SUSTAINABILITY INDEX FOR A MANUFACTURING INDUSTRY: A CASE STUDY OF CEMENT INDUSTRY IN NEPAL

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Abstract

This paper addresses the gap in applying indicator-based approaches to assess sustainability at the industry level by developing a sustainability index specifically for the manufacturing sector. It incorporates four key factors: material supply, energy supply, socio-economic, and environmental aspects. The cement industry in Nepal, one of the most energy- and emission-intensive sectors, was selected as a case study to test the methodology. The sustainability index was validated by comparing it with trends in energy use, revenue, and production costs. The study revealed that variation in the overall sustainability index was driven by changes across the various indicators representing each sustainability factor. Findings also highlighted that even basic interventions like regular maintenance can lead to notable improvements in sustainability. The proposed approach provides a valuable tool for government bodies and regulatory agencies to assess industry performance over time, particularly when no predefined benchmarks exist. Additionally, the framework supports the setting, monitoring, and evaluation of targets aligned with UN Sustainable Development Goal 12, promoting sustainable production practices. This methodology could further aid in establishing standards and certification systems for sustainable industrial operations.

Keywords: Sustainability, Energy intensity, Sustainability index, Manufacturing industry, Cement industry

1. Introduction

Different factors act as the driving force while economic development through industrialization, notably, mechanization from steam energy in the 19th century, automation in the 20th century and sustainability factor in the 21st century. It has been reported that to implement sustainable production required for fulfilling the needs of the growing world population and maintaining the planet's ecological balance, there is a need for a significant reduction in energy use, material consumption, and environmental degradation of over 90 percentage by 2040. This is also referred as "factor 10 approach" indicating the use of only one-tenth of the present scale of resources for achieving the current level of industrial growth (O'brien, 1999). In order to achieve sustainable development, there is a need for a fundamental shift in the attitudes of governments, industries, and consumers. The Johannesburg Plan of Implementation, adopted by the United Nations in 2002, identified sustainable production as one of the major policy intervention measures for realizing sustainable socio-economic development thereby eradicating poverty and managing natural resources. The Rio Declaration on Environment and Development calls on nations to implement sustainable production for achieving sustainable development goals.

Sustainable production refers to operations intended to provide an item or service without negatively affecting society or the environment, including the principles of intra- and inter-generational responsibility (Habek and Lechowicz, 2019). Lowell Center for Sustainable Production, University of Massachusetts Lowell states sustainable production as the creation of goods and services using processes and systems that conserve energy and natural resources,

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non-polluting, economically viable, safe and healthful for workers, communities, and consumers, and, socially and creatively rewarding for all working people (Alayón et al., 2017; Veleva et al., 2001). It emphasizes considering the interdependence of the economic, environmental, and social systems while production and consumption of things (Alayón et al., 2017).

In line with this, UN SDG Goal 12 has emphasized ensuring sustainable production patterns by 2030 (UN, 2023). Likewise, UN SDG Goal 7 and beyond approach emphasized on productive end-use of modern and clean energy besides universal access for sustainable economic transition (World Bank, 2015). These days, the sustainable industrial methods have prioritized the environmental aspect in the pretext of national and international initiatives to follow low-carbon economic development path. Besides the low carbon economic transition can also results in several environmental, energy security and energy equity co-benefits which are of utmost importance, especially for the developing countries (Shakya et al., 2023). Infrastructure development is crucial for any economic development and transition.

Access to the energy and material resources required for the construction of infrastructures will play a major role in realizing the goal of economic transition. Cement is one of the major construction materials required for infrastructure development and its demand is increasing rapidly, mostly in developing countries, due to the rapid growth of the economy to attain the level of the developed countries and maintaining economic development in the context of the developed world (Shakya et al., 2022). Cement production is a highly energy-intensive process, making it a major contributor to sustainability challenges. In fact, energy consumption accounts for 50-60 percentage of the total production costs in the cement industry. Thermal energy, in particular, comprises 20-25 percentage of the energy used in cement production. As a result, the cement industry is particularly vulnerable to energy price fluctuations (Wang et al., 2009). As such, the conservation of raw materials and energy resources, as well as the abatement of CO_2 emissions are the major issues the cement industry is facing (Jokar and Mokhtar, 2018; P. Singh and Shakya, 2016). According to the United Nations Environment Program Report (Scrivener et al., 2018), the global demand for cement is increasing at an annual growth rate of about 6 percentage resulting about 6 percentage of global anthropogenic greenhouse gas (GHG) emissions. In the case of Nepal, demand for cement is increasing rapidly due to an increase in development works, reconstructions after the massive earthquake in 2015, and booming construction of residential and commercial buildings. The Nepalese industries have been able to fulfill the growing demand by increasing their existing production capacity and establishing new industries, some also through foreign direct investment (FDI). As an indicative example, the production of cement has increased by 150 percentage from the year 2014/15 to 2018/19 (Thakuri et al., 2021). This has raised concerns on the sustainability of the supply of the input resources for cement production as well as the potential environmental and socio-economic implications that may arise from this development.

1.1. Sustainable Production Representation

The definition of sustainable production (Veleva et al., 2001) presents a vision and long-term objectives for companies and industries to become more sustainable. While the vision that the definition tries to provide is being implemented, many companies don't have ideas on where they stand on the way of gaining sustainability in production. Because of this dilemma, there is a slow pace in gaining sustainability.

In order to know where an industry stands on the perspective of gaining sustainability, there must be some indicators defined, on which the company can know its performance and work on improving its condition. Use of performance indicators can serve as the means for the evaluation sustainable manufacturing practices in the manufacturing industries (Scrivener et al., 2018). Lowell Center developed a framework for indicators of sustainable production. Its purpose is to increase companies' understanding of the concept of sustainable production and promote its practical application (Alayón et al., 2017). Sustainability indicators and composite indices are increasingly recognized as a useful tool for policy making and review as well as for public communication in conveying information on countries and corporate performance (Thakuri et al., 2021).

1.2. Cement Production

Cement dominates the construction industry, which is responsible for the modification of infrastructure and the improvement of living standards (Rodrigues and Joekes, 2011). As the industrial and infrastructural sectors are the engines of progress, cement is essential for the nation's economic growth. In developing countries, there is a huge demand for infrastructure development, which is driving the demand for cement. The production of cement is associated with tremendous natural resource and energy consumption. However, limited availability of the required raw materials and energy resources as well as resulting environmental emissions have been a vital challenge the cement industry is facing (Jokar and Mokhtar, 2018). Cement is produced by grinding cement clinker along with gypsum to a specified fineness depending on the requirements of the cement consumers. Cement clinker is produced on a large scale by heating finely pulverized calcareous and argillaceous materials at 1400 °C in rotary kilns (Moumin et al., 2020).

As the Government of Nepal (GoN) works to increase access to education, transportation, health, and other basic infrastructures, the need for cement production in the country is growing. The manufacturing sector, dominated by cement, is considered to be the pillar of the country's economy. Central Bureau of Statistics (CBS) reports in 2022 indicated almost 10 percentage annual increase in the construction sector (GoN, 2022). As the government of Nepal strives to become a middle-income country by 2030, large investments in the cement sector are expected to meet the growing infrastructure needs caused by urbanization. Nepal, being rich in natural resources, has an abundant limestone reserve, providing an opportunity for the manufacturing industry like cement to flourish. At present, 55 cement industries are operational in Nepal: three are FDI based, two are government-owned, and the other 50 are locally and privately owned. Besides, two FDI-based industries are under construction. The cement industry had a total installed capacity of 15 million metric tons but only produced 7.5 million metric tons, which was less than the demand of 9.05 million metric tons in 2018–19 (Nepal Rastra Bank, 2021). The Global Cement Report – 15th Edition estimates the domestic cement demand of Nepal for 2024 as 8 million metric tons (International Cement Review, 2025). Although it might appear that Nepal is almost entirely self-sufficient in cement is a positive sign, the import of fuel and raw materials from other nations is making Nepal's cement industry less sustainable.

Gypsum, which accounts for 5 percentage of the cement, is one of the essential raw materials used to control the settling time of the cement and is imported from a third country like Bhutan (Nepal Trade Information Portal, 2023). Coal is an essential source of energy for cement manufacturing. As per the World Coal Organization, it takes about 200 kg of coal to manufacture a ton of cement (World Coal Association, 2023). Nepal is heavily reliant on countries like South Africa, Australia, and India for its coal demand. Also, energy consumption for Nepalese cement industries is around 156.08 kWh per ton which is more than the standard consumption of 105 kWh per ton. Similarly, for clinker-based production, thermal energy consumption is 5.411 MJ/kg, which is more than the global standard consumption of 3.138 MJ/kg as per the Ministry of Industry, Commerce and Supplies (GoN, 2019). The energy cost per unit production for Nepalese cement industries is 100 percent more than the international average (Shrestha et al., 2016). This raises the question of the sustainability of the cement manufacturing industry in Nepal. In this study, we have developed the sustainability index for the cement industries based on the availability of the data with the intention of knowing the level and trend of sustainability thus helping identify the policy interventions required for sustainable cement manufacturing.

2. Materials and Methods

Energy is used worldwide to identify the inefficiencies of the system (Arango-Miranda et al., 2018), but it lacks a proper index to identify the self-sustainability of the system. In this paper, we have developed a sustainability index to analyze the shelf life and future of the manufacturing industries. For the development of the sustainability index for the cement industry, the methodology has been divided into three stages. The available literature was initially analyzed, and the definition of sustainability and its indicators were identified. Second, based on the available data for a case study, indicators relevant to the cement industry were selected for analysis considering indicators for sustainable production from the Organization for Economic Cooperation and Development (OECD, 2023). Finally, a sustainability index was developed for a particular case study taking reference year as a base value.

2.1. Selection of Context-based Indicators and Derivation of Factors

From the literature review, four factors of sustainability are identified, and they are further defined by the indicators. The use of the indicators was supported by an examination of a limestone-based cement industry. The availability of data of the industry was considered while selecting the indicators for analysis. The indicators with numerical values are given priority for the development of the index. These indicators are selected since they can illustrate the level of existing sustainability and show the extent to which an industry is moving towards sustainable production practices. The major identified factors are energy supply sustainability, material supply sustainability, socio-economic sustainability, and environmental sustainability, as shown in the Figure 1.

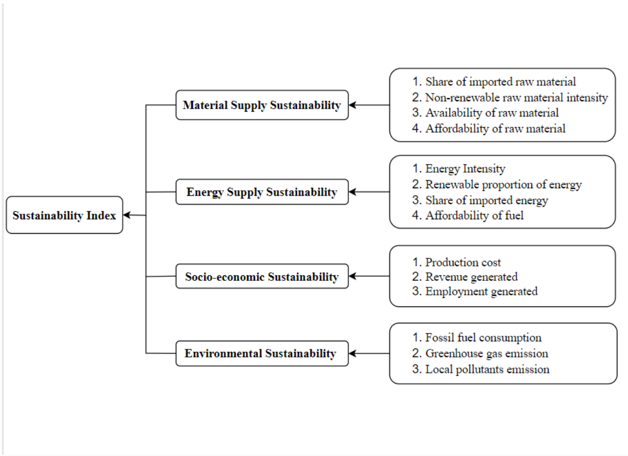

Figure 1. Development of sustainability index

2.2. Development of the Sustainability Index

The sustainability index is calculated by assigning equal weightage to each factor and indicator. The indicators were used to develop the value of the factors, and the factors later on paved the way for the sustainability index calculation. To integrate each indicator, the indicators were selected such that they represented the ratio making them unitless. For calculating the value of any indicator, a reference year was selected as a base year and value of the indicator for that year was assumed to be unity. The value of a particular indicator for the following years below unity recommends the poor functioning of the industry in the domain of that indicator where else the value of a particular indicator above unity recommends better performance. To calculate the value of each indicator for following years, the below mentioned formula in Equation (1) was used.

$$I_{\text{current}} = 1 + \frac{V_{\text{current}} - V_{\text{base}}}{V_{\text{base}}} \tag{1}$$

Here, sign convention is:

- Positive sign is used when the increasing value is desired in coming years.
- Negative sign is used when the decreasing value is desired in coming years.

For a particular industry, the desired value of indicators, factors and index as a whole for the following years is above unity. Below unity suggests that the manufacturing industry needs some renovation and upgrade to improve its sustainability for its long-term operation. Further, the validation of the obtained result is done with a case study of the cement industry in Nepal.

2.2.1 Material supply sustainability

The quantity of raw material imports defines the resource security of supply, which is one of the important parts of sustainable production. Higher imports may have a greater vulnerability to required materials supply due to a lack of domestic control in determining the price and quantity, geopolitical effects, transportation constraints and other cross-boundary issues. From national perspectives, importing raw materials can have various social, economic and environmental impacts, including impacts on employment as well as trade balance. Material supply sustainability i.e., raw material sustainability is defined by four indicators:

a) **Share of imported raw material**

Share of imported raw material indicates dependence of the industry to foreign suppliers which are prone to supply disruption due to cross-boundary control of its price and quantity and potential geopolitical events which the domestic market cannot have control. The share of imported raw material was calculated as shown in Equation (2):

$$S_{\text{imp}} = \frac{R_{\text{imp}}}{R_{\text{total}}} \tag{2}$$

b) **Non-renewable raw material intensity**

The use of non-renewable raw material is unsustainable in nature as its increasing use will result constraint on its supply due to non-replenishing inventory. High intensity of non-renewable raw material reduces the sustainability of the industry so it is considered as an indicator for material supply sustainability. It was calculated as shown in Equation (3):

$$I_{\text{nr}} = \frac{R_{\text{nr}}}{R_{\text{total}}} \tag{3}$$

I_{nr} = Non-renewable raw material intensity

R_{nr} = Non-renewable raw material per unit production

R_{total} = Total raw material consumed per unit production

c) **Availability of raw material**

Availability entails having ample resources available at all times as reserves (Sovacool and Mukherjee, 2011) so that there is no halt in the work due to the lack of resources. The availability of supply side information is presented in terms of reserves and its diversification trend (Martchamadol and Kumar, 2012) but the cement industry diversification in raw material is almost hard to imagine. For the quantitative approach in this study, the number of days availability of raw material in inventory has been consideration. The index value is calculated on the basis of average days availability of raw material in a year as shown in Equation (4):

$$A_{\text{rm}} = A_{\text{inv}} \tag{4}$$

A_{rm} = Availability of raw material

A_{inv} = Availability of raw material in inventory

d) **Affordability of raw material**

For a manufacturing industry, being able to produce products at the lowest possible cost, having stable resources is essential (Martchamadol and Kumar, 2012). The cost of raw material accounts a larger proportion of the production cost. Acquiring the raw material at the lowest cost increases the profitability of the industry making it more sustainable. So, the production cost is taken into consideration to examine the affordability of raw material as shown in Equation (5):

$$A_{\text{rm}} = C_{\text{rm}} \tag{5}$$

A_{rm} = Affordability of raw material

C_{rm} = Raw material cost for a bag of cement

2.2.2 Energy Supply Sustainability

Not only for any manufacturing process, the need for a stable supply of sufficient amounts of energy comes out on top of the list of priorities for any country (Šprajc et al., 2019). Energy supply sustainability can be defined in a variety of contexts and over time similar to the energy security (Ang et al., 2015). To define the term supply security the number of indicators can vary from single to many based on the condition and the context (Abdullah et al., 2020). There is no single indicator as the notion of energy security, as it is highly context dependent (Kruyt et al., 2009). As this study focuses on the energy supply sustainability of the manufacturing industry, only those indicators that have significance to the industry and that are quantifiable are selected.

a) **Energy Intensity**

Energy intensity, in simple terms, is defined as the amount of energy used to produce a given level of output or activity expressed as kilowatt hour per ton or KJ per ton in many industrial processes. A product's energy intensity is determined by the amount of energy needed to make a unit output, hence utilizing less energy to produce a product lowers the intensity. More efficient technology, energy recovery in the same process or further use of waste energy in different processes, increased energy efficiency, or optimized operational practices can all contribute to reduced energy intensity (R. K. Singh et al., 2012) in a manufacturing process. A reduction in energy intensity of the energy intensive industrial sector would significantly reduce the greenhouse gas emissions caused by the burning of fossil fuels and the production costs associated with energy use (Bühler et al., 2018). Reduced energy intensity means consuming less energy and driving industry towards a sustainable production. For the index calculation in this study, energy intensity represents both the thermal and electrical energy consumed during a manufacturing process converted to a single unit i.e., kilojoule per metric ton Equation (6).

$$E_{\text{int}} = \frac{E_{\text{th}} + E_{\text{el}}}{P_{\text{cement}}} \tag{6}$$

E_{int} = Energy intensity

E_{th} = Thermal energy consumed

E_{el} = Electrical energy consumed

P_{cement} = Cement production (per ton)

b) **The renewable proportion of energy**

Based on any manufacturing process, both the renewable and non-renewable energy can be consumed as needed. The use of renewable energy improves the sustainability of the industry increasing the availability and access of energy resources. Higher proportional of renewable energy is desired in any manufacturing process. In this study, the renewable proportion of energy was calculated as in Equation (7):

$$R_{\text{prop}} = \frac{E_{\text{ren}}}{E_{\text{total}}} \tag{7}$$

R_{prop} = Renewable proportion of energy

E_{ren} = Total renewable energy consumed per unit production

E_{total} = Total energy consumed per unit production

c) **Share of imported energy**

The percentage import of fuel is a major indicator for mapping sustainable production (Wang et al., 2009). The increase in the percentage of fuel imports may increase the cost of production leading to higher prices for products. The issue of energy import is also associated with the energy supply security of the industry due to long lead time, transportation and other geopolitical constraints. In this study, the imported electrical energy from India is also taken into account to determine the share of imported energy. The indicator is estimated as follows Equation (8):

$$S_{\text{imp\_energy}} = \frac{E_{\text{imp}}}{E_{\text{total}}} \tag{8}$$

$S_{\text{imp\_energy}}$ = Share of imported energy

E_{imp} = Imported energy consumed per unit production

E_{total} = Total energy consumed per unit production

d) **Affordability of fuel**

In terms of fuel, affordability is being able to buy the fuel required for a production or manufacturing process at a lowest cost possible. The price of the fuel or energy is an integral component of the final production cost. In this study, to develop the sustainability index, only the price of coal was taken into consideration as the cost of the electricity was found to be almost constant during the analysis period. For multiple fuel weightage average cost of fuel can be considered. To quantify the affordability of fuel, the price of coal was taken as shown in Equation (9):

$$A_{\text{fuel}} = P_{\text{energy}} \tag{9}$$

A_{fuel} = Affordability of fuel

P_{energy} = Price of energy per kJ

2.2.3 Socio-economic Sustainability

The manufacturing sector is one of the major pillars of the national economy and is essential for the creation of structural change, high-paying jobs, and long-term economic growth (Eurostat, 2023). The economic prosperity of the industry has been examined based on the production cost per unit production and revenue generated by the industry, as this study is focused on a specific industry. The potential for the industry to create and maintain jobs serves as the basis for assessing social sustainability (Dale et al., 2013). Based on the data that is currently available, three key indicators for socioeconomic sustainability have been established.

a) **Production cost**

Production cost consists of material, energy, labor, and other overhead cost borne by an industry to develop a product. The cost of production may rise as a result of rising energy and raw material prices as well as labor costs. Production costs for a given industry should be as low as possible when compared to its counterparts in the market. An industry can assess its own sustainability by comparing its current year's production costs to those from past years, as was done in this study as in Equation (10):

$$C_{\text{prod}} = C_{\text{rm}} + C_{\text{energy}} \tag{10}$$

C_{prod} = Production cost per bag of cement

C_{rm} = Cost of raw material per bag of cement

C_{energy} = Cost of energy per bag of cement

b) **Revenue generated**

Profit, which generally related to revenue, is used to gauge how well a given industry is doing financially. It is essential for any industry to generate positive revenue for its long-term sustainability. In this study, revenue generated by an industry in a year is taken into account for uniformity and easier evaluation Equation (11).

$$R_{\text{rev}} = P_{\text{sell}} \times N_{\text{bags}} \tag{11}$$

R_{rev} = Revenue generated

P_{sell} = Selling cost of a bag of cement

N_{bags} = Number of cement bags sold in a year

c) **Employment Generation**

Employment generation means the number of people employed by a manufacturing plant. Higher number of employment opportunity in the industry helps to improve life standard of the people around the locality. To quantify the employment generation for index development, employee number is taken into account based on the reports published by the industry Equation (12).

$$E_{\text{gen}} = N_{\text{staff}} \tag{12}$$

E_{gen} = Employment generation

N_{staff} = Average number of staff of industry in a year

2.2.4 Environmental Sustainability

In terms of a manufacturing industry, environmental sustainability is an ability of an industry to sustain without any detrimental effects to the environmental (O'brien, 1999; Rodrigues and Joekes, 2011). Emissions play a significant role in sustainability and are regarded as a key indicator in sustainability indices. Emissions show the quantity of pollutants and greenhouse gases that are released into the atmosphere as a result of industrial activities, which can have detrimental effects on the ecosystem, local and global climate. This study identifies the usage of fossil fuels as a significant factor in environmental sustainability since these fuels cause local pollutants and greenhouse gas emissions.

a) **Fossil fuel consumption**

For a manufacturing process, energy is essential whether it comes from a renewable or non-renewable source. Fossil fuels, which make up the majority of non-renewable energy, release carbon dioxide into the atmosphere, resulting climate change effects. In the manufacturing sector, coal and petroleum products make up fossil fuels. To calculate the fossil fuel consumption, coal consumption, electricity from coal, diesel and natural gas-based generation plants are taken into consideration. Depending on the industry, any fossil fuel can be considered for the analysis in terms of per unit production as shown in Equation (13).

$$F_{\text{cons}} = C_{\text{coal}} + E_{\text{fossil}} \tag{13}$$

F_{cons} = Fossil fuel consumption

C_{coal} = Coal consumed in kJ

E_{fossil} = Electricity from fossil fuels in kJ

b) **Greenhouse gas emission**

The direct greenhouse gas emission in the manufacturing sector come from the burning of fossil fuels such as coal, which is utilized to fulfill the energy requirements and the production of electricity, obtained from an external source like the national grid, leads to indirect CO_2 emissions (Proaño et al., 2020). To calculate the CO_2 emission by the industry, the emission factor is taken as 0.97 kg of CO_2 per unit kWh for electricity from coal based thermal plant, 0.70 kg of CO_2 for electricity from diesel based thermal plant, 0.45 kg of CO_2 for electricity from natural gas based thermal plant and 1.36 kg of CO_2 for electricity from lignite based thermal plant (Bhawan and Puram, 2018) along with 2.62 kg of CO_2 per kg of coal (IPCC, 2023) for coal consumption in Equation (14).

$$GHG_{\text{em}} = \sum F_{\text{cons}} \times EF_{\text{fuel}} \tag{14}$$

GHG_{em} = Greenhouse gas emission

F_{cons} = Fossil fuel consumed

EF_{fuel} = Emission factor of the fuel

c) **Local pollutants emission**

The burning of fossil fuels not only contributes to the GHG emission but also causes local pollutants emissions (Shakya et al., 2023). The ambient local pollutants are not solely the results of the localized use of fossil fuels it also consists of trans-boundary sources as well (Robinson, 2018). In this study, the general local pollutant emission factors of fossil fuels, mainly coal, were used as in Equation (14).

For the analysis purpose, the data related to raw material used, cement production, specific heat consumption were obtained from the industry's technical audit report and physical verification reports (Hetauda Cement Industry Limited, 2022a; Hetauda Cement Industry Limited, 2022b; Hetauda Cement Industry Limited, 2022c). The data on coal, gypsum, iron ore imports, and other financial indicators were sourced from the Ministry of Finance's Yellow Book (MoF, 2024). Emission factors for GHG emission and local pollutant emission were used based on (Bhawan and Puram, 2018; IPCC, 2023; Robinson, 2018).

3. Case study of Hetauda Cement Industry Limited in Nepal

The plant selected for the case study was Hetauda Cement Industry Limited (HCIL) located at Lamasure, Hetauda of Nepal producing mostly Ordinary Portland Cement and it was established in 29 September 1976 under the Company Act 1964 of GoN. It has a designed annual production capacity of 260,000 metric tons and began its commercial production in December 1980. Despite aging machinery requiring rehabilitation, the industry is known for producing high-quality cement in Nepal (Baardali, 2023).

To provide an overview of the present trend and help validate the results obtained from the calculation of the sustainability index in the later section, we analyzed the key performance indicators of the industry which include clinker production, raw coal consumption percentage, specific power consumption, and total revenue of the industry.

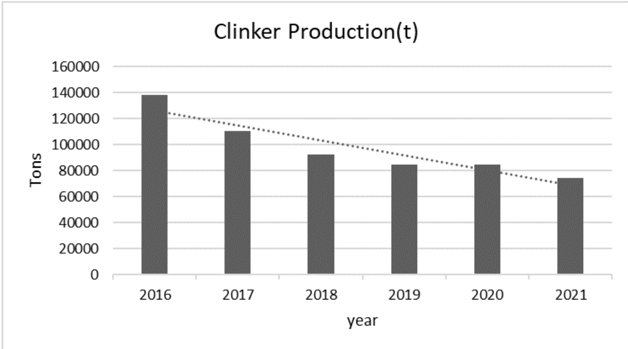

Figure 2. Clinker Production

Clinker production statistics are used to evaluate the performance of the cement industry as cement can be generated from stored clinker over time. In 2016, the clinker production was 138,100 tons which gradually declined till 2019. As a result of maintenance in the second half of 2015 and the first few months of 2016, which was caused by the devastating earthquake in 2015, production increased in 2016. After the decline in production during 2016 to 2019 there was a modest improvement in 2020 as it went into maintenance in 2019 and followed by a decrease in 2021. The falling trend of clinker production indicated that the industry is not operating in a sustainable manner. This comparison shows that the industry is even falling short of its past performance levels as clinker production declined by 46% from 2016 to 2021 as shown in Figure 2 (Baardali, 2023; Hetauda Cement Industry Limited, 2022a).

According to the World Coal Organization, 200 kg of coal is required for the production of 1 tonne of cement (Nepal Trade Information Portal, 2023), which means that 20% of raw coal is consumed. The percentage of coal in cement can be seen to be increasing every year. This can be due to the incompetence of the machinery to perform to their optimum capacity and also due to the decrease in production rate of clinker as justified by Figure 2 (Baardali, 2023; Hetauda Cement Industry Limited, 2022a; Hetauda Cement Industry Limited, 2022b). The increase in coal consumption Figure 3 points towards the increase in coal

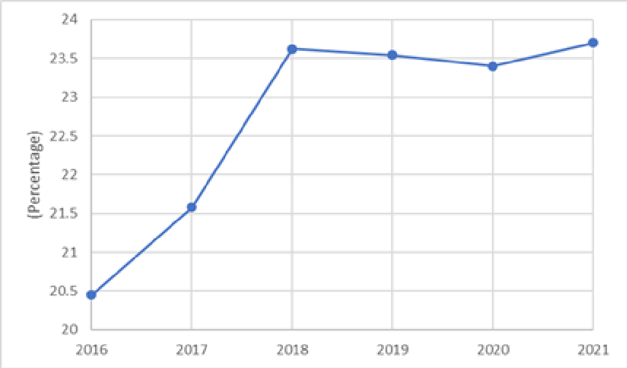

Figure 3. Raw coal consumption percentage

imports, which in turn affects the sustainability of the plant. This increase in consumption of raw material also increases the overall price of the product.

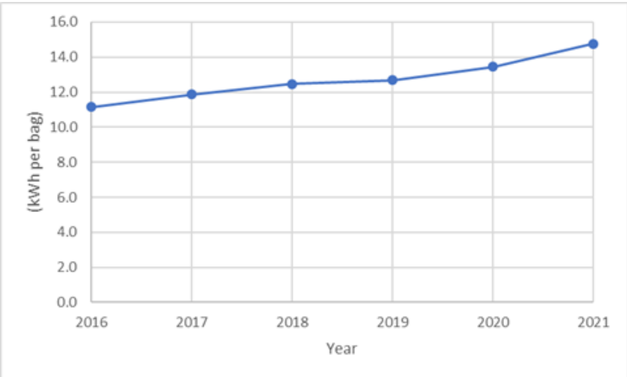

Figure 4. Electricity consumption for a bag of cement, kWh

In terms of electricity consumption, it represents the energy used for the combined thermal and electrical end-use applications to produce a bag of cement which is represented in Figure 4 (Hetauda Cement Industry Limited, 2022a; Hetauda Cement Industry Limited, 2022b). From 2016 to 2021, there was a gradual increase in the total amount of electricity used to produce one bag of cement as shown in Figure 4. The cost of producing cement has grown due to the rise in power usage, reducing the profit margin. As a result, the industry hasn't been able to invest in maintenance and modernization, which can lead to a drop in sustainability.

Revenue is the total money collected from the sales of the cement products. For an industry to be economically sustainable, it is necessary to generate sufficient revenue that could lead an industry to financial benefit. Revenue saw a dramatic drop from NRs.1995.4 million in 2016 to NRs.1010.3 million in 2019 as shown in Figure 5. Following the maintenance, the revenue generation increased in 2020, but it started to decline again in 2021 (MoF, 2024). Due to its current predicament, the industry is being forced

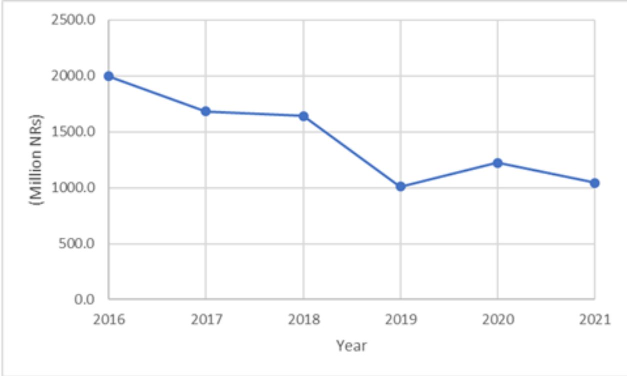

Figure 5. Revenue of the industry, Million NRs

to take on debt creating financial obligations. A major cause of revenue decline may be due to the increased competition after the establishment of large-scale cement industries in the country. The introduction of new industries reduced the market price of the cement and as a result, the industry was forced to sell at a lower price than the production cost to maintain its market share. A key indicator of whether an industry will survive or not is its income situation, which shows that the industry is not sustainable.

4. Result and Discussion

The methodology developed in this study was tested and validated with the case study. Primarily focusing on the above-mentioned indicators of sustainability, secondary data were collected from HCIL. This includes data on raw material imports, fuel imports, and emissions. The available data is then used to define the sustainability status of HCIL. Based on the developed methodology, the values of all the indicators, factors and the overall index value was calculated as shown in Table 1 and 2.

Table 1. Calculation of factor wise indicators

Factor	Indicator	2016	2017	2018	2019	2020	2021
Material supply sustainability	Share of imported raw material	1	0.7486	0.6268	0.8029	0.8319	0.8126
	Non-renewable raw material intensity	1	1.0001	1.0000	1.0003	1.0003	0.9998
	Availability of raw material	1	1	0.7333	0.8333	0.9000	0.5000
	Affordability of raw material	1	0.9594	0.7700	0.7111	0.8687	0.9003
Energy supply sustainability	Energy intensity	1	0.9475	0.8835	0.8721	0.8423	0.7433
	Renewable proportion of energy	1	1.0081	0.9741	1.0143	1.2756	1.2025
	Share of imported energy	1	1.0078	0.9799	0.9773	1.1781	1.0714
	Affordability of fuel	1	1.0409	0.9150	0.9334	0.9065	0.8952
Socio-economic sustainability	Production cost	1	0.9593	0.7700	0.7110	0.8687	0.8089
	Revenue generated	1	0.8439	0.8229	0.5063	0.6138	0.5229
	Employment generated	1	1.0140	0.9906	1.1991	0.8290	1.1124
Environmental sustainability	Fossil fuel consumption	1	0.9547	0.8593	0.8856	1.1089	0.9559
	Greenhouse gas emission	1	0.9429	0.8410	0.8617	0.9249	0.8919
	Local pollutants emission	1	0.9447	0.8449	0.8488	0.8557	0.8410

The value for each indicator represents the future scenario of the particular resource that defines the indicator. Here, to assess the sustainability of industry, 2016 is taken as a base year such that the index value of each indicator for that year is taken as unity which is clearly seen in Figure 6.

Table 2. Calculation of integrated Sustainability Index

Factors	2016	2017	2018	2019	2020	2021
Material supply sustainability	1	0.9270	0.7825	0.8369	0.9002	0.7803
Energy supply sustainability	1	1.0011	0.9381	0.9493	1.0506	0.9781
Socio-economic sustainability	1	0.9391	0.8612	0.8055	0.7705	0.8147
Environmental sustainability	1	0.9475	0.8484	0.8654	0.9632	0.8963
Overall sustainability index	1	0.9536	0.8576	0.8643	0.9211	0.8674

The value of indicator beyond unity represents the sustainability of the industry improving whereas the value below unity represents the declining situation of sustainability of the industry. The index value of any indicator or factor and even overall sustainability can be any real number. After the calculation of indicators as such the value for each factor was calculated with equal weigh given for each indicator under a factor.

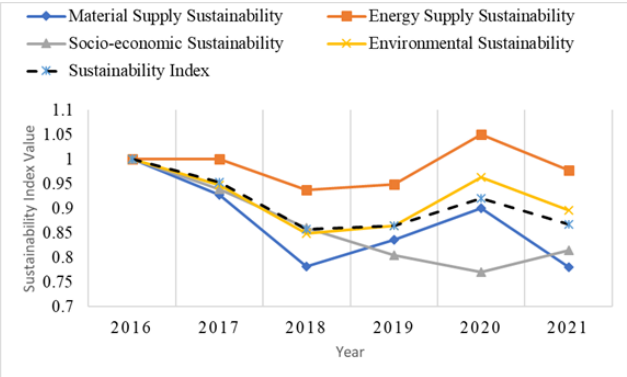

Figure 6. Sustainability Index

The calculation for different factors indicates the condition of the industry has changed significantly over the years. After the base year 2016, the sustainability of the industry has declined from 1 to 0.576 in 2019. The improvement can be seen for the year 2020, as the industry went under maintenance during the period of 2019 and also the non-renewable raw material and energy import was reduced during that period. This indicates that regular and preventive maintenance can significantly improve the sustainability of the industry. The sustainability index over the years suggests that the industry is not sustainable in comparison to its own performance over the years.

The sustainability of the material supply has decreased throughout time, although it appears to be improving in the year 2020, when the industry was impacted by COVID-19. A diminishing material supply shows that importing materials has been challenging for this industry for some time. The price of the raw material has played a significant role in this. As the cost of importing energy and the percentage of imported energy have risen over time, the sustainability of the energy supply has decreased linearly. The decline in energy sustainability is partly a result of the increase in energy intensity brought on by inefficient industrial techniques. Energy and material supply sustainability issues have raised manufacturing costs, which in turn have a negative impact on socioeconomic sustainability. As the amount of revenue earned has decreased and production costs have increased over time, the socioeconomic sustainability of the industry has plummeted. The low socio-economic sustainability score makes it abundantly evident that the external environment can have a significant impact on an industry's ability to sustain itself. As the GHG emission and local pollutant ($PM_{2.5}$) emission have increased due to the increased use of fossil fuels over the years, environmental sustainability has deteriorated.

The calculated sustainability index and analysis of key performance indicators over the years provided similar results. This suggests that the sustainability index calculated in this study is justifiable. The industry's sustainability index was calculated using a quantifiable indicator using accessible industry-specific data and secondary data. Understanding the state of each aspect is made easier by using indicators to quantify the sustainability of the energy supply, material supply, socioeconomic sustainability, and environmental sustainability. The development and use of an industry-specific sustainability index can be instrumental in developing standards, certification, setting targets, monitoring and verifications of targets achieved, which will ultimately help in attaining the UN SDG goals and low-carbon economic transition initiatives by national and international institutions.

5. Conclusions

The necessity for sustainability assessments has been recognized in the modern world, but there is currently no standard index that can be used to gauge and quantify the sustainability of a specific industry. A sustainability index has been created for a nation, but it needs a difficult technique to apply that index to an industry. This study was conducted to provide a straightforward and quantifiable sustainability index that can be used by any industry to gauge its development. For the development of the index, available data sources of the industry were considered. In our case study, the analysis of the industry's main performance indicators confirmed the fall in the sustainability index. The fundamental elements of an industry's sustainability can be fully appreciated by taking into consideration variables like socioeconomic sustainability, environmental sustainability, and the sustainability of the material and energy sources. The grouping of many indicators under these categories made it easier to examine the sustainability in terms of components.

Due to technological and geographic limitations, it may not be possible for one industry to compare its performance with that of comparable industries. The index proposed in our study can be used in such circumstances with the use of limited accessible information during short period. To remain competitive in the market, the industry must increase its own sustainability over the course of the year. The owners and operations team's understanding of their shortcomings will be aided by the calculation of the sustainability index using the technique described in the study. The government can monitor the domestic industries adopting similar approach. It will help the government develop and review standards, rules and regulations and make informed policy decisions. The findings of the study can be emulated in other sectors and are expected to help in the setting, monitoring and evaluation of the targets set for achieving the UN SDG Goal 12 of sustainable production as well as for standardization and certification of sustainable production in the country.

In this study, a small number of indicators have been chosen based on the availability of data from the industry. Based on the available information, these metrics can be altered depending on the sector. The major factors as material supply sustainability, energy supply sustainability, socio-economic sustainability and environmental sustainability give a complete overview of the sustainability for an industry. In this study, all the indicators and factors have been given equal weight-age, which signifies their equal importance. But for an industry, each indicator may have its hierarchy of importance, so a further study is recommended to value the weight-age of the indicators, develop the national and international standards and certification systems for enhancing sustainability at the industry level.

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