Life cycle analysis (cost and environmental) of different renewable natural gas from waste procedures based on a multivariate decision-making approach: a comprehensive comparative analysis

Mobin Ghasempour Nejati[1,†], Seyedeh Elham Kamali[2], Mohamad Javad Zoqi[3], Fatima Moayad Sami[4], Mohammed Kassim Al-hussainawy[5] and Hadi Fooladi[6,*,‡]

[1]The Paul Merage School of Business, University of California, Irvine, CA 92697-3125, USA; [2]Department of Mechanical and Industrial Engineering, University of Newhaven, Newhaven, CT, USA; [3]Department of Civil Engineering, University of Birjand, Birjand, Iran; [4]Department of Medical Laboratory Technics, Al-Noor University College, Nineveh, Iraq; [5]National University of Science and Technology, Nasiriyah, Dhi Qar, Iraq; [6]Department of Energy Engineering, Faculty of Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

Abstract

This article presents a framework that focuses on structural considerations within gas networks to evaluate and rank various feasibility options for renewable natural gas (RNG) cases. Specifically, the analysis examines and compares a range of methods for producing RNG using natural gas from waste (NGFW), considering different types of waste as feedstock. To analyze and evaluate the different methodologies, the article uses a decision architecture based on life cycle analysis (cost and environmental). These tools are used to determine the most favorable path for the NGFW process. The preferred pathway is identified by considering a range of decision scenarios that take into account variables such as geographical conditions, the availability of various feedstocks and the different stakeholders' priorities. The results show that according to the economically neutral scenarios and those that favor economic considerations, the pathway involving RNG generation from landfill gas coupled with a pressure swing adsorption (PSA) upgrading technology emerges as the optimum choice. Conversely, in a scenario where environmental sustainability is a priority, the process that emerges as most advantageous is the use of animal manure with the addition of a PSA upgrading unit. The designed structure can be adapted to different regions, each with its own unique geographical features and feedstock resources, and can be customized to meet the varying interests of stakeholders. Based on both parametric assessments and analytical interpretations, this article not only identifies optimal pathways but also provides a set of recommendations and strategies aimed at improving economic behavior.

Keywords: life cycle analysis; renewable natural gas; waste; biogas upgrading; multivariate decision-making approach

*Corresponding author:
fooladi.hadi18@gmail.com;
mghasemp@uci.edu

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†, https://orcid.org/0000-0001-9414-618X
‡, https://orcid.org/0000-0001-7746-1452

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1 INTRODUCTION

The population growth of the world, together with the expansion and progress of community and industrial initiatives, has led to a significant increase in energy consumption in the industrial, agriculture, building, etc. sectors in recent years [1, 2]. Fossil energies continue to provide a notable proportion of the energy needed for various applications such as industrial processes, power generation and building services [3–5]. Natural gas in particular stands out within the fossil fuel spectrum for its ease of use. It is conveniently transported and distributed through pipelines for purposes such as heating, cooking and as a fuel for industrial operations and power plants [6, 7]. While natural gas is a major player in the global energy market—accounting for over 3% of consumption in its own industry—environmental issues associated with the use of traditional natural gas are putting considerable pressure on the field [8, 9]. As a result, there is a growing impetus to adopt environmentally sustainable practices in order to remain competitive in the international marketplace [10, 11]. In light of these environmental concerns, evaluations are currently underway aimed at transforming the energy portfolios of plants and companies to decline the environmental footprint associated with traditional natural gas utilization [12, 13]. Consequently, the integration of alternative fuels into existing gas infrastructures is considered one of the most important and strategic solutions to pave the way for a more sustainable energy future [5, 14, 15].

The fuel in question, which is considered a viable substitute, has the potential to be injected directly into the current natural gas pipeline infrastructure, making it a crucial alternative to conventional fossil fuels [16]. This environmentally friendly option is primarily biogas, which is produced by the anaerobic decomposition of organic matter. To be considered as a substitute for natural gas, biogas needs to be treated to improve its quality and meet certain purity standards to ensure compatibility with existing gas networks [17, 18]. Renewable natural gas (RNG) is produced using biogas from a variety of sources, including MSW landfills, livestock operations, manufacturing factories and wastewater treatment units. At the same time, strategies such as biomass fuel gasification and power-to-gas technologies are in the pipeline and awaiting more comprehensive analysis [19–21]. Some studies have examined the feasibility and practicality of assimilating RNG generation routes into existing gas infrastructures from various perspectives, such as the type and availability of feedstocks, economic assessments, environmental considerations and optimization processes [10, 22, 23]. It had been documented that replacing fossil-based natural gas with RNG could cause significant financial gains, including revenues from carbon tax and energy sales [24, 25]. In addition, Norouzi *et al.* [26] reported that membrane separation (MSP) technology for biogas upgrading is the most popular technology due to country-old knowledge regarding gas permeation membranes. According to Chen *et al.* [27], a two-stage process involving water hydrolysis followed by anaerobic biogas generation was evaluated. Their results indicated an optimum volatile solids ratio of 1:3 when wastewater from pulp was combined with the subcritical water-treated food waste hydrolysate for biogas production.

Numerous works had reported primarily on the technoeconomic assessment of RNG generation paths. However, the assessment of the environmental impact of such investments is equally critical to their financial viability. Otero Meza *et al.* [28] reported the potential for converting landfill gas-to-energy in Colombia. From their results, the use of MSW could increase grid energy capacity by about 112 800 kW. In addition, they found that the energy generated from landfill gas could supply approximately 474 000 households with electricity for a period of 25 years. Continuing the theme of environmental assessment, Oever *et al.* [29] examined the compressed biogas from organic waste and manure (under anaerobic digestion process) and evaluated the process through a life cycle environmental assessment. They discovered that increased crop production required improved fertilizer storage techniques. There was also a need to significantly reduce emissions from the use of digestible materials. There was a notable lack of published research on life cycle assessment, particularly in relation to total environmental impact.

Lee *et al.* [30] investigated the benefits of reducing the emitted greenhouse gas by producing RNG from various feedstocks. The results showed that the carbon footprint of RNG produced from waste materials was significantly lower compared to other feedstocks. However, this research did not include a comprehensive assessment of additional environmental impacts. Discussions that encompass the economic, environmental and societal pillars are essential when considering the sustainability of an energy initiative. Despite various reports in the literature on the potential and practicality of assimilating pathways for RNG production into existing gas infrastructures from different perspectives, a thorough review of the literature reveals certain research deficiencies, which include:

- The analysis of the sustainability of a RNG plant often fails to adequately address the economic, environmental and social dimensions together, as evidenced by the paucity of literature reporting on the combined life cycle assessment of these three pillars.
- There is a paucity of literature on the use of multicriteria decision-making techniques to identify the favorable path in RNG plants.
- There is a lack of available studies that have reported on investment feasibility analysis for waste-to-energy projects, particularly with regard to incorporating collaborative uncertainty assessment and addressing the diverse interests of stakeholders.
- There is a lack of discussion in the literature on the suitability of different pathways for the production of RNG from waste, particularly in terms of addressing geographical variations and integrating expert and stakeholder perspectives.

This article has therefore been prepared to fill the identified research gaps by developing a framework with a focus on the structure of gas networks. This framework is intended to facilitate the comparison and prioritization of various feasibility options for RNG plants. The discussion within the article revolves around different methods of producing RNG through the NGFW process and compares these pathways with respect to the use of different types of waste as feedstock. To investigate and evaluate routes, the present research has used life cycle analysis (LCA), both cost (LCA-C) and environmental (LCA-E) methodologies. The primary objective of this study is to establish a decision support system and a strategic model within the LCA-C and LCA-E assessments to determine the most appropriate route for the NGFW process. In addition, the best approach to RNG production is identified by examining different scenarios that require decision-making across multiple variables. This process takes into account different geographical circumstances, the availability of various feedstocks and the stakeholders' priorities. Based on this, the current work proposes a novel framework for determining the most advantageous route for waste-to-RNG by integrating a life-cycle methodology with a multicriteria decision program. This framework takes into account different local environments and stakeholder interests, a combination not previously explored in the existing literature. In addition, this research provides recommendations and advice on how to increase profitability and reduce investment barriers for NGFW initiatives through parametric, analytical and interpretive research. The findings presented in this paper may prove useful and constructive to city administrators, energy facility investors and engineering professionals.

The next section describes the research methodology including system description, modeling and analysis. In the third section, the results obtained from the research were discussed. Finally, the last section expresses the conclusion and the key points of the research and the perspectives.

2 METHODOLOGY

The creation of RNG plants, aimed at incorporating this fuel into the existing portfolio of the natural gas industry, has the potential to alleviate many of the concerns associated with the depletion of reserves and environmental crises associated with fossil fuels. The article discusses and contrasts different methods of producing RNG under the NGFW processes, with variations in the production pathways dictated by the types of waste feedstocks available. LCA-C and LCA-E were used to facilitate the discussion and comparison of different RNG-from-waste pathways. Essentially, the objective of this work is to address a decision framework, based on LCA-C and LCA-E methodologists, which will assist in the selection of the most favorable NGFW pathway.

Figure 1 illustrates the overview architecture of the methodological structure developed. As shown, the offered structure follows three major phases: (i) project definition, (ii) performing a LCA and (iii) making decisions based on multiple variables. In addition, the pathways for NGFW are developed under potential technologies and vary according to different feedstocks. These are evaluated in three different areas characterized by variable populations. Consequently, the choice of feedstocks and technologies is determined by those that are both common and feasible, as presented in scientific publications, and depends on the availability of feedstocks in the regions desired. As obvious in Figure 1, various routes are first assessed and compared using the mentioned analysis methods. Following this evaluation, the suitability of an approach is considered through a multivariate decision process. This decision-making approach uses the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which is adept at finding a solution that is close to the ideal point, as reported in [31, 32].

2.1 Feedstocks and technologies

Currently, the foundation of NGFW plants is implemented under a triad of processes: anaerobic digestion, thermal gasification and power-to-gas process [33]. Biomass sources, the decomposition of organic matter and the separation of water using electricity are the respective methods for producing the necessary hydrogen for these processes [34]. The NGFW technology described in this article utilizes the process of anaerobic digestion. While the process of water electrolysis represents a sustainable and forward-looking direction, its widespread commercial deployment has been hampered by its significant electricity requirements and the current early stage of development of the technology [35]. Conversely, anaerobic digestion is already approved and recognized [36, 37]. The anaerobic digestion process transforms organic fraction of waste, including landfill gas, MSW, sewage sludge (SS) and manure, into biogas. The resulting product consists of a mixture of methane, water vapor, CO_2 and other components [38].

The pressure swing adsorption (PSA) process uses variable pressure to remove carbon dioxide from biogas. The biogas is first purified via activated carbon to remove hydrogen sulfide; then dried to remove any water vapor. Following these steps, the gas stream is compressed to 0.5 MPa before being fed into the PSA unit for further processing. In this module, CO_2 is separated and the enhanced gas flow is flowed to subsequent processes designed to remove additional contaminants [39, 40]. The next stage is the removal of dissolved CO_2 [41]. The efficiency of this method is around 97% [42]. For this reason, all feedstocks are assessed across four biogas-upgrading methods. According to different feeds and technologies, the 12 scenarios are proposed. The definition and characteristics of different scenarios are tabulated in Table 1. In addition, assessments were carried out in three regions characterized by different population densities.

2.2 Simulation and analysis

The first pillar is assessed using LCA-C, while the assessment of the last two pillars is based on LCA-E. Accordingly, the economic pillar includes two factors, namely financial feasibility and economic viability [43, 44]. Table 2 illustrates the performance indicators for all three pillars. As demonstrated, the LCA-E is based on aspects such as impact on climate change, impact on ecosystem, impact on human health and impact on depletion of resource [45]. In addition, LCA-C considers life cycle cost (LCC), return on investment and levelized cost of energy (LCOE).

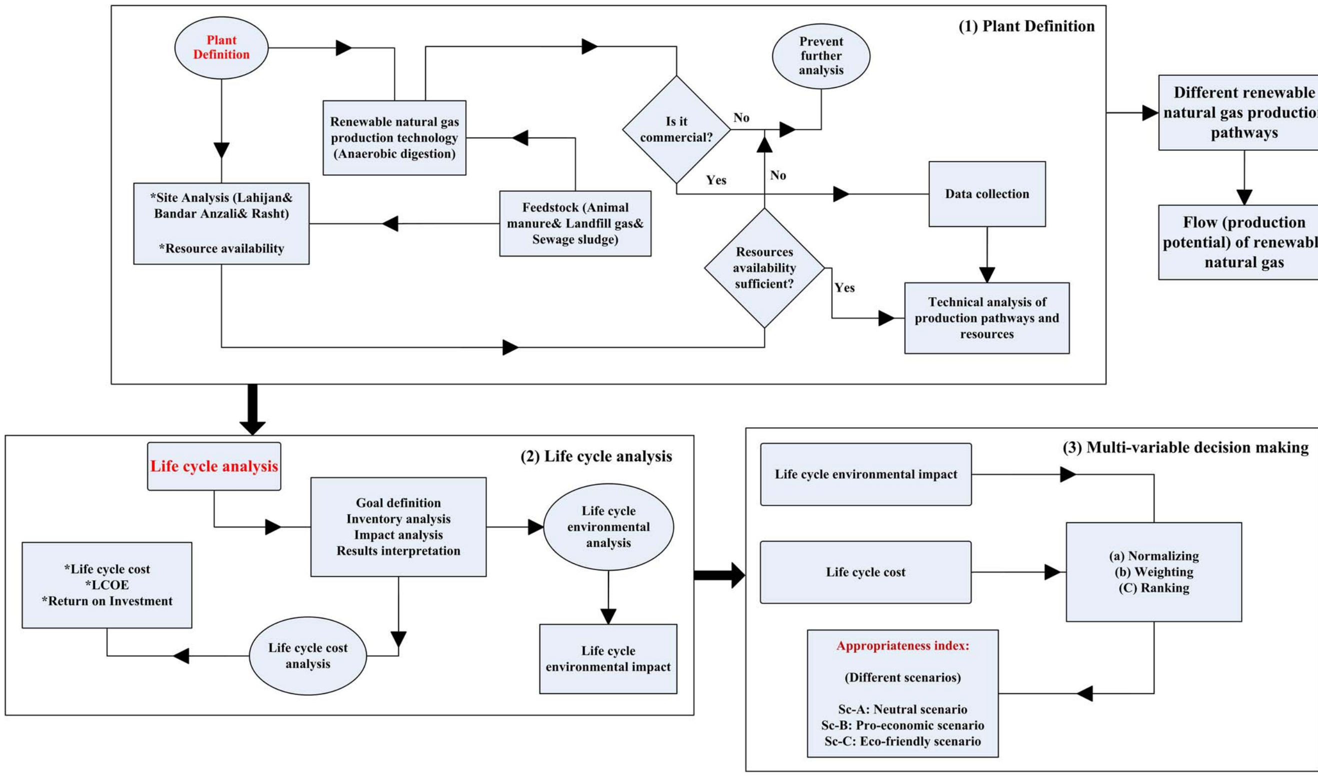

Figure 1. *The overview architecture of the methodological structure developed.*

Table 1. *The definition and characteristics of different scenarios.*

Scenario	Sc-1	Sc-2	Sc-3	Sc-4	Sc-5	Sc-6	Sc-7	Sc-8	Sc-9	Sc-10	Sc-11	Sc-12
Biogas upgrading												
MSP	✓				✓				✓			
CSC		✓				✓				✓		
PSA			✓				✓				✓	
HWS				✓				✓				✓
Feedstock												
AM	✓	✓	✓	✓								
LFG					✓	✓	✓	✓				
SS									✓	✓	✓	✓

HWS: high-pressure water scrubbing; LFG: landfill gas; SS: sewage sludge.

Table 2. *The performance indicators for all the LCA-E pillars.*

Performance criteria pillars	Section	Subsection
Economy	Financial viability	Life cycle cost
	Economic feasibility	LCOE& Return on investment
Environmental	Climate Change	Ozone depletion& GHG emissions
	Impact on ecosystem	Eutrophication& Acidification& Eco-toxicity
	Resource depletion	Fossil depletion& Water depletion& Metal depletion
Society	Human health (HH)	Ozone formation& Particulate matter & Human toxicity& Ionizing radiation

2.1.1 *Life cycle analysis-environmental (LCA-E)*

According to the ISO 14040 standard, this analysis goes through four stages: goal and scope definition, life cycle inventory analysis, life cycle impact assessment and results interpretation [46, 47]. In this context, the environmental analysis developed focuses on assessing the environmental impacts of various NGFW routes.

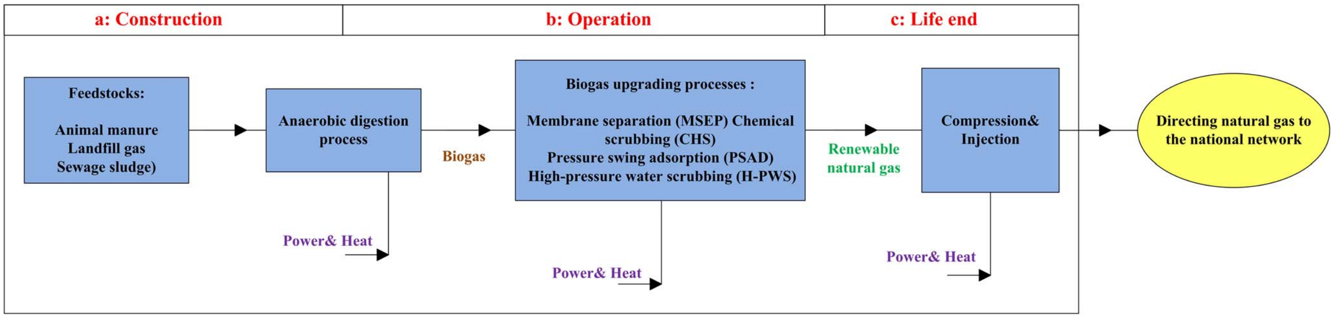

Figure 2. *The boundaries of system for the LCA-E.*

Table 3. *The materials and fuels required for the construction of a NGFW plant employing an anaerobic digestion cycle coupled with a biogas upgrading technology.*

Material	Value	Waste	Value
Concrete	115 m^3	Plastic	1380 kg
Polyethylene/polystyrene	180/ 560 kg	Polyvinylchloride	325 kg
Steel/reinforcing steel	1.28/ 10.9 t	Reinforced concrete	300 tons
Copper/synthetic rubber	0.24/ 1.2 t	Polystyrene	568 kg
Glued laminated timber	85 m^3	Untreated wood	6480 kg

The boundaries of system for the LCA-E are shown in Figure 2 (the construction, operation and end of cycle phases). The plant boundaries start with the choosing and directing of feedstocks into the plant and ends with the directing of compressed RNG into the national grid.

The subsequent stage is a stocktaking exercise, involves compiling all input and output data over the life of the project. Information from reported publications in was utilized for data collection [48]. Table 3 shows the materials and fuels required for the construction of a NGFW plant employing an anaerobic digestion cycle coupled with a biogas upgrading technology, which falls under the inventory analysis category, as available in the database of Ecoinvent [49].

In line with the literature [50, 51], the weights of accumulation of the midpoint categories for the impacts on climate changes and human health were considered to be 0.2 and 0.5, respectively. Further, these weights were considered to be 0.125 and 0.333 for the impacts on the ecosystem damage and depletion of reserves, respectively. The generation rate of RNG (R_{RNG}) under animal manure (AM) feedstock can be formulated with the following equation:

$$R_{RNG} = R_{AM,tot}.Sol_{tot}.\alpha.y_{BG} \quad (1)$$

where,R_{AM}, Sol_{tot}, α, and y_{BG} are the feedstock rate, overall solids in feedstock, availability coefficient, and yield of biogas, respectively. Furthermore, the generation rate of RNG under landfill gas feedstock is estimated by

$$R_{RNG} = \eta_f.\frac{R_{LG}.PR_{CH_4}.m_{BTU}}{Q_{BTU}} \quad (2)$$

Here, η_f is the efficiency factor, PR_{CH4} refers to the methane content in feedstock and Q_{BTU} denotes the heating conversion rate. Finally, the generation rate of RNG under SS feedstock is determined as [52, 53]:

$$R_{RNG} = \eta_f.\frac{SS_{in}.PR_{SS}.m_{BTU}}{Q_{BTU}} \quad (3)$$

2.1.1 *2.1.2 Life cycle analysis-cost (LCA-C)*

This analysis includes the financial feasibility, specifically the overall costs, of a plant in its life cycle [54]. The capital costs of a RNG generation plant include components such as costs of gas generation, storage and grid and the costs associated with distribution to the consumers [55]. Two components, CAPEX (capital expenditure) and OPEX (operating expenditure), are addressed in the cost analysis of the project [47]. Indeed, the costs associated with the feedstock processing, the digestion cycle and accumulation and storage processes are all measured components of the costs associated with the digestion cycle [56]. Estimates of capital expenditure for natural gas production pathways are derived from estimates based on plant capacity [57]. Equation (4) is employed for CAPEX determination [58]:

$$CAPEX = \left(\frac{Capacity_{desired}}{Capacity_{base}}\right)^{0.6} \times \text{Cost}_{base} \quad (4)$$

Moreover, the capital cost of the biogas upgrading technology is formulated by [59]:

$$C_{BG,UP} = 130,000 \times R_{RNG}^{0.56} \quad (5)$$

Table 4. *Data considered for economic calculations.*

Parameter	Value	Parameter	Value
Pipeline capital	272e+03 US$/km	Financing debt	58% of CAPEX
Debt financing term	10 y	Insurance	2% of CAPEX
Management and monitoring	1.3 M$	Discount rate	12%
Working capital	6%	Working costs	5%
Contingency cost	9%	Annual hours	8570 hours
Financing equity	42% of CAPEX	Electric power cost	0.125 US$/kWh
Tax rate	38%	Project lifetime	20 years
Interest rate	7%	Minimum LG rate	35 000 m^3/h

Economic calculations can be considered under the data tabulated in Table 4. The next component of the feasibility calculation is the maintenance and operating costs (or OPEX), based on variable and fixed expenses. Since it is assumed that the feedstock is collected on site, transport costs are not taken into account [60]. The OPEX of the digestion cycle ($C_{O\&M,DG}$) and the electricity cost ($C_{E,DG}$) are formulated as [61]

$$C_{O\&M,DG} = y_{BG}.x_{O\&M} \tag{6}$$

where, $x_{O\&M}$ is the O&M rate.

$$C_{E,DG} = y_{BG}.P_E.EC_{tot} \tag{7}$$

where, P_E and EC_{tot} are the electric power price and power utilization, respectively. Moreover, the feasibility determination for the upgrading cycle is derived from the information reported in [52].

The economic performance of the NGFW routes can be evaluated using three criteria based on the LCA-C. The first cost indicator is LCC and is expressed by [62, 63]

$$LCC = \frac{C_{iv} + C_{f,tot} + C_{v,tot} + C_{DS}}{R_{RNG}} \tag{8}$$

The LCOE is an essential indicator in the cost feasibility of the plant and serves as an appropriate standard for comparing the feasibility of the project with that of comparable ones. This indicator is expressed by [64, 65]

$$LCOE = \frac{\sum C_{iv,i} + C_{OM,i}/(1+r)^n}{\sum E_{RNG,i}/(1+r)^n} \tag{9}$$

2.1.3 *Multivariate decision process*

The TOPSIS technique has the ability to find a solution that is close to the desired point. This technique does not allow the identification of positive/negative desired points [66]. Power plants' infrastructure is entirely related to the preferences of experts/stakeholders, leads to various weightings being applied to various indicators [67]. The current study considers three various decision-scenarios, each under different weightings. The baseline scenario (S-i) is proposed under a neutral setting (all criteria are under the equal weights). In the scenario S-ii (pro-economic scenario), economic criteria are given priority. The weight given to cost criteria (75%) is 3-fold higher than the weight given to environmental ones (25%). Finally, under the scenario S-iii (eco-friendly), the emphasis is on environmental impacts, with the weighting of environmental criteria being 3-fold that of economic ones (see Table 5). These weights can be varied according to the decision makers' preferences. An appropriateness index (API) is obtained by normalizing the findings.

Table 5. *The weighting of the scenarios considered for the multivariate decision process.*

Indicator	Scenario		
	S-i	S-ii	S-iii
Life cycle cost	0.125	0.25	0.0833
Levelized cost of energy	0.125	0.25	0.0833
Return on investment	0.125	0.25	0.0833
GWP	0.125	0.05	0.15
Impact on ecosystem	0.125	0.05	0.15
Impact on resource depletion	0.125	0.05	0.15
Impact on human health	0.125	0.05	0.15
Life cycle impact	0.125	0.05	0.15

3 RESULTS AND DISCUSSION

The three different population levels consist of a medium-sized municipality (i.e. Behshahr), an urban municipality (i.e. Amol) and a large urban municipality (i.e. Sari). These cities are located in the Mazandaran province (north of Iran). To analyze and compare the various NGFW routes in the desired areas under consideration, the potential of RNG generation using various inlet feedstocks and upgrading cycles was assessed. The flows of RNG were calculated for all areas under 12 scenarios. Figure 3 illustrates the flow of RNG for all areas under mentioned scenarios. It's logical to assume that an area under a higher population rate could potentially address a higher RNG generation rate. As demonstrated from the data, in all scenarios, the RNG flow is higher in

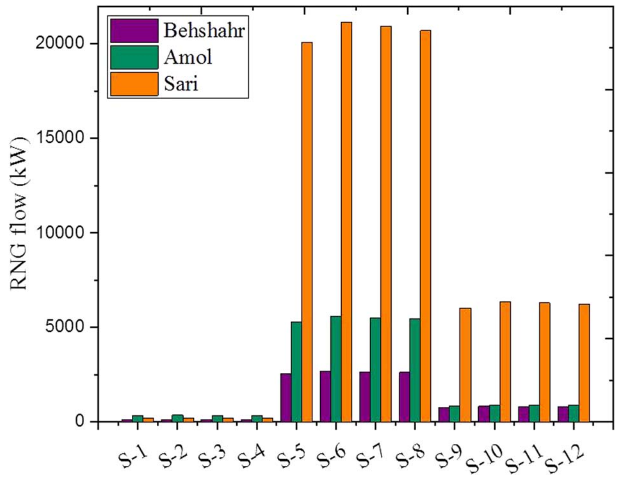

Figure 3. *The flow of RNG for all areas under proposed scenarios.*

Sari than in Amol and Behshahr. It is interesting to note that the RNG output in all cities based on the landfill gas input notably exceeds the potential of the other ones. Furthermore, the upgrading cycle under the chemical scrubbing (CSC) unit can address the maximum RNG output compared to other ones. In Sari, the RNG generation potential from landfill gas employing CSC unit is approximately 0.95–5.2% greater than using other ones.

3.1 Results of LCA-E

It is worth noting that the LCA-E takes into account 18 weights for the aggregation of the midpoint impact categories. These weights include depletion of stratospheric ozone (I1), global warming potential (GWP), ecotoxicity to fresh water (I6), marine & terrestrial ecosystems, land use, eutrophication of marine (I7) & fresh water (I5), human carcinogenic & non-carcinogenic toxicity (I8), terrestrial acidification, ozone formation affecting human health (I3) & terrestrial ecosystems (I4), ionizing radiation (I2), water (I9) & fossil fuels & mineral resource depletion and particulate matter formation, as referred to in Ref. [43]. The life cycle impact assessment under all proposed scenarios and midpoint impact elements are determined for areas (see Figure 4). It is worth noting that in all scenarios and for all areas, the largest impacts of all elements are related to human carcinogenic toxicity and eutrophication of fresh water.

The available evidence leads to the conclusion that the most significant impacts on the freshwater ecosystem and human well-being are from the various processes considered. The main contributors to these significant impacts are likely to be the emission of NOx to the atmosphere and the introduction of nitrates into groundwater sources via the stages of RNG generation. The results also suggest that the environmental impacts associated with the reduction of fossil and mineral resources are of minimal importance in all cases and in all geographical areas. To improve the accuracy of the analysis and to gain a more comprehensive understanding, the impacts on the three items of depletions of

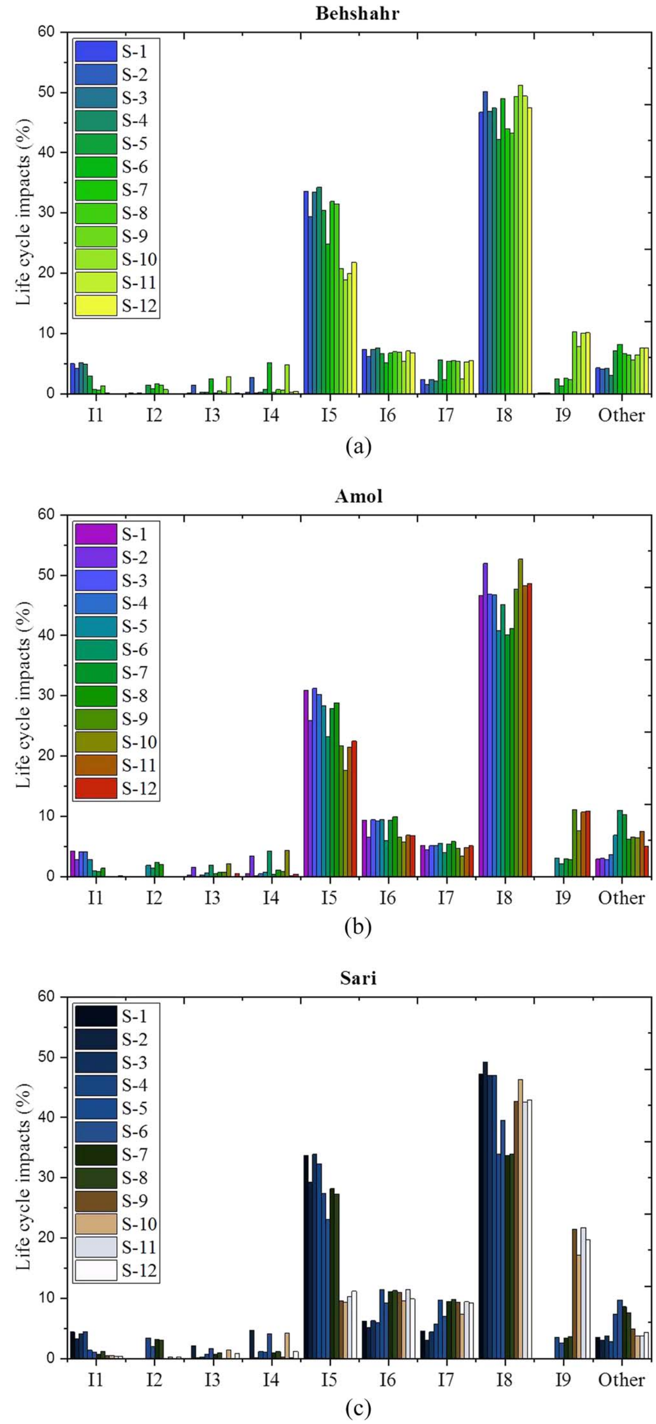

Figure 4. *The results of the life cycle impact assessment for different cities: (a) Behshahr, (b) Amol and (c) Sari.*

resource and their impacts on the ecosystem and human health are consolidated. Figure 5 displays the life cycle impacts on the combined items for all scenarios and for the areas considered. It is clear that the impact on human health outweighs the other two factors in all cases and in all three regions considered. The

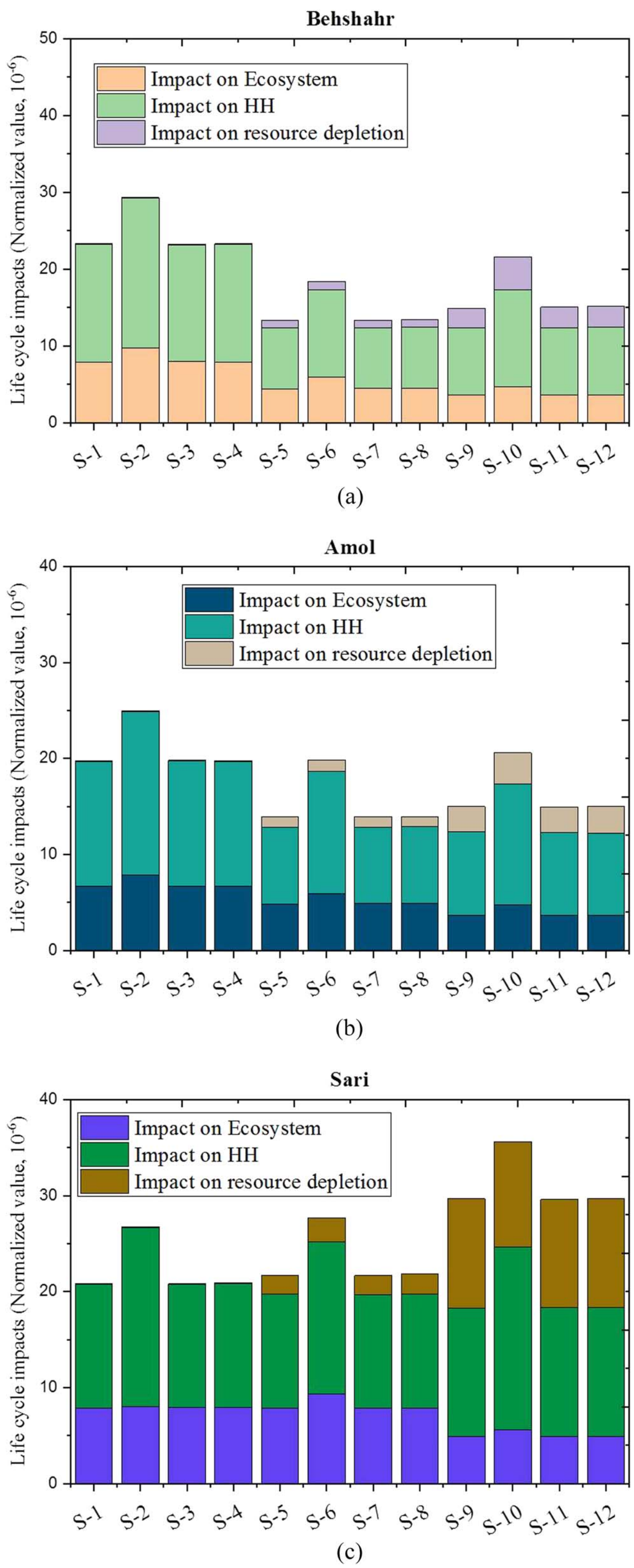

Figure 5. *The life cycle impacts on the combined items for all scenarios and for the areas considered: (a) Behshahr, (b) Amol and (c) Sari.*

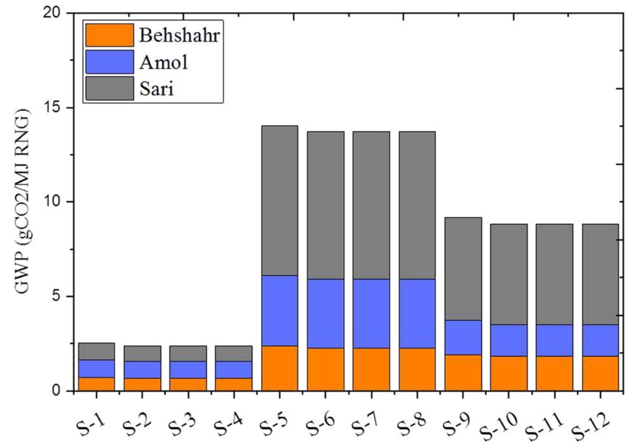

Figure 6. *GWP values under various scenarios cases for all areas considered.*

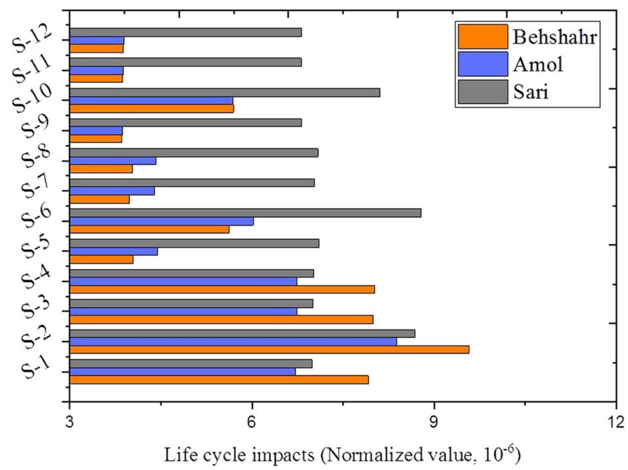

Figure 7. *The normalized impacts over the whole life cycle under all scenarios considered in the areas.*

graphs also show that among the range of biogas upgrading methods, chemical washing (using manure) had the most significant impacts on health of human (HH) at the Behshahr and Amol sites.

However, in Sari, the main impacts on HH are attributed to the SS utilization as a raw material. This phenomenon could be attributed to the significant contents of industrial and urban wastewater in Sari, corresponds to its higher population density compared to the other two regions. Under the visual representations, the combined three factors impacts in Sari associated with SS are ~32 and 29% higher than those associated with manure and landfill gas, sequentially. The depletion of resource impacts of manure and landfill feedstock are <10.5% of the overall environmental impacts. In general, across all areas, the impact on depletion of resource is lowest for manure feedstock and highest for SS ones.

GWP is a key parameter for assessing the environmental behavior of different NGFW routes. Figure 6 facilitates the comparison of GWP values for the suggested scenarios within all areas. It is clear from the data that the highest GWP values in all areas are

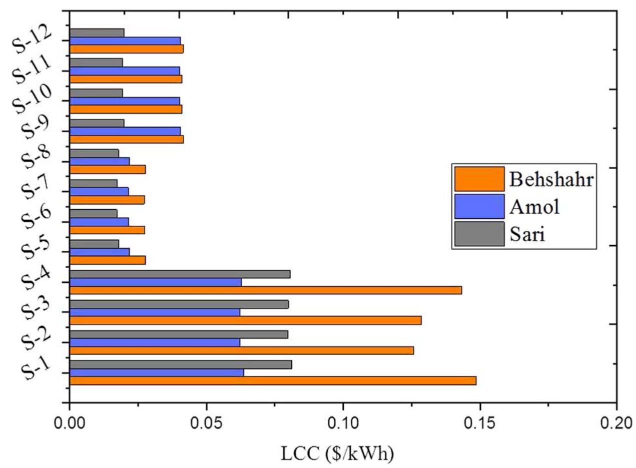

Figure 8. *The LCC estimates for all scenarios analyzed in the desired areas.*

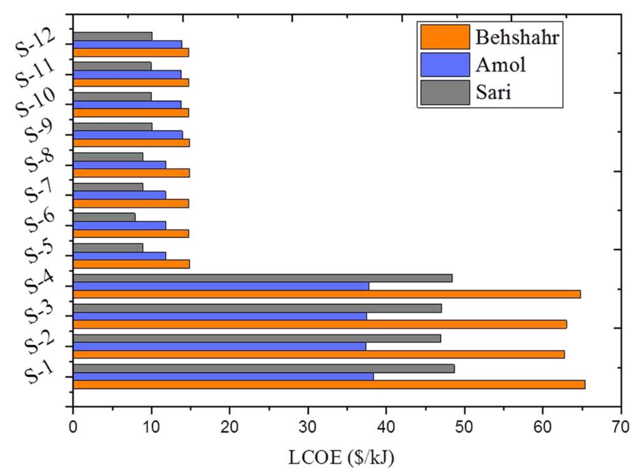

Figure 9. *The values of LCOE for all scenarios proposed in the desires areas.*

associated with scenarios involving SS and landfill gas. It is also obvious that the model of upgrading cycle does not have a notable influence on the GWP values. The peninsula's contribution to global warming from the use of AM is greater in Amol than in the other ones. A lower GWP value does not necessarily indicate lower impact and damage.

Figure 7 displays the normalized impacts over the whole life cycle under all scenarios considered in the areas. The graphs exhibit that the life cycle impacts of feeding manure exceeds that of the other feedstocks. The impacts of SS and landfill gas are near identical. Also, in terms of the upgrading cycle's model, CSC process has the highest life cycle environmental impact, while MSP has the lowest.

3.2 Results of LCA-C

LCCs include the projection of all capital and operating costs (such as construction, operation, grid feed-in, maintenance, etc.) associated with the NGFW routes over its lifetime. The LCC estimates for all scenarios analyzed in the desired areas are depicted in

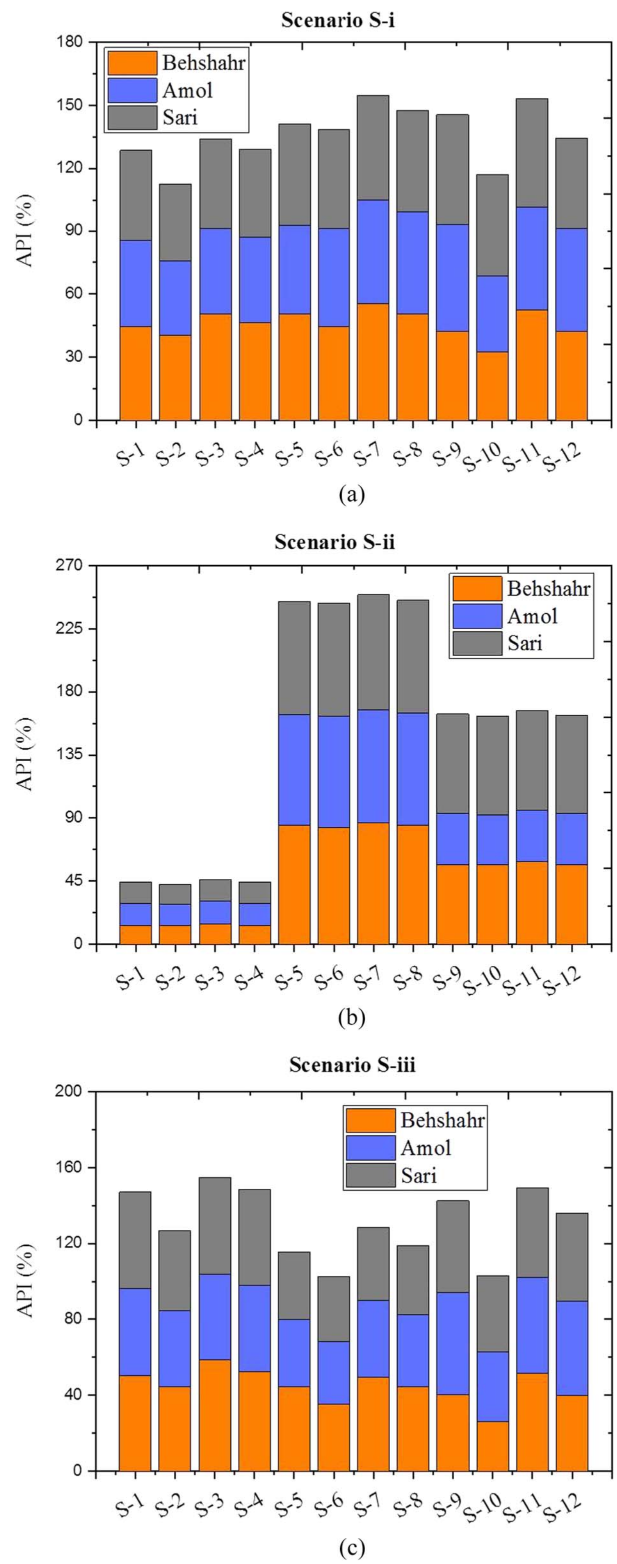

Figure 10. *The APIs for various scenarios proposed for all areas; (a) S-i, (b) S-ii and (c) S-iii.*

Figure 8. From the graphs, it can be concluded that the availabilities and abundance of the input feeds have a significant impact on the cost patterns of the NGFW processes. That's why the energy generation cost is lower in Sari, where there is a greater population and therefore a greater feedstock frequency. Nevertheless, the producing energy cost from AM is slightly higher in Sari than in Amol.

The levelized cost of electricity is a key factor in assessing the viability of a plant, as it exhibits the lowest selling price of RNG in comparison with similar technologies. Figure 9 illustrates the values of LCOE for all scenarios proposed in the desires areas. It is clear that an increase in renewable gas production capacity can lead to lower LCOE amount. Due to the lower potential of RNG output from manure feedstocks compared to other ones, the LCOE is relatively higher for scenarios based on this input feed. Further, the LCOE for scenarios under the manure-input feed is higher in Sari than in Amol and Behshahr. Further, the types of upgrading cycle do not have a significant influence on the LCOE and this factor is more influenced by the RNG generation potential.

3.3 Appropriateness of investment

The scenarios have been developed with different weightings, including a neutral scenario, a scenario prioritizing economic performance and a scenario prioritizing environmental performance. The scenarios are established to specify an optimum API. The APIs for various scenarios proposed for all areas are displayed in Figure 10. In S-i, the maximum API is associated with S-7 in Behshahr, reaching ∼55%. In a situation labeled S-ii (a scenario emphasizing economic criteria), the API could potentially enhance by ∼29% for the same situation. In contrast to the other two scenarios, the specific model of upgrading cycle does not have a notable influence on the API in the S-ii. It is also evident that cases associated with CSC technology for upgrading cycle result in comparatively lower APIs. In the S-ii, which focuses on SS as an input feed, the highest APIs are associated with the area of Sari, indicating the abundant availability of SS from the industrial and municipal wastewaters.

Accordingly, within the S-i and S-ii scenarios, the preferred and advantageous choice involves the NGFW routes under the landfill gas-input feed and the PSA-based upgrading cycle. This result can be characteristic via the increased cost effectiveness of the mentioned route, resulting in a comparatively high output due to minimal losses of methane, as supported by [58]. In contrast, within the S-iii scenario, the preferred and advantageous pathway is the NGFW route under the manure and the PSA-based upgrading cycle. The rationale behind this choice is the limited amount of the manure-input feed available, results in less environmental crisis. Therefore, the NGFW routes under manure-input feed have the lowest impacts on GWP. In addition, the large-scale design of such pathways can be challenging due to locational and geographical constraints, particularly in terms of abundant access to feedstock. Therefore, the availability of feedstocks plays a critical role in determining the high API. The outcomes of the offered decision-making technique can offer various finance approaches to satisfy the diverse needs of stakeholders. Furthermore, as the API varies by area, the outcomes can be extrapolated by adjusting for geographical data.

4 CONCLUSIONS

It is fascinating to read about the development of structural considerations within gas networks in your article. The comparison and prioritization of various feasibility scenarios for NGFW plants using various routes and waste feedstocks is an important contribution. This type of analysis is crucial for advancing sustainable and efficient energy production. The primary objective of this research was to establish a decision framework and structure for conducting LCA (cost and environmental) to select the optimal course of action for the NGFW process. In addition, various multivariable decision scenarios were used to identify the most favorable approach to RNG production. These scenarios took into account various geographical data, access to various waste input feeds and interests of stakeholder. Based on this, this study presented a novel framework for determining the most advantageous approach to NGFW using an LCA and a multivariate decision technique. Importantly, this approach had not been previously documented in the existing publications. According to the findings, the volume of RNE flow in Sari exceeds that of Amol and Behshahr. Compared to alternative technologies, biogas upgrading using the CSC process offers the greatest RNG output. Of all routes assessed, the impacts on the freshwater ecosystem and HH are the most significant. In all scenarios and areas, the impacts on mineral and fossil resource depletion were found to be negligible. Similarly, the impact on ozone depletion is minimal. In addition, the specific model of upgrading cycle does not have a notable influence on the LCOE, which is more influenced by the RNG output level. The NGFW routes under the manure as a driver were found to have the lowest impacts on GWP. However, in this specific route, the RNG yield is lower compared to other ones.

AUTHOR CONTRIBUTIONS

Mobin Ghasempour Nejati (Methodology [equal], Project administration [equal], Writing—review and editing [equal]), Seyedeh Elham Kamali (Investigation [equal], Software [equal], Writing—review and editing [equal]), Mohamad Javad Zoqi (Formal Analysis [equal], Resources [equal], Writing—review and editing [equal]), Fatima Moayad Sami (Investigation [equal], Resources [equal], Writing—review and editing [equal]), Mohammed Kassim Al-hussainawy (Software [equal], Validation [equal], Writing—original draft [equal]) and Hadi Fooladi (Methodology [equal], Project administration [equal], Writing—original draft [equal]).

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