A novel Metric of Sustainability for petroleum refinery projects

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A R T I C L E   I N F O

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A B S T R A C T

Infrastructure projects will continue to be developed in the coming years, particularly in developing countries such as Iran. These projects can have major impacts on all three pillars of sustainability, i.e. social, economic, and environmental. Among these projects, energy as well as oil & gas projects can have an even bigger impact on all three pillars, in terms of magnitude and severity of the consequences. As such, energy and oil & gas projects are not only important from political and strategic point of view, but they are also of major significance when it comes to principles of sustainability. Therefore, it is important to introduce methods and solutions to improve the level of sustainability at which such facilities are designed, constructed, and operated. Although existing studies have suggested various methods to implement sustainable development principles in infrastructure projects, effective assessment of sustainability and proper definition of its indicators are scarce in this industry in general. Among oil & gas projects, Petroleum Refinery Industry (PRI) projects lack a reliable sustainability assessment system, although in practical terms, many elements of sustainability are incorporated in refineries nowadays.

This research aims to develop a sustainability assessment framework including proper indicators for such an assessment. This framework can serve as a reference for future research in PRI projects. Sustainability indicators in all three pillars of sustainability are consolidated and structured under the proposed framework, which is designed to deal with the complicated makeup and operation of oil refinery projects. This article presents a novel Metric of Sustainability (MOS), which can help the decision makers, most notably strategic managers, to properly set up the process for design, construction, and operation of new refinery projects or audit and appraise the operating ones.

Based on the proposed framework and the resulting MOS, a real refinery project is assessed according to the available data and required accuracy. The outputs are then presented in Fig. 3 for discussion. The results of this case study show that the environmental concerns are the most important issue in distillation units. Also, GHG emissions in the operating phase have the most adverse effect on the sustainability profile of the case refinery.

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1. Introduction

The concept of sustainable development is inherently complicated since it has different meanings for different people. Thus, different interpretations (in particular in multidisciplinary projects like PRI) lead to diverse types of research (Hall, 2006). As Norgard puts it:


Obviously, no single discipline’s perspective can ensure the overall realization of sustainability and sustainable development adequately.

Oil and gas projects and related industries are crucial when it comes to enhancing world’s economy and increasing national GDPs. Besides, due to its big economic impact, Oil and Gas Industry (OGI) is, quite frequently, a key player in politics and strategic...
decision making in governments. Despite this undeniable influence on economic development, OGI is also notorious for its environmental and social devastation, destroying habitats and adversely affecting the livelihood of communities living near operating plants or construction sites. The simultaneity of great economic benefit (in particular in the short-term), tremendous environmental damage and serious social upheaval (especially in the long-run), and complicated long-term fiscal matters, warrants more research on how to address sustainability concerns in OGI projects.

The contribution of this paper is to develop a comprehensive, integrated, and facilitated sustainability indicator framework for PRI and a novel sustainability metric that helps managers make better futuristic decisions. Also, this framework and MOS will be the foundation for future studies in this regard. This study addresses the following questions, (1) What would be the sustainability indicators for a PRI with regard to three pillars of sustainable development, (2) What are the factors that could be used to represent the degree to which various indicators have been reached, (3) Considering the complicated and multi-disciplinary nature of PRI projects, how could we make sure that the set of indicators used for sustainability assessment are comprehensive and valid for PRI projects, (4) How can we measure the degree of sustainability for a given petroleum refinery, and (5) How could all of these steps be followed for a real refinery project.

2. Literature review

In the context of sustainability in OGI projects, a recent study was performed in order to incorporate sustainability elements and investigate opportunities and threats in an oil and gas company's settings (George, et al., 2016). Other studies have noted rising expenditure on activities related to sustainability matters such as environmental remediation and industrial energy management among petroleum firms located in the US (Verdantix, 2014). However, such increases in spending do not reflect a concerted effort to embrace sustainability, especially as new cost-effective methods of extracting unconventional reserves adversely impact the environment and have made renewable energy less competitive (Lozanova, 2014).

In recent years, OGI companies have been accused of ‘green-washing’ in their marketing campaigns and corporate reports (Pulver, 2007). OGI companies generally perceive that incorporation of sustainability and long-term thinking into OGI operations, would result in reducing their profitability. Thus, giant OGI companies prefer to spend their budgets on competitive investment opportunities. Consequently, they mainly concentrate on developing other cleaner ways of using fossil fuels, such as carbon capture and sequestration (CCS) technology rather than renewable energies such as wind, solar and hydropower which are not economic (Webb, 2009). In view of human dependence on non-renewable energy, which leads to the oil industry's continued existence, any effort to reduce the negative impact of such a destructive industry, however minimal, should not be undermined (George et al., 2016).

Among various OGI sectors, PRI is a key sector, as it provides the vital commodities for transportation, buildings, and other industries. In terms of employment, in the European Union alone, 140,000 people are directly employed on PRI facilities, and another 600,000 are involved with the distribution and sale of products; also many more have jobs that are indirectly related to PRI (Brussels, 2015). Besides, PRIs are important contributors to GDP, high-skill jobs, technical know-how, etc. which are valuable, integrated parts of the industrial supply chain. Across the EU, the sector generates 23 billion Euros a year of added value and 270 billion Euros in revenue from fuel taxes (Brussels, 2015). Beyond transport fuels, PRI products are used as feedstock for further downstream processes that contribute to a wide range of products that we use in our everyday lives. For instance, PRI products are used as plastics in packaging, as synthetic fibers in clothing, as detergents in domestic cleaning, and as agricultural fertilizers. Also, the close integration of PRI with sectors such as petrochemicals strengthens those valuable industries. Additionally, it is very hard to replace such products and their feedstock with valuable and sustainable alternatives. Thus, although this research is focused on PRI projects, it is related in many ways to OGI projects in general.

Due to negative sustainability effects, in particular, environmental and human lifestyle impacts in the vicinity of the construction sites, as well as long-term economic problems due to safety and maintenance costs, OGI is intrinsically an unsustainable industry. Therefore, in this research, when we talk about cradle-to-grave and life-cycle sustainability assessment, the goal is to minimize the negative repercussions an oil refinery project could have on the environment and a country's social and economic sustainable development. With that in mind, strategic decisions of OGI development projects can be made by considering all aspects of life-cycle sustainability.

2.1. An overview of PRI sustainability

This review will constitute general review of sustainability aspects of PRI addressed by various researchers, as well as compilation and screening of sustainability indicators introduced and/or used in previous research, covering all three pillars of sustainability individually and as a whole. The latter part, i.e. the compilation of indicators, will serve as a prerequisite to establishing the sustainability indicator framework that will be pursued in section 3, and development of the Metric of Sustainability that will be presented in section 4.

According to our literature review, a variety of studies have been carried out regarding sustainability in energy and electricity production. For instance, various electricity production scenarios were investigated and compared in terms of their whole life cycle in order to achieve the target 80% GHG reduction until 2070 in the UK (Stamford and Azapagic, 2014), Felix and Gheewala (2012) evaluated the environmental impact of electricity production in Tanzania with a life-cycle approach, and predicted milestones in subsequent years where significant increases would occur in such environmental impacts. Besides, energy sustainability was monitored with an indicator-based methodology in Greece (Angelis-Dimakis, et, al., 2012). This methodology also was used in order to build a sustainability self-regulated system for urban assessment (Hiremath et al., 2013). Furthermore, energy sustainability in sewage treatment projects is studied with sensitivity analysis and comparative studies (Halaby et al., 2017). Besides, as the relationship between the environment and technology is, however, complex and paradoxical (Grübler, 1998; Grübler et al., 2002), sustainability of technology is also assessed with a conceptual framework based on dynamic system approach (Musango and Brent, 2011). All in all, OGI projects/plants, although being important parts of energy production and electricity supply chain of industries, they have large negative impacts on sustainable development and its environmental aspects in particular. Since this article is focused on PRI projects, and due to complex and multidisciplinary nature of such projects, a comprehensive literature review has been performed, in order to ensure the proposed list of indicators that will serve as the basis for the proposed MOS is comprehensive. In addition to indicators, we have also identified various factors for each indicator, which can be used as tools to gauge the level of realization of each indicator.

Energy and environmental issues are always of prominence to
both citizens and their governments (Cucchiella and D’Adamo, 2013). The more primitive societies and their technologies were powered by renewable energies like wind, water, and wood. In contrast, modern technologies are predominantly powered by nonrenewable energies like oil, coal, and gas. Moreover, the total amount of energy in the universe is constant and we have to take into account that the rapid use of finite resources and energy supplies would definitely be an important concern.

Petroleum and its most derivatives such as gasoline, kerosene, diesel, etc. are among the most prominent and widely used types of fossil fuel. The realization that fossil fuel resources required for the generation of energy are becoming scarce and that climate change is related to carbon emissions to the atmosphere has increased interest in energy saving and environmental protection (Vine, 2007). On the other hand, petroleum refineries are mega projects and so complex and costly. Hence, the strategy is to reduce negative effects (greenhouse gas emissions, environmental contaminants, safety hazards, etc.) and increase positive ones (Profit, Green economy, human health, biodiversity, etc.) simultaneously (Mahmoud and Shuhaimi, 2013).

Silvestre studied two important problems in the offshore oil and gas industry; namely “lack of uniformity” and “inefficient enforcement”, and offered some recommendations (Silvestre and Gimenes, 2017). Clancy proposed a weighing and multi-criteria decision analysis (MCDA) for assessing and comparing petroleum vs. wood-based materials (Clancy et al., 2013). Also, Hadidi developed an optimization model that identifies the best gas emission mitigation technology with minimum cost for oil refineries (Hadidi et al., 2016). Some other studies, regard petrochemical projects as an alternative and by using questionnaire surveys and different optimization algorithms evaluate the alternatives (Heravi et al., 2015). However, as it is mentioned before, PRI projects are complex and we would not be able to consider them as a simple alternative. Thus, it’s important to clarify what the intended purpose of an alternative is. This research proposes three levels for data gathering, i.e. Level 1 which is at the level of utility and process, Level 2 which is at the level of refinery units, and Level 3 which is at the level of refinery components. These levels will be based on the current phase of the project which managers want to make decisions, the level of data which is available and measured, and the level of authority that auditors have in the project. These three levels of data gathering make three different frameworks with different levels of accuracies. Finally, combining measurement tool with the level of data availability will result in the sustainability framework.

2.2 PRI sustainability indicators

The majority of previous research on sustainable development is carried out based on three pillars of sustainability (Environmental, Social, Economic), which dates back to UN Conference in Rio de Janeiro in 1992. Sustainable development of energy and water projects has been perceived as strategic and important and previous research in this field can be categorized into four main groups (Duic et, al. 2015):

- Energy issues, which are considered in energy systems and power generation particularly in buildings
- Water issues, which are mainly water scarcity, relations between energy and water, and wastewater treatment
- Environmental management
- Sustainability methods and schemes

Indicator-based sustainability assessment is an appropriate methodology in order to ensure the comprehensiveness of the assessment. As an example, an indicator-based framework was proposed for sustainability evaluation of geothermal energy projects (Shortall et al., 2015). Also, indicator-based systems as a self-regulated system that integrates development and environment protection is widely used for sustainability assessment of cities (Hiremath et al., 2013).

For sustainability appraisal in complex systems like the ones commonly seen in OGI, Indicator-based approaches would definitely be useful. A major reference in this regard, is a technical report by United Nations Statistical Commission (UNSC) on the process for development of an indicator framework for the goals and targets of the post-2015 development agenda (UN, 2016). Sustainability factors derived from this reference, have been inserted with their corresponding code numbers in the following tables for easier reference. Moreover, emission estimation protocol for petroleum refineries which is developed by the US Environmental Protection Agency (EPA) was a primary tool in the environmental evaluation (EPA, 2015). Based on the cited information and using expert judgment via meetings with professionals in this field, the indicators and the related factors are developed in line with the requirements of petroleum refinery projects. Although there is sometimes a considerable overlap between indicators and their corresponding factors, in this study, for the sake of simplicity in the complex environment of petroleum projects, in such cases the item has been allocated to the closer side, either as an indicator or as a factor.

2.2.1. Environmental indicators

Perhaps the most important indicator category in sustainability studies, which has been regarded as a core in previous studies is the environmental indicator category. As an example, Jovanovic used US’s EPA TANKS software in order to develop a comprehensive model for tank farm emissions. In particular, volatile organic compounds (VOCs) were investigated among other environmental concerns (Jovanovic et al., 2010). Another piece of work was carried out to investigate possibilities to reduce CO2 emissions within the Swedish petroleum refining sector and to estimate the related costs (Holmgren and Sternhufvud, 2008).

Gas emissions from PRI facilities often contain groups of highly reactive gasses as defined by the National Ambient Air Quality Standard (NAAQS) (US EPA, 2015; Hadidi et al., 2016). PRI facilities are major contributors to Green House Gas (GHG) emissions, toxic chemicals, ambient particulate matter, Noise effects, industrial sewerage, land and natural resource degradation, bio-contamination, and many other negative effects. In this research, environmental indicators are divided into four major categories which are as follows:

- Atmosphere
- Water (Fresh Water, Ocean, Sea, Coast)
- Land & Soil pollution
- Natural Resource
- Biodiversity

Upon listing of indicators, corresponding factors were determined based on a comprehensive literature review. These factors are presented in Table 1.

2.2.2. Social indicators

Sustainable development is defined as “The possibility that
human and other forms of life will flourish on the Earth forever” (Ehrenfeld, 2004). Hence, every development needs to satisfy human needs and sustain social development in the first place. From this perspective, every construction projects, and OGI and PRI projects in particular, are developed to satisfy different human need. Besides, it has been found that with growth of sustainability scope and framework, the social dimension of this framework lacks increasingly the scientific basis as well as operational considerations; and thus needs further development (Missimer et al., 2016a, 2016b). What is certain is that, development of these projects must not result in human difficulties and unsustainability in social development.

Herein, factors of social sustainability are first defined using United Nation’s 2015 indicators (UN, 2016), and then interpreted according to PRI projects needs and requirements. For instance, “Frequency rates of fatal and non-fatal occupational injuries and time lost due to occupational injuries by gender” with the code number of 8.8.2 in UN’s indicators published in 2015, was customized to “Frequency rates of fatal and non-fatal occupational injuries”. Furthermore, other studies in this regard are investigated to ensure the comprehensiveness of the social factors defined for every indicator.

This research aims to categorize social sustainability into five indicators which are as follows:

- Poverty & Equality
- Health
- Safety & Security
- Education
- Welfare

Furthermore, a variety of factors by which above-said indicators can be assessed is defined in Table 2.

### Table 1

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Source</th>
<th>Code</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>SDG-UN-2015</td>
<td>2.4.1</td>
<td>Emissions of greenhouse gases per ton of refinery product (CO2, CH4, N2O, HFCs, CCl4, CH3CCl3, CCl3F, CF2Cl2, C2Cl3F3)</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>7.a.1</td>
<td>Net carbon intensity per kilowatt electricity production</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>11.6.2</td>
<td>Level of ambient particulate matter per ton of refinery product</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.4.1</td>
<td>Level of hazardous chemicals(HAPs) and wastes per ton of refinery production</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.4.2</td>
<td>Levels of selected contaminants in air caused by to refinery operation: Acid Gas (SOX, NOX), VOCs, CO, Ozone, Hydrocarbons, H2S, NH3</td>
</tr>
<tr>
<td></td>
<td>Shen, 2010</td>
<td></td>
<td>Level of noise pollution due to project/plant construction/Operation</td>
</tr>
<tr>
<td>Water (Fresh Water, Ocean, Sea, Coast)</td>
<td>SDG-UN-2015</td>
<td>6.3.1</td>
<td>Percentage of wastewater safety treated to standard levels: Cooling Water, Process Water, Sanitary Sewage water, Storm Water</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>6.4.1</td>
<td>the proportion of wastewater contamination in the refinery output to absorbable pollution by water resource (sea, river, etc.)</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>6.4.2</td>
<td>the refinery efficiency in water resource usage</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>6.5.1</td>
<td>Level of integrity in water resource management in different process units</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>14.3.1</td>
<td>Average acidity (pH) of the water resource and water stress value</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.4.2</td>
<td>Average levels of contaminants in water per ton of refinery production (BOD)</td>
</tr>
<tr>
<td></td>
<td>Hall-UNCSD</td>
<td></td>
<td>Number of local households and businesses affected by water contamination</td>
</tr>
<tr>
<td></td>
<td>Hall-UNCSD</td>
<td></td>
<td>Annual withdrawal of ground and surface water as a percentage of refinery demanded water separately</td>
</tr>
<tr>
<td>Land &amp; Soil Pollution</td>
<td>SDG-UN-2015</td>
<td>11.6.1</td>
<td>The amount of solid waste produced by refinery per ton of production</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.5.1</td>
<td>Per capita waste generation (in kg) for refinery employees</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.5.2</td>
<td>Recycling rate and percentage of industrial waste reuse</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>15.3.1</td>
<td>Level of soil degradation due to construction/operation of the project/plant</td>
</tr>
<tr>
<td></td>
<td>Hall-UNCSD</td>
<td></td>
<td>Residence status of the project area (the number of households within a radius of 50 km)</td>
</tr>
<tr>
<td></td>
<td>Shen, 2010</td>
<td></td>
<td>Level of Protection to landscape and historical sites</td>
</tr>
<tr>
<td>Natural Resource</td>
<td>SDG-UN-2015</td>
<td>7.1.2</td>
<td>The extent to which the refinery can satisfy the demand of “non-solid fuel”</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>7.2.1</td>
<td>Renewable energy share in the total energy of refinery final energy consumption</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>7.2.2</td>
<td>The extent of documentation issued in the refinery project/plant on the utilization of renewable energy</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>8.4.1</td>
<td>Indicator of crude oil efficiency (ratio of crude oil to product)</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.2.1</td>
<td>Percentage of electricity demand of the refinery which is accommodated by the crude oil in the refinery processes</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.2.2</td>
<td>Percentage of required refinery procurement with approved LCA sustainability assessment documentations (Equipment, material, etc.)</td>
</tr>
<tr>
<td></td>
<td>Hall-UNCSD</td>
<td></td>
<td>Certified wood used in construction/operation of refinery project/plant</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>SDG-UN-2015</td>
<td>14.3.2</td>
<td>Level of damage to the flora by refinery construction and operations</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>14.4.1</td>
<td>Level of damage to fauna by refinery construction and operation</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>15.1.2</td>
<td>Percentage of vegetation coverage in the refinery site and local region</td>
</tr>
</tbody>
</table>

2.2.3. Economic indicators

Petrochemical industries have a tendency toward production cost reduction and increase in or consistency of the quality of the products simultaneously. Also, an important economic concern in today’s market with the high variability of energy prices, is the lack of reliability in earning estimations (Neels, 2008) which will complicate the economic situation in PRI projects. Furthermore, the economy depends heavily on the international political strategies and consequently, an unstable economy with many complications. Also, an important economic concern in today’s market with the high variability of energy prices, is the lack of reliability in earning estimations (Neels, 2008) which will complicate the economic situation in PRI projects. Furthermore, the economy depends heavily on the international political strategies and consequently, an unstable economy with many fluctuations, deeply affects availability of raw materials. On the other side, economic performance directly affects the availability of the petroleum products which will add to its complexity.

OGI projects are economically fascinating projects and governments are always looking forward to finding an opportunity to develop a new project if applicable. In this regard, US petrochemical industry, for instance, employs nearly 160,000 people and
generates product shipments and value added of $83.2 billion and $88.5 billion respectively (Neelis, 2008). Thus, every owner and operator in this industry seeks to reduce costs, boost profit margins, and enhance product quality.

In this research, five indicators are introduced for economic development as follows:

- Energy consumption
- Financial
- Economic Performance
- Occupation
- Earning

Due to vast economic effects, its significance, and complexity, a variety of quantitative factors is allocated to every introduced indicator (Table 3).

### 2.3. Level of accuracy

The petroleum derived from crude oil fields is always transported to crude oil storage tanks or directly to refineries by pipeline or shipping. Next, the crude oil transported from the oilfields and storage tanks to the refineries is converted to refined products such as gasoline or petrol, kerosene, jet fuel, diesel oil, heating oil, fuel oil, lubricants, waxes, asphalt, natural gas, and LPG. Subsequently, the refined products are transported to destinations via different modes of transportation.

PRI is at the core of the above-said process. Sustainability assessment, optimization of Process, and choosing the most environmentally and socially friendly options with greener economic attributes will be ensured by quantitative evaluation of indicators. The main question in this regard, is how a complex alternative for a PRI project can be thoroughly illustrated and quantitatively assessed in the framework of indicators while the proposed framework needs a large amount of information and that may not be prepared or gathered shortly. This will depend on the amount of information and/or data which is available in the current phase of the project. The more information is provided as input, the more accuracy and detail will be achieved in the outcome of the assessment. For instance, seeking information in the first phases of a project, will not result in accurate and detailed information. Hence, the assessment has to be used with a lower level of accuracy. Or if the necessary information in a refinery were not available and needs to be collects later, the assessment accuracy level should be lowered as well. To facilitate the assessment process, this study proposes three levels for PRI projects (in order to measure indicators and related factors for them). These levels are:

- Level 1- Utility & Process: All in all, petroleum refineries are made up of different parts which are either producer or consumer of energy and utility. The utility is considered to represent the portions that produce energy, while the process is considered to represent the areas that consume energy. Therefore, all of the sustainability factors are defined as consumers and producers of a petroleum refinery as a whole.

- Level 2- Refinery units: A petroleum refinery is a collection of units which, from an operating standpoint, has the biggest impact on the sustainability outcome of the refinery. Thus, if we are in the operating phase, this level is recommended. These units are defined below:

- Desalter: this is a processing unit in an oil refinery that removes salt from the crude oil. (Depending on the quality of the crude oil, this could be optional in certain circumstances)
- Distillation: atmospheric and vacuum distillation units are processing units in which desalted crude oil is separated to different derivatives by a process of heating and cooling
### Economic factors.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Source</th>
<th>Code</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption</td>
<td>SDG-UN-2015</td>
<td>7.3.1</td>
<td>Achievement rate of the designed energy usage in the operation phase</td>
</tr>
<tr>
<td>Financial</td>
<td>SDG-UN-2015</td>
<td>7.3.2</td>
<td>The efficiency of electricity production in the refinery (output to input)</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>7.b.1</td>
<td>The economic energy efficiency in the refinery (the economic return per unit of energy consumed)</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>9.4.2</td>
<td>Required energy intensity per unit of value added</td>
</tr>
<tr>
<td></td>
<td>Shen, 2010</td>
<td>7.a.2</td>
<td>The foreign direct investment (financing) or mobilizing domestic financial resources in order to achieve more advanced technologies and cleaner fuel production</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>7.b.2</td>
<td>The level of international cooperation in the refinery project in order to facilitate access to clean and sustainable energy that is consumed in the project</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>9.5.1</td>
<td>Number of man-hours in the research and development in order to promote technologies in clean energy utilization in the refinery project/plant construction/operation</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>9.a.1</td>
<td>Investment program (Annual credit flow) in the refinery project</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>9.a.2</td>
<td>Percentage of financiers on the short list who are interested in participation and are willing to pay for the refinery project</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.a.1</td>
<td>Amount of spending on R&amp;D by owner to achieve sustainable production and consumption in the Refinery Project</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>12.a.2</td>
<td>The amount of reward which is intended in the contract to cover costs of patent in sustainable production and consumption of refinery project</td>
</tr>
<tr>
<td>Economic Performance</td>
<td>SDG-UN-2015</td>
<td>8.1.1</td>
<td>Level of refinery participation in increasing GDP</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>8.1.2</td>
<td>Level of refinery participation in inclusive wealth</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>8.2.1</td>
<td>Growth rate of GDP per capita per employed person in the refinery</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>8.2.2</td>
<td>Export diversification of the refinery products in terms of products and markets</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>13.1.2</td>
<td>Amount of financial losses due to climate change and natural disasters risks in the refinery project/plant</td>
</tr>
<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>9.2.1</td>
<td>Percentage of growth in GDP per capita by the refinery among other available alternative projects</td>
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<tr>
<td></td>
<td>SDG-UN-2015</td>
<td>9.2.2</td>
<td>Ratio of created jobs in the refinery project/plant to job opportunities in other available alternative projects</td>
</tr>
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<td></td>
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<td>SDG-UN-2015</td>
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<td>The financial and time losses resulting from accidents in the refinery project/plant</td>
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<td>1.3.2</td>
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</table>

- Unifiers: Different type of unifiers may be utilized in a petroleum refinery by which the distilled oil will enhance its quality by lowering its detrimental environmental and health impacts but with an expensive initial cost.
- Buildings: industrial and non-industrial buildings are of secondary importance among other units. Because they consume and produce energy, utility and emissions far less than other units. So, this research considers the sustainability of refineries regardless of buildings.
- Storage tanks: Tanks play an important part in a petroleum refinery plant. However, they are like buildings in sustainability studies. Thus, they are eliminated from the study as well.

Level 3- Refinery Components: A petroleum refinery plant is a collection of thousands of components which altogether make up the whole refinery. These components are divided into the following categories:

- Structural components (ST): backfill Material, formwork, concrete, rebar, anchor bolts, steel structure, etc.
- Mechanical components (MD): Drum, tower, exchanger, tube, heater, tank, air cooler, filter, etc.
- Rotary Equipment’s components (RE): Pump, Compressor, Dryer, Power generator, HVAC equipment, etc.
- Piping Components (PI): Cap, collar, reducer, pipe, elbow, flange, gasket, spacer, valve, tee, etc.
- Electrical components (EL): Continuous loads, Standby loads, and intermittent loads (these components are mostly utilities)
- Instrument components (IN): control valve, hand switch, high alarm, positioner, level gauge, level indicator, etc.

There are some other components, e.g., fire stationary and mobile equipment (HSE components) which are not included in this study. The whole process of level 2 and 3 are depicted in Fig. 1. The more detailed information is available; the higher accuracy level shall be chosen. As we go from level one to three, the amount of information is deepened. Thus, with regard to the level of available information, level of accuracy shall be chosen.
3. The framework of indicators

Rapport et al. believed that a proper economic analysis would need to consider the monetary value of environmental benefits (Rapport et al., 2008). As a consequence, a petroleum refinery evaluation particularly in the first phases of a project, would not only have to assess the financial results of the investment in its traditional sense, and the efficiency of the production process, but the monetary value of environmental and social benefits has to be factored in as well. The huge cost of treatment for employees and locals especially in the operating phase due to illnesses caused by the refinery, as well as the increase in the cost of environmental decontamination from toxic air pollutants emitted by the refinery, are some examples of such environmental and social costs which have to be considered in a refinery project assessment.

Sustainability indicators under three pillars of sustainable development are defined and quantified with a variety of factors as shown in Tables 1–3. Consequently, based on indicators, factors, and the available/required level of accuracy, a specific framework for every PRI project will be organized in order to evaluate its sustainability. The general preference in makeup of this framework is to use a life cycle approach to sustainability evaluation, most preferably a cradle-to-grave approach; however, due to certain complexities inherent in this approach, we will sometimes resort to more simplified approaches such as gate-to-gate approach. For example, energy consumption rate is mostly relevant in operation and construction phases, or air pollution has the biggest impact in operating condition.

By the proposed framework, there could be a variety of methodologies that can assess the sustainability of PRI projects. Any methodology will put together a set of indicators that could be used by managers to reach proper decisions. In this research, a novel methodology has been used which is illustrated in the following section.

4. Metric of Sustainability (MOS)

The main question in sustainability assessment of PRI projects is how the sustainability framework which is comprised of different factors in diverse fields, and different units and measurement tools, could serve the purpose in an integrated way. We borrow from the approach that was introduced by Chong, in which he proposed a sustainability measurement tool for life-cycle assessment of waste-to-energy systems to ensure the integrity of the assessment (Chong et al., 2016). Accordingly, this study proposes a novel Metric of Sustainability (MOS) in order to seamlessly integrate inputs and to achieve reliable outputs, so that, it could be the basis for decision making in this industry.

For each sustainability factor, we can identify two limits. One is the maximum value, which is when the factors reaches the limit set by the relevant standard, which is called here $X_{\text{max}}$, and the second is the minimum value, which occurs when the factor reaches the ideal condition, defined by the industry’s best practices. For example, based on general and professional rules and regulations in PRIs, refineries have to keep their effluents and wastes below specific standard levels. Thus, keeping below the standard level, would be a prerequisite for each specific factor; this would be regarded as the maximum value for the factor in the proposed MOS. Also, the best scenario for every factor is identified based on the national and local ideal condition. This level is marked as the minimum amount for the proposed factor. As a result, factors can be normalized for every indicator, factor, and phase in the following way:

$$X_{1}^{p-j}(T) = F - \left( \frac{X_{\text{max}} \cdot X_{\text{min}}}{2} \right)$$  

For $P = 2.3$

$$X_{1}^{p-j}(T) = 1 - \left( \frac{F - \left( \frac{X_{\text{max}} \cdot X_{\text{min}}}{2} \right)}{X_{\text{max}} - X_{\text{min}}} \right)$$  

For $P = 1$

where:

- $F$: value for the factor in the current case;
- $X_{\text{max}}$: maximum value for the factor based on relevant standard;
- $X_{\text{min}}$: minimum value for the factor based on ideal condition;
- $i$: $i$th indicator, $i = \{1, 2, ..., I\}$;
- $j$: $j$th factor, $j = \{1, 2, ..., J\}$;
- $p$: $p$th Pillar of sustainability, $p = \{1$ for environment, $2$ for economic, $3$ for social$\}$;
- $T$: time and phase of the measurement or valuation, $T = \{1$ for pre-construction, $2$ for construction, $3$ for post-construction, $4$ for product lifecycle$\}$;
- $X$: Normalized factor;

Factors could be deterministic or probabilistic and as a result, the measurement tool has to be deterministic or probabilistic. The following formulas will sum up the values of factors for various indicators and phases for any of the three pillars of sustainability:

$$S_{p} = \begin{cases} \sum_{i=1}^{I} \sum_{T=1}^{4} \sum_{j=1}^{J} X_{1}^{p-j}(T) & ; \text{For Discrete values} \\ \int_{1}^{I} \int_{1}^{4} \int_{1}^{J} X_{1}^{p-j}(T) \, df \cdot dT \cdot dl & ; \forall p \in \{1, 2, 3\} \end{cases}$$
Sustainability pillar weights depend on many items such as political, market, technical, and technological matters. Thus, for any specific project, based on its specific properties, the weights of pillars have to be determined by a panel of experts. Based on expert opinion, the MOS will be calculated after incorporating the relative weight for each pillar of sustainability, using the following equation:

\[
MOS = \sum_{p=1}^{3} W_p \times S_p
\]

where:

\( W_p \): Weight for \( p \)-th pillar of sustainability;

Other critical factors, which can be helpful for decision makers are as follows:

\[
X_{p} = \left\{ \begin{array}{l}
X_{p}^i = \sum_{j} X_{p}^{i,j}(T) \quad \forall i \in \{1, 2, ... , I\} \\
\end{array} \right\} \forall p \in \{1, 2, 3\}
\]

\[
X_{p}^{i,j} = \left\{ \begin{array}{l}
X_{p}^{i} = \sum_{j} X_{p}^{i,j}(T) \quad \forall j \in \{1, 2, ... , J\} \\
\end{array} \right\} \forall p \in \{1, 2, 3\}, \forall i \in \{1, ... , I\}
\]

\[
X_{p}^{T} = \left\{ \begin{array}{l}
X_{p}^{T} = \sum_{j} X_{p}^{T,j}(T) \quad \forall T \in \{1, 2, 3, 4\} \\
\end{array} \right\} \forall p \in \{1, 2, 3\}
\]

Analytical outputs:

\[
\begin{align*}
Cr_{p}^i & = \max \left\{ X_{p}^i \right\} \\
Cr_{p}^{i,j} & = \max \left\{ X_{p}^{i,j} \right\} \\
Cr_{p}^{T} & = \max \left\{ X_{p}^{T} \right\}
\end{align*}
\]

where:

\( Cr_{p}^i \): Critical indicator in \( p \)-th sustainability pillar;

\( Cr_{p}^{i,j} \): Critical factor in \( p \)-th sustainability pillar;

\( Cr_{p}^{T} \): Critical phase in \( p \)-th sustainability pillar;

Also, interlinking statuses could be defined. For instance, what the important indicator in the construction phase is, or what the most influential factor in post construction phase is. Besides, sensitivity analysis for every factor, indicator, and phase could be done by the proposed approach as well.

5. Case study

The case study is a real heavy crude oil refinery project which is in the design phase. In this study, we cannot reveal confidential information, so we solely discuss the results and measurements. Since this project is in its initial stages, and detailed information about the exact components to be used is not available, the second level of accuracy which is refinery units is chosen to be followed in this case. Moreover, in this small case, no manufacturer, vendor, and contractor has got involved yet; therefore, Cradle-to-Gate studies are not applicable. Besides, the exact target product market and its destination have not been clarified yet. As such, Gate-to-Grave studies will have little accuracy and availability. Thus, the following refinery units are investigated for Gate-to-Gate assessment according to the proposed framework and MOS for the design phase alone, in order to reach meaningful results:

- Desulfurization
- Desalter
- Atmospheric distillation
- Vacuum distillation

The mentioned limitation and assumptions could compromise the comprehensiveness of the sustainability assessment tool, and the work needs to be improved as complementary data is gathered. However, this study was targeting the proper set up of the assessment methodology, and a complete and comprehensive assessment will be the subject of upcoming studies.

Gate-to-Gate assessment has its own association in decision making and different sensitivity analysis in order to achieve the best and sustain choices in design phase. Moreover, this assessment can assist designers in having a sustainability-based design.

5.1. Environmental specifications

There are many air pollutants during construction, including due to fuel consumption in construction equipment engines and excavation-backfill process, which creates significant amounts of airborne particles. During operation, air pollution is mainly due to furnace exhaust system and flare's stack. There are many airborne contaminants including, but not limited to, NOx, SOx, CO2, CO, TSP, etc. Noise creation is also a major problem, both during construction and during operation. Major sources of water contamination are leaking from equipment, sewage, as well as industrial and non-industrial wastewater. Furthermore, refinery products themselves tend to undermine sustainability. Thus, the level of damage to the environment should be considered in the life cycle of the products as well. In summary, refinery construction, operation, and products have a great environmental footprint.

In this study, all utilities (electricity, water, fuel….) required for each unit are taken into account. Also, the total effluent due to utility services and/or the operation of that unit is considered as its footprint. Besides, every unit has its share in the flare unit effluents as well. Therefore, in this case “Atmosphere” and “Water (Fresh Water, Ocean, Sea, and Coast)” are the prime indicators to monitor for environmental sustainability assessment. All in all, the

![Fig. 2. Selected factors for implementing the case study measurements.](image-url)
summary output for this pillar is presented in Fig. 3.

For instance, for the atmospheric distillation unit, according to Iran’s Environmental Protection Organization (IEPO), sulfur dioxide limit is 7.2 PPM, which represents the upper limit ($X_{\text{max}}$). However, project specifications don’t specify a best practice limit for that; therefore, lower limit ($X_{\text{min}}$) is set to be zero. Besides, as stated in the process design outputs, sour water from atmospheric column reflux drum (as one of the contributors to atmospheric column effluents) which at a normal continuous flow of $6.3 \left( \frac{m^3}{h} \right)$ with density of $974.1 \left( \frac{kg}{m^3} \right)$ contains 350 PPM of $H_2S$. Sour water will be routed to wastewater treating plant which is designed to thoroughly eliminate $H_2S$. Thus, at the end of the process, atmospheric column’s $H_2S$ output will be zero. Therefore:

$$X_{1}^{1-5}(2) = 1 - \frac{0 - \left( \frac{2}{7.2} \right)}{\left( \frac{2}{7.2} \right)} = 0$$

5.2. Social specifications

The local community in project area had a population of about 29,000, according to 2012 census. Also, literate population in the project vicinity is 86% and only 36% are economically active among which 31 percent have been working in industrial projects and the rest of the working population have worked in agriculture and service sectors. Estimated average human resource demand in construction and operation phases for this project are 4000 and 300 respectively. Hence, the project will have a great influence on local community’s employment rate.

In this study, as the project is in its first stages, some of the factors which are related to the construction and operation phases, like “Number of people having an accident in the project/plant” are not included. Two pivotal indicators in this pillar of sustainability, which are important at this stage, are “Education” (because of technical knowledge and know-how which could be learned or practiced during the project) and “Safety & Security” (because of design for safety based on existing procedures, standards, rules, and regulations). The results are summarized in Fig. 3.

For instance, based on previous experience, for the atmospheric column, 4000 man-hours is needed in the design phase. Thus, 4000 man-hours of engineers gain valuable experience and develop their knowledge. Besides, according to the EPA (Enterprise Process Assets), with the same productivity and quality, 5000 engineering man-hours could be allocated to the design of the atmospheric column at max. Also, best practices indicate that the minimum man-hour required for the design of the unit is about 3000, which will represent the lower limit. Thus, the corresponding factor is calculated as follows:

$$X_{2}^{4-1}(2) = \frac{4000 - \left( \frac{5000 \times 3000}{2} \right)}{\left( \frac{5000 \times 3000}{2} \right)} = 0$$

5.3. Economic specification

Forecasted investment in this project is more than $130 million with an internal rate of return of 33% and a payback period of 3 years. The construction phase will be finished in 3 years and the estimated operation phase is about 15 years with the capacity of 35,000 barrels per day of production. Obviously, the project is one of the contributory factors in the economic development of the project region and the country.

In this study, there are no international finances. Also, occupation and energy consumption status are indistinct and based on the estimations in preliminary studies and conceptual design phases. Thus, “Energy Consumption”, “Occupation”, and “Economic Performance” play the important roles in sustainable economic pillar in this project and during this phase. The results of the economic pillar are represented collectively in Fig. 2.

For instance, for the atmospheric column, a number of national and international vendors/manufacturers documents which should be issued is about 500 drawings or documents. If every document takes an average 50 man-hours to prepare and revise based on engineering comments, it will take 25,000 man-hours and about 30 vendors/manufacturers involved in the project in the design phase. Besides, according to the enterprise process asset, it could be at least 15,000 and a maximum of 30,000 (number of revisions to achieve agreement) with the same quality. Hence, the factor will measure as follows:

$$X_{3}^{4-1}(2) = \frac{25000 - \left( \frac{10000 \times 15000}{2} \right)}{\left( \frac{10000 \times 15000}{2} \right)} = 0.33$$

6. Conclusion

The case study result shows that in the abovementioned scope, assumptions, and restrictions as a whole, the refinery project is socially sustainable and environmentally unsustainable. It would be an important information which can help the managers with regard to other limitations and policies to make the best decisions.

The atmospheric and vacuum distillation units have the most

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2 Increasing the man-hour of the project will adversely affect sustainable economic development which would be measured in the economic pillar separately.
unsustainable environmental impacts among other units in the refinery project and have the most sustainable economic effects simultaneously. Hence, the country/region priorities will justify the tradeoff between economic and environmental concerns. Atmospheric and vacuum distillations make the core in the refinery process by producing the main products of the refinery unit while desalter and desulphurization units are preliminary and somewhat expensive units. Also in this regard, in some other cases enhiners have not economic justification and postpone in the future development phases. Thus, these two distillation units have the sustainable economy and positive value in the assessment.

Moreover, refinery plant has a positive social sustainability impacts in different units due to education and training the new staffs, create a vast variety of job opportunities, etc. However, desulphurization unit is technology-intensive and new packages have to be check and train by designers, as well as operators. Hence, the indicator value in this unit is the highest value in the evaluation process. Besides, since desulphurization unit is one of the prominent contributors in enhancing the quality of the product and increase market share, if the product were included in the assessment process, desulphurization definitely would have a greater environmental sustainability impact.

The Proposed MOS is completely flexible to satisfy every standard and specification based on the governing policies and priorities, as well as contractual and other requirements. Also, categorizing a PRI project attributes into different levels and assigning every relevant feature to various categories, helps the researcher do a sensitivity analysis on one hand, and process design and optimization using sustainability-based methodologies on the other hand.

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