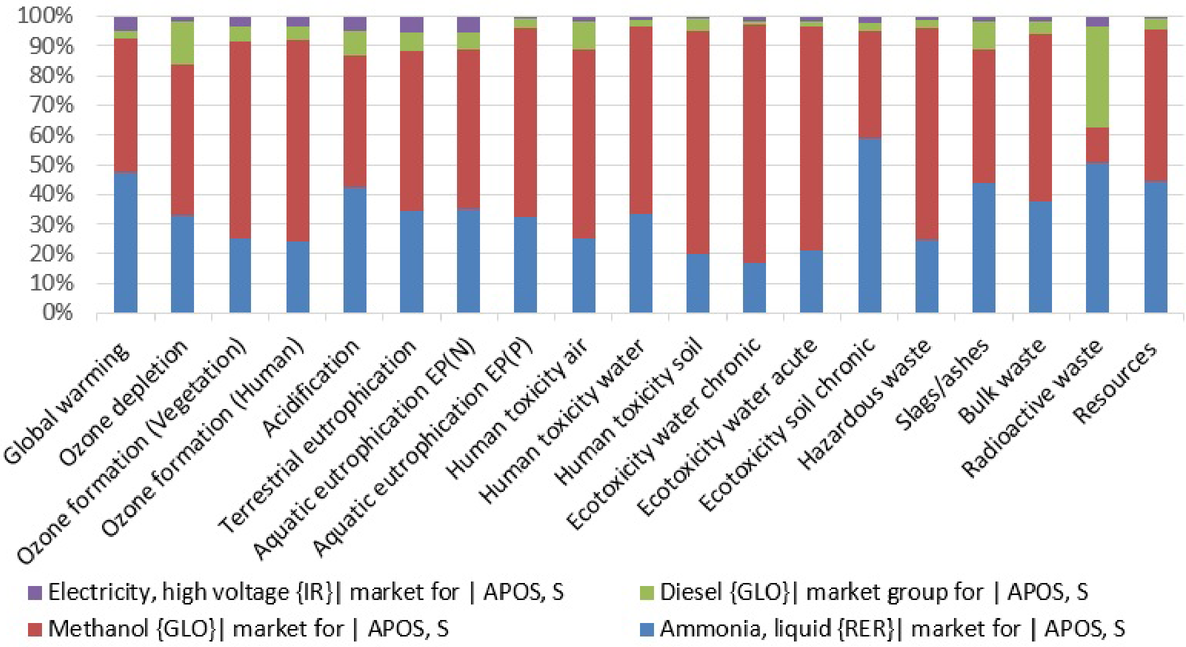

Figure 7. Results of applying EDIP 2003 characteristic coefficients in calculating impacts

ing, soil toxicity and radioactive waste are the three impacts in which ammonia have the dominant effect. Also, the effect of 33% diesel on the form of radioactive waste impacts can be reflected.

Normalized and weighted values are shown in Figure 8. The ultimate environmental score of this process is 6.6 Pt. The dominant impacts in the life cycle is the production of 800 kg of hexamine plus 200 kg formalin, degradation of ozone layer with a share of 28% of the overall score. Aquatic eutrophication, human toxicity and radioactive wastes each play a 14% role in the environmental impact of the process life cycle.

Methanol and ammonia play a role in creating all impacts. The overall effect of methanol, ammonia, diesel and electricity was 50, 35, 11 and 2 percent of the overall score, respectively.

Impact 2002+ modeling results

In Figures 11-15, the results of modeling by the IMPACT 2002+ method are better illustrated by applying

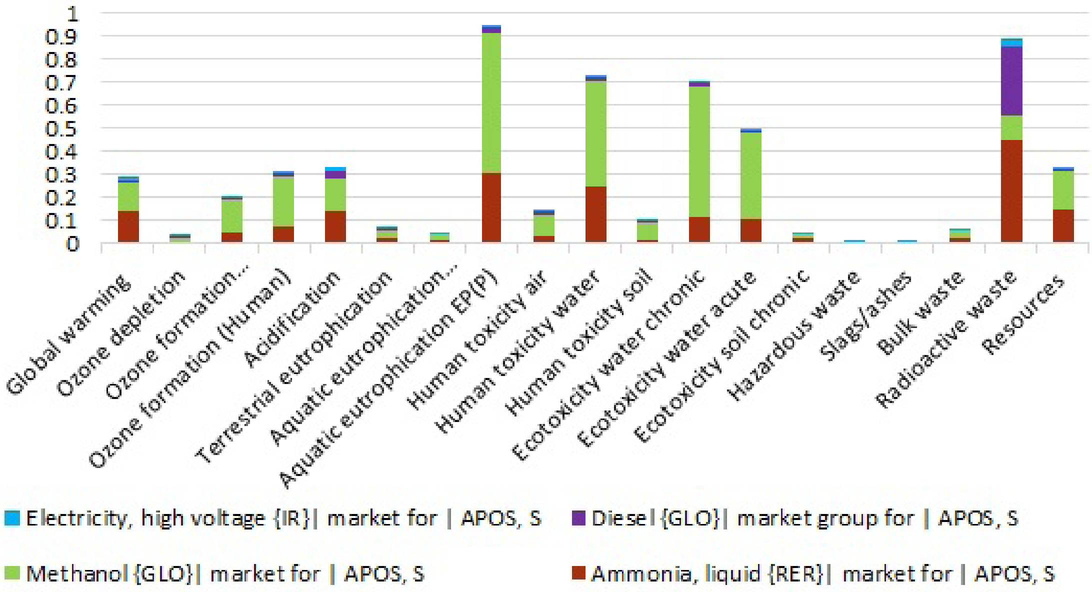

Figure 8. Results of applying normalization coefficients of the EDIP 2003 method in calculating impacts

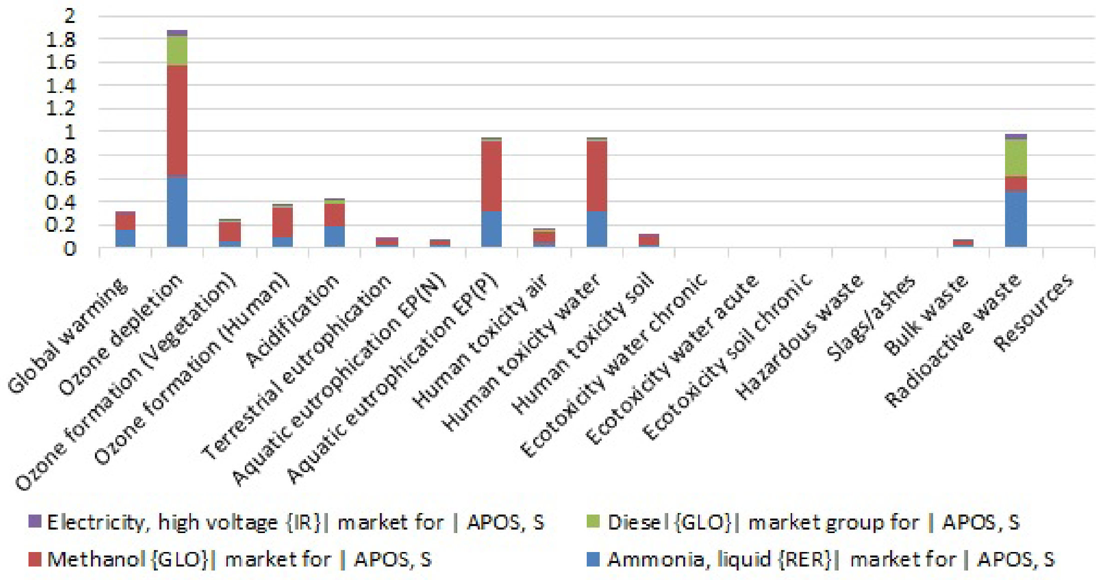

Figure 9. Results of applying weighting coefficients of EDIP 2003 method in calculating impacts

characteristic determination coefficients, category of damage, normalization, weighting and individual environmental score.

The totality of the results of Figure 11 is similar to the results of Figures 2 and 7. Methanol is the dominant input in creating 12 impacts. The highest effect was on carcinogenic impacts (87%) and the lowest was in ionizing radiation impacts (23%). The effect of ammonia in two impacts of ionizing radiation and global warming is more than methanol. The effect of these two substances on respiratory inorganics is the same. The total values of damage categories by IMPACT 2002+, are 0.001636 DALY, 2038.305 PDF.m²yr, 2091.536 kg CO_2 equivalents and 61.87139MJ surplus. Ammonia has the most impact on global warming damage. The dominant input in the formation of three other injuries is methanol (Figure 12).

According to the weighting coefficients, the overall schema of the Figures 13 and 14 are quite similar. The 5 main impacts are concurrent production of hexamine and formalin, non-renewable energy consumption (55%), global warming (20%), respiratory inorganics

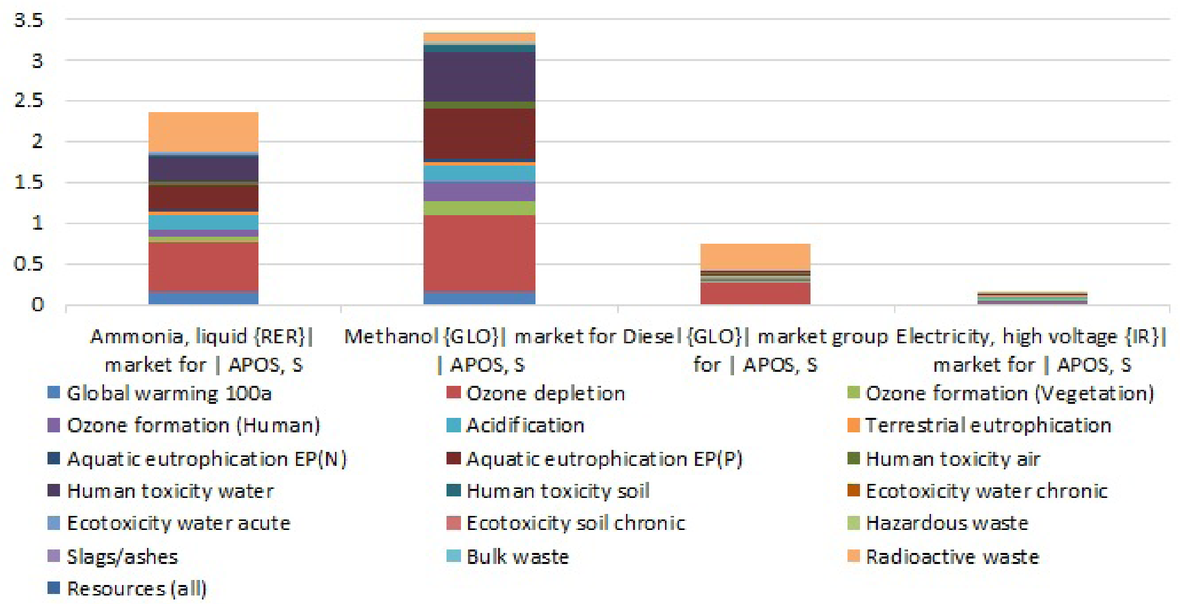

Figure 10. Final environmental points (single score) of life cycle scores using the EDIP 2003 method

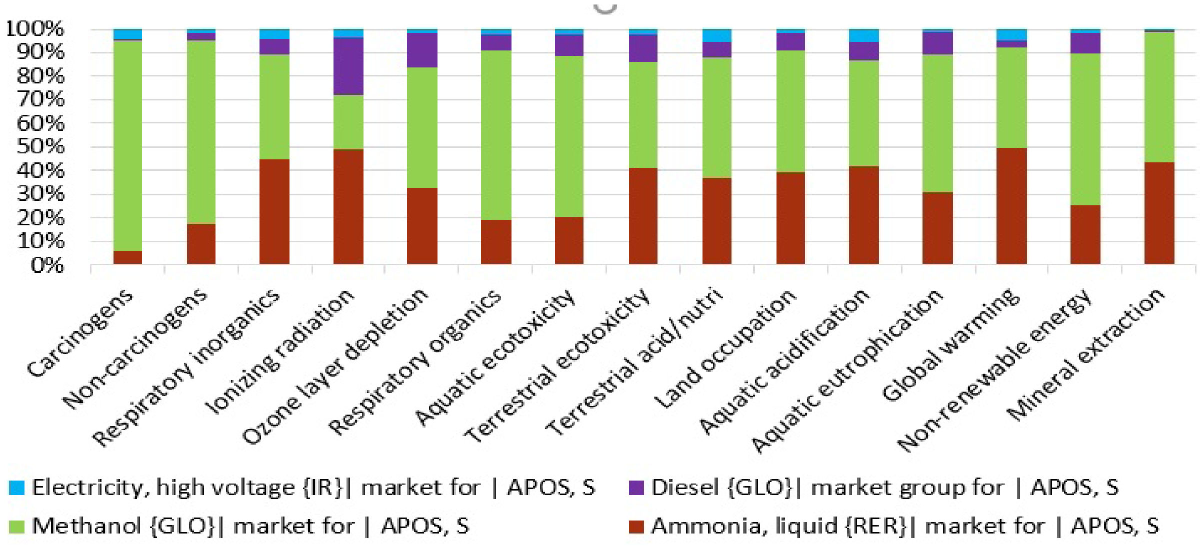

Figure 11. Results of applying impact 2002+ characteristic coefficients in calculating impacts

(13%), carcinogenicity (7%), and terrestrial ecotoxicity (2%). The effect of 87% methanol on carcinogenic impacts can be contemplated.

Finally, in Figure 15, the influence of each input is observed in the overall life cycle score. 58% of the environmental impact of life cycle is due to methanol consumption, which consumption of non-renewable energy sources has a 61% effect on this amount. After methanol, ammonia, diesel and electricity, the influential inputs with a share of 32, 6 and 3% are in the overall life cycle rating of hexamine and formalin (Pt 1.04).

In this research, the environmental performance of formalin and hexamine production units of Gameron Petro Industry Complex was studied by using life cycle evaluation method.

The functional unit under study was the production of 800 kg of hexamine along with 200 kg of formalin in this complex. Also, three evaluation methods: 99Eco-indicator, 2002 IMPACT and 2003 EDIP were used to model the environmental impacts.

Applying the 99 Eco-indicator method showed that ammonia is the most effective input in creating the effects of climate change, radiation and toxicity. The contribution of ammonia and methanol to respiratory inorganics is the same and in other effects, methanol is the dominant input. The effect of methanol and ammonia on human health is approximately equal (44% ammonia

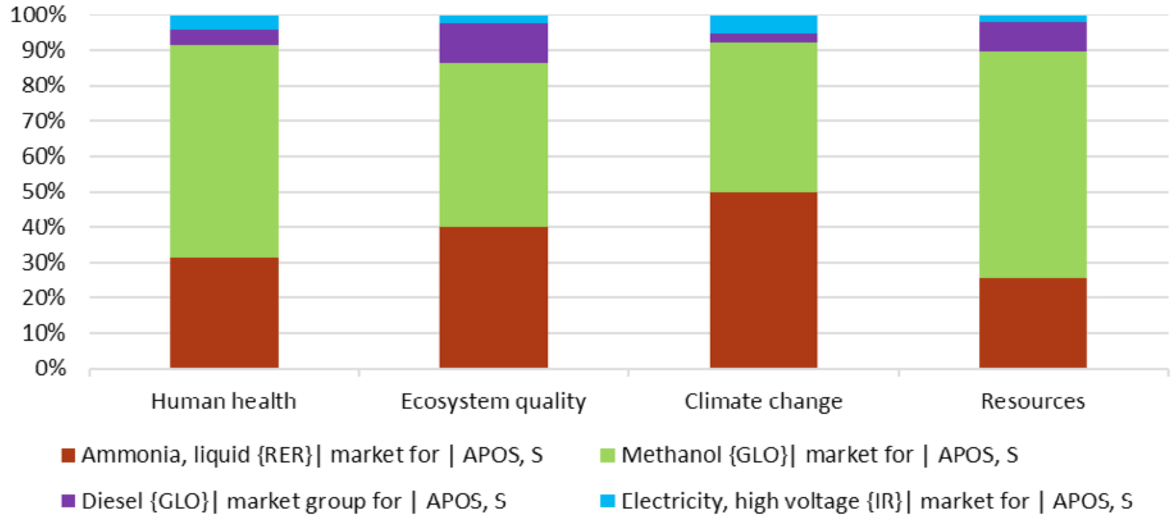

Figure 12. Results of impact 2002+ method in damage calculation

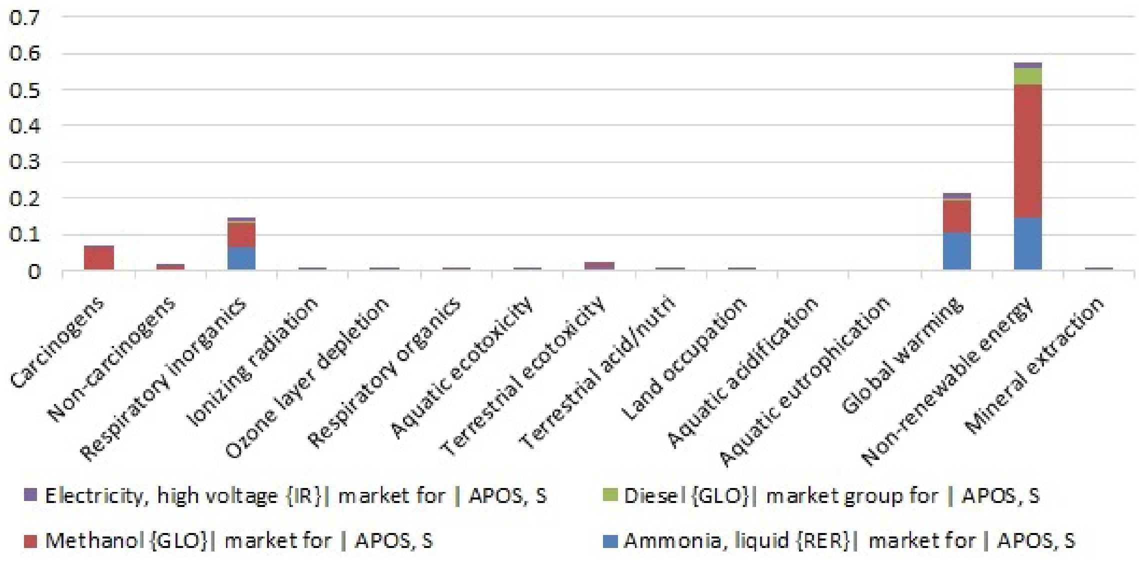

Figure 13. Results of applying normalization coefficients of the IMPACT 2002+method in calculating impacts

and 48% methanol). Ammonia consumption has a 56% effect on ecosystem quality and methanol consumption, with a 64% share among all inputs, in causing damage to resource consumption. Methanol, ammonia, diesel and electricity fuels are the four main inputs in creating environmental impacts and damages of life cycle, with a share of 60, 30, 7 and 2 percent, respectively.

In the IMPACT +2002 method, methanol is the dominant input in creating 12 effects. The highest effect is on carcinogenic effect and the lowest effect is due to ionizing radiation percentage. The effect of ammonia on ionizing radiation and global warming is more than methanol. The effect of these two substances on respiratory inorganics is the same. Ammonia has the most impact on global warming damage. Methanol plays a role in the formation of three other injuries. 58% of the environmental impact of life cycle is due to methanol consumption, which consumption of non-renewable energy sources has a 61% effect on this amount. After methanol, ammonia, diesel and electricity, the influential inputs with a share of 32, 6 and 3% are in the life cycle of hexamine and formalin production.

Gameron Petro Industry Complex with the approach of green product production and environmental pro-

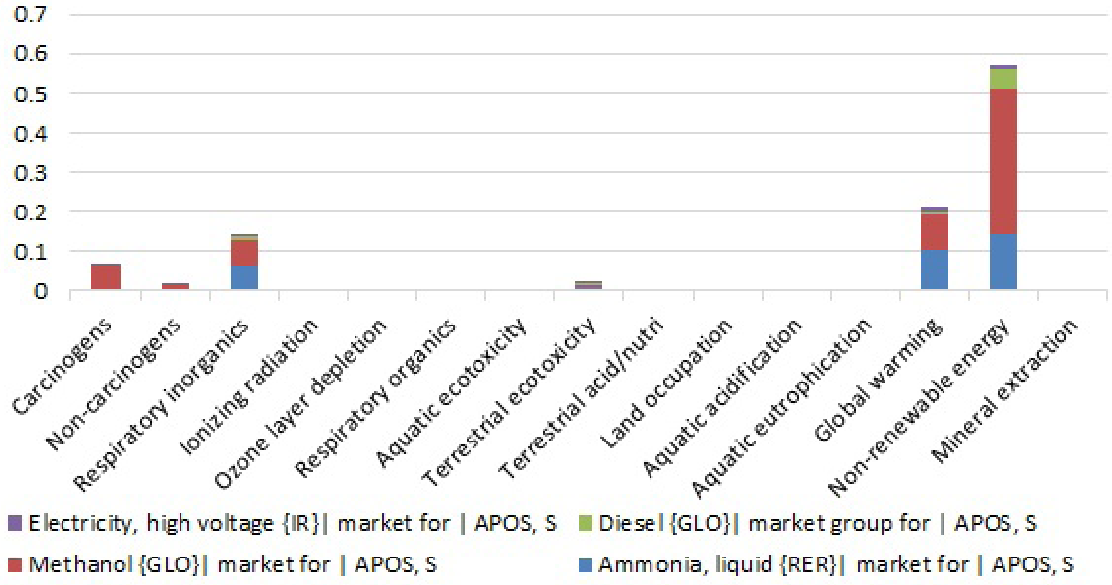

Figure 14. Results of applying weighting coefficients of the IMPACT 2002+ method in calculating impacts

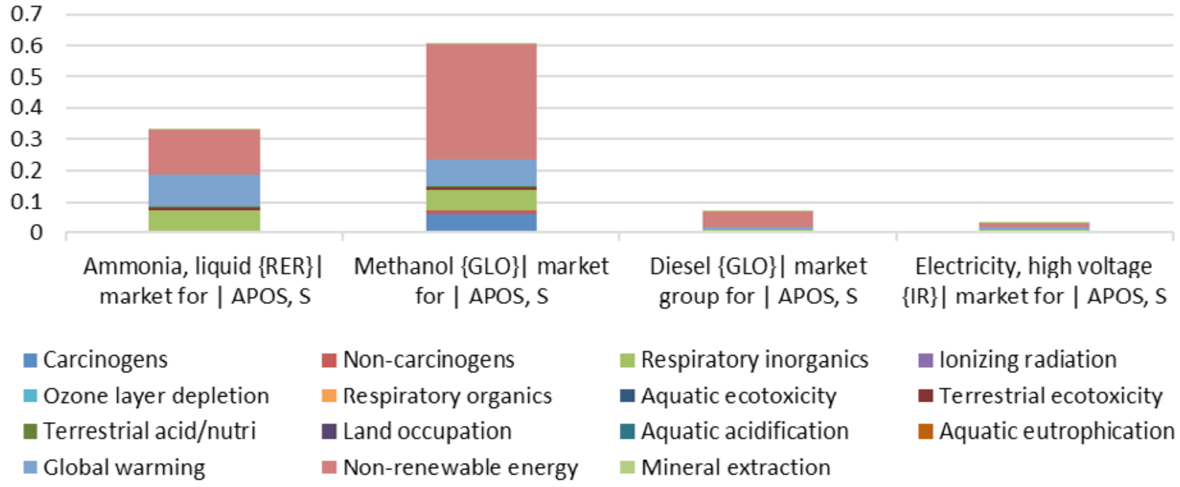

Figure 15. Final environmental points (single score) of life cycle scores by the impact 2002+ method

tection and in order to reduce the impacts of formalin and hexamine production, the control and mitigation measures were studied and implemented stablishment of a Health, Safety, Environment & Energy section and implementation of standard of ISO18001: 2007 OHSAS) and ISO 14001: 2015, utilization of Off Gas system and use of exhaust gases in steam production, gas burning of boilers and elimination of the use of diesel from the production process, use of electronic antifouling to remove boiler sediments and increase boiler thermal efficiency in order to reducing water and energy consumption, installation of electronic descaling system and removal of anti-fouling chemical solvents in the cooling tower and chiller system, electronic antifouling installation and removal of acid washing process, design of ammonia flow return system in order to ensure ammonia reduction in these flows and Save water and energy consumption and prevent groundwater pollution, increasing the efficiency of the cooling system by using a chiller to control the temperature of the circulating water in order to reduce the consumption of water resources, management of energy consumption by reducing the consumption of fossil fuels and replacing excess gases in the production process, installation and modification of thermal insulation of pipelines to reduce energy consumption and thermal pollution, use of process currents for heating or cooling in different parts of the production process to optimize consumption energy, management of soil resource pollutants through compliance with soil environmental standards, laws and regulations, continuous monitoring and control of process leaks and management of normal and special wastes by collecting and separating from the source, commitment to implement a self-declared plan in monitoring and analyzing effluents and flue gases and controlling parameters in order to comply with environmental standards [28].

4. Conclusion

In this study, only the environmental dimensions of the problem were examined. But, according to the principles of sustainable development, in order for projects to be sustainable, it is necessary to consider all three environmental, economic and social dimensions. For this purpose, multi-criteria optimization models based on technical, environmental, economic and social criteria are proposed.

Considering that effective inputs in the production process of various integrated products have been identified in this research, it is suggested to study alternative solutions for the production of these materials as well as alternative materials (if any).

One of the most important benefits of LCA is the comparison of several production processes of a product from an environmental perspective and the selection of a superior process. It is suggested that other processes of formalin and hexamine production be studied and compared with the results obtained from this study.

Ethical Considerations

Compliance with ethical guidelines

The study was approved by the Ethics Committee of Bandar Abbas Branch, Islamic Azad University (Code: 11421214972007).

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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