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Policy Intervention to Reduce Energy Consumption and Mitigate Environmental Emission in Cement Industries of Nepal

Pradeep Singh[1], Shree Raj Shakya[2]

[1]Nepal Electricity Authority, Durbarmarg, Kathmandu, Nepal
[2]Center for Energy Studies, Institute of Engineering, Tribhuvan University, Lalitpur, Nepal

Email address:
pradeepsingh.nea@gmail.com (P. Singh), shreerajshakya@gmail.com (S. R. Shakya), shreerajshakya@ioe.edu.np (S. R. Shakya)

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Abstract: Nepal is a developing country with huge potential of investment in agriculture, cement and hydropower sector. Industrial development in Nepal is at a pre-mature state and requires lot of technical and financial investment. Cement industry is one of the potential industries to grow in the future, mainly because of the reserved limestone and increasing developmental activities. This study analyzed the energy and environmental implications of implementing best available technologies in cement industries of Nepal by using Long-rand Energy Alternatives Planning system (LEAP) framework. Production capacity of cement in 2014 is estimated to be 2.46 million MT which is expected reach 25.41 million MT by 2030. The final energy demand for the base year, 2014 is 5.4 PJ. It would increase to 13.69 PJ, 16.91 PJ and 25.67 PJ in 2030, under normal (BAU), medium growth (MG) and high growth (HG) scenarios respectively. Compared to the BAU scenario, the cumulative energy demand would increase by 21.46% for MG scenario and 78.00% for HG scenario during 2014 to 2030. The CO_2 emission for the base year 2014 is estimated to be 365.40 thousand MT. It would increase to 1,540.70 thousand MT, 2,292.90 thousand MT and 4105.60 thousand MT in 2030, under BAU, MG and HG, respectively. Compared to the BAU scenario the cumulative CO_2 emission would grow as high as 78.06% under HG scenario. This indicates the need for introducing the energy efficient and low carbon technologies to address the issues related to energy supply security and environmental degradation. This study also analyzed the three policy intervention scenarios consisting of introduction of efficient technology (EFF) scenario, CO_2 emission mitigation (MIT) scenario and waste heat recovery for power generation (WHRPG) scenario. Under EFF scenario, the cumulative energy consumption would decrease by 11.67% during 2014 to 2030 as compared to the BAU scenario. Likewise, CO_2 emission would decrease by 33.64% under MIT scenario as compared to the BAU. Under WHRPG scenario, there would be cumulative electricity generation of 1,446.31 GWh worth NRs. 9.11 billion as compared to the BAU scenario during the study period. This study also indicates the need of formulating appropriate energy efficiency and climate change related policies of the country.

Keywords: Energy, Environment, Efficiency, Cement Industry, Modeling, Alternative Fuels, Waste Heat Recovery

1. Introduction

Industries, considered as backbone of the national development, are facing different energy related problems at present in Nepal. Industrial sectors in the country account for 3.3% (13369.8 TJ) of the total primary energy demand, after residential sector and transport sector in 2010 [1]. However, due to the energy crisis, the energy demand has not been adequately fulfilled. Hence, it is necessary to develop appropriate framework for addressing future energy security along with issues related to greenhouse gas (GHG) emissions and climate change.

Nepal is a developing country with huge potential of investment in the sectors like agriculture, cement and hydropower. Industrial development in Nepal is at a pre-mature state and requires lot of technical and financial investment. Cement industry is one of the potential industries to grow in the future, mainly because of the availability of untapped limestone and increasing developmental activities.

Lime deposits totaling 1.07 billion tons comprising 540 million tons of proven, 110 million tons of semi-proven and 420 million tons of feasible limestone deposits have been discovered in different areas of the country. A total of 13 cement industries with 8,450 ton per day capacity have been established and are in operation using those limestone as raw materials, while 10 cement industries are under construction [2]. Moreover, development activities and commercialization would make a greater impact on the demand of cement in the domestic market.

Also, around 26 clinker grinding industries are operating throughout the country. The grinding industries rely on the domestic and imported clinker, as raw material. For the past four years (2009 to 2012) the cumulative clinker import was around 5 million MT worth around NRs. 30 billion [3]. A total of 7 rotary plant and 9 VSK plants are in operation.

2. Literature Review

With the increasing concern toward energy security and environment issues, new technologies have been introduced and conceived in different energy intensive industries especially in the developed countries. Being an energy intensive industry there are numerous areas for increasing energy efficiency and reducing environmental emissions.

2.1. Cement Manufacturing Process

Cement manufacturing include intensive process with throughput at different stages of raw material processing. Raw materials should be mixed precisely to manufacture cement. Cement manufacturing includes first the production of clinker from the raw mix composed of mined limestone, iron ore, bauxite, clay and coal. The cement clinker requires appropriate amount of compositions of the elements calcium, silicon, aluminum and iron. All these raw materials together with the fuel ash must be combined to form the typical clinker composition as shown in Table 1.

Table 1. *Composition of dry cement manufacturing process [4].*

Elements	Composition (%)
CaO	65 ± 3
SiO_2	21 ± 2
Al_2O_3	5 ± 1.5
FeO_3	3 ± 1

In dry cement manufacturing process, which uses nearly dry raw mix containing less than 20% moisture by mass. However, in a wet process, water is added to the raw mix to form slurry and then is transported to the kiln. Raw meals are grounded, blended, pre-calcined, and burned in manufacturing cement.

In a cement manufacturing process, limestone and calcium, silicon, aluminum and iron oxides are crushed and then milled into a raw meal. This raw meal is blended in blending silos and is then heated in the pre-heating system. This will dissociate carbonate to calcium oxide and carbon dioxide. A secondary fuel is supplied to the preheating system so that temperature is sufficiently high. The meal then passed through the kiln for heating. Then a reaction takes place between calcium-oxide and other elements. This reaction will produce calcium silicates and aluminates at about 1500°C. Primary fuel is used to keep the temperature high enough in the burning zone for the chemical reactions to take place. A nodular product named clinker is produced and then allowed to leave the kiln. The clinker will be inter-ground with gypsum, limestone and/or ashes to a finer product called cement [4].

2.2. Energy Consumption in Cement Industries

Cement production is an energy intensive industry. Energy utilization in cement production accounts for 50–60% of the total production costs [5]. Thermal energy accounts for about 20–25% of the cement production cost [6]. The typical electrical energy consumption of a modern cement plant is about 110–120 kWh per ton of cement [7]. The main thermal energy is used during the clinker making process, while electrical energy issued for cement grinding and other auxiliaries [8]. Fig. 1 shows electrical and thermal energy flow in a cement manufacturing process.

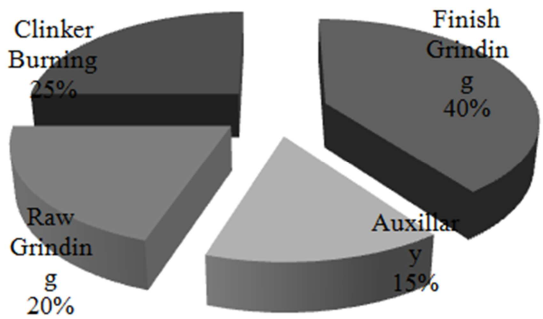

Figure 1. *Energy Distribution among Cement Manufacturing Equipment.*

2.3. Energy Analysis and Modeling in Cement Industries

Demand for cement depends on various socio-economic parameters. Cement production in China has been studied as a function of GDP growth, cement consumption per capita, non linear effect and saturation effect [9]. Similarly, study in Iran has verified the impacts of population and GDP growth on cement demand and production over the next 20 years [10]. Long-range Energy Alternative Planning system (LEAP) Framework has been extensively used to study the impact of various policies on the reduction of CO_2 emission in Chinese [9] and Iranian [11] cement industries.

Lawrence Berkeley National Laboratory (LBNL) has developed a guidebook which contains different energy efficiency improvement technologies and measures which are commercially available for the cement industries throughout the world [12]. Likewise, Madlool et. al [4] have reviewed the different energy efficiency technologies used in cement industries.

Different energy analysis techniques have been employed in industrial energy system modeling. Modeling techniques like decomposition of energy trends, econometric methods, and 'top-down' models, 'bottom-up' models and industry-specific micro-economic analyses are common in analyses of industrial energy [13]. The bottom-up CO_2 abatement cost curve (ACC) model was used for the Thai cement industry to determine the potentials and costs of CO_2 abatement, taking into account the costs and CO_2 abatement of different technologies. Different 41 CO_2 abatement technologies and measures for the cement industry were analyzed for cement industries in Thailand [14].

Ref. [15] developed an optimization model for CO_2 reduction in cement production process. The economic model on the basis of best selection strategy with the least cost was analyzed for a cement industry and found that up to 23.6% reduction in CO_2 emission per ton of cement can be achieved. Ref. [16] analyzed the co-benefit of change in local air pollutants emission while introducing CO_2 mitigating technologies and goals in the cement industries of China by using bottom up optimization model. Similarly energy efficiency improvement and CO_2 reduction potential through the use of 22 energy efficiency measures were studied for India by using forward looking bottom-up Conservation Supply Cure (CSC) model [17]. A statistical approach has been used for finding the relationship between kiln parameters with clinker quality for Spanish cement factory and found that a decrease in the kiln Sintering Temperature (standardized at 50°C) yielded produced the same level of quality in the final product, thus paving the way for reduction in petroleum coke consumption and reduction in CO_2 emissions [18].

2.4. Use of Alternative Fuels and Generation of Electricity in Cement Industries

In 2009, International Energy Agency, estimates the CO_2 emissions from cement production to be about 5% of the total global anthropogenic CO_2 emissions [19]. Different alternative fuel, used for thermal energy, emitting lesser GHGs are been recommended for the cement production. Alternative fuels being used in the cement industries can be classified as solid, liquid or gaseous state [20].

Energy intensive industries like cement release huge amount of low grade heat as a result of heat treatment and clinker burning. As a result, the exit heat, at a temperature lower than 400°C, is released as waste from the clinker cooler and pre-heater. The waste heat being released in the environment can be utilized in a cogeneration power plant established in the plant facility [21]. Different researches and studies have concluded that the waste heat can be re-used to generate electric energy, basically known as Waste Heat Recovery for Power Generation (WHRPG). WHRPG has been implemented in cement industries throughout the globe along with CDM program. The various cement capacity establishment in India [22], Thailand [23] and [24] have been benefited through the CDM projects.

3. Methodology

3.1. Data Collection

Detailed data collection questionnaire were developed and used to collect information on cement production and energy use from the surveyed plants (5 rotary plants, 4 shaft kiln and 12 clinker based plant). Similarly, the data from the baseline study of cement industry for grinding and clinker manufacturing were also used in the study [25]. The baseline study, conducted by GIZ, includes the study in 26 cement industries, and intends to increase the efficiency level of the industries by implementing different efficiency improvement measures. Hence, the compilation of the primary and survey data encompasses around 86% of cement production in Nepal.

The data forms requested for specific information on the plant lines, their age, their clinker and cement-making capacity, and annual data of clinker and cement productions. The energy consumption sheet were developed for important processes like raw quarrying, raw material grinding, additive processing, pyro-processing and clinker cooling, cement grinding and auxiliaries. Similarly, the questionnaire also requested for the information on the implementation of the recent available best practice technologies, as found in different literature. Table 2 shows the fuel consumption for the year 2010/11. Thermal energy was basically generated from coal bituminous and petroleum coke. Coal bituminous is used in pyro-processing of rotary kiln and petroleum coke in vertical shaft kiln technology. Electricity comprises the grid electricity and electricity generated by on-site diesel generators. Diesel generators produce around 26% of electricity in the base year. Likewise the clinker to cement ratio is found to be 0.88.

Table 2. *Year 2010/11 Fuel Consumption in Cement Industries [25].*

Fuel Type	Consumption
Coal (GJ)	3,836,603
Electricity (GWh)	168

3.2. Benchmarking and Energy-Saving Potential

Benchmarking is a commonly used term that generally means comparing a defined characteristic of one facility to other facilities or other 'benchmarks'. This study focuses in the energy consumption benchmarking with the international best practice. Different international energy benchmarks are considered as found in literature [4, 12, 26] and the reference from BEST-Cement[1]. A spread sheet model is generated and domestic energy consumption is compared with the international best practice using and energy intensity index (EII), calculated on the basis of facility's energy intensity and the benchmark energy intensity, as in Eq. (1) [27].

1 BEST-Cement is the cement industry energy benchmarking software package developed for China by Lawrence Berkeley National Laboratory. It can be downloaded from: http://china.lbl.gov/research/industry /benchmarking/best-cement/best-cement-china.

$$EII = 100 * \frac{\sum_{i=1}^{n} P_i * EI_i}{\sum_{i=1}^{n} P_i * EI_{i,BP}} = 100 * \frac{E_{tot}}{\sum_{i=1}^{n} P_i * EI_{i,BP}} \quad (1)$$

where:

EII=energy intensity index.

n=number of products to be aggregated;

EI_i=actual energy intensity for product i;

$EI_{i,BP}$ = best practice energy intensity for product.

P_i = production quantity for product i.

E_{tot}= total actual energy consumption for all products.

The EII is one of benchmarking method which performs analysis by comparing the production intensity of the facility to the benchmark or reference intensity. The international benchmark will have an EII of 100. In reality, plant facilities will have EII greater than 100, which shows the potential saving opportunities.

Table 3. Fuel Energy Intensity at Base Year and Projected Years.

Scenario	Technology	Final energy intensity by technology (GJ/tclinker)				
		2011	2014[2]	2015	2020	2030
Base Case	Rotary Kiln	4.54	4.54	4.54	4.54	4.54
	Shaft Kiln	7.89	7.89	7.89	7.89	7.89
Efficiency	Rotary Kiln	4.54	4.54	3.6	3.4	3.4
	Shaft Kiln	7.89	7.89	7.89	0	0
Best Practice	Rotary Kiln	4.54	4.54	3.6	3.4	3.4
	Shaft Kiln	7.89	7.89	7.89	0	0

3.3. Demand Forecast

The historical cement production data have been collected from the economic survey 2014/15 [2]. The data presented in the economic survey report do not seem to present correct data. Even the total production of the visited industries is more than the data presented. Hence, regression analysis is used to determine the actual demand of cement.

The end-use demand of cement is estimated using the following equation, as mentioned in different literatures [28, 29, 30].

$$ESD_{cement,t} = \left(\frac{VA_t}{VA_o}\right)^{\beta} x\ ESD_{cement,0} \quad (2)$$

where,

$ESD_{cement,\,t}$ = end use service demand in year t for cement sector,

VA_t = GDP value added in the cement sector in year t,

β = sectoral value added elasticity of demand for cement industry,

The future growth of GDP is forecasted using the regression model from the data available from various sources. The GDP growth rate is calculated at low growth rate which is considered to be 4.45% per year. Similarly, GDP growth rate for medium and high growth rate are considered to be 5.5% and 7.5% respectively. The forecasted GDP growth rate is used to generate the future growth rate of value addition of manufacturing sector. The sectoral value added elasticity for cement sector is calculated using historical data of service demand and GDP value addition in Eq. (2). The end-use cement demand, in the base year is considered to be the cement demanded by the domestic market which is fulfilled by production within the country. Unauthorized expertise opinion claims that this demand is just enough to meet around 50 percent of total domestic demand.

Twenty year historical data from 1990 to 2014 for national level cement demand [2] and manufacturing value addition (constant 2005 US$) [31] are obtained from various sources. The elasticity of demand for cement industry was determined to be 2.16, which is comparable to the one found in literature [28]. Year 2014 estimates production capacity of cement being 2.46 million metric ton which is expected to reach 10.37 million MT in 2030, with a cumulative cement demand of 96.00 million MT, from 2015 to 2030 in normal (BAU) growth rate scenario. Similarly, the cement demand would rise to 14.88 million MT in 2030 with cumulative demand of 117.14 million MT, in Medium Growth (MG) rate scenario. In case of high growth (HG) rate scenario, the cement demand rises from 2.46 million MT in 2014 to 25.41 million MT, with cumulative of 172.90 million MT. The historical and future cement demand is shown in Fig. 2.

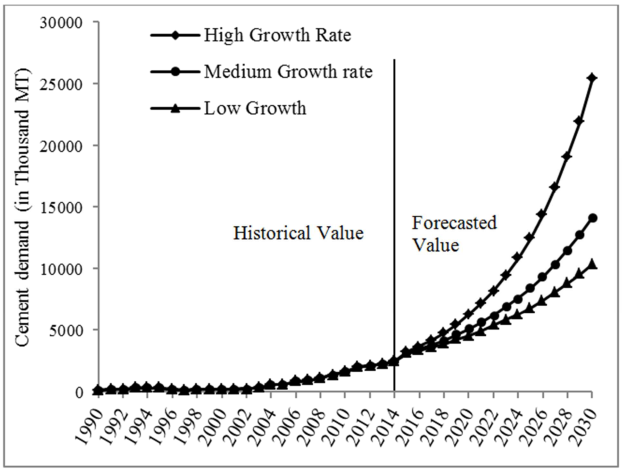

Figure 2. Historical and Forecasted Cement Demand Projection (1990-2030).

Since the total cummulative cement production in fifteen years accounts for 9%, 11% and 16% of the total limestone reserved, in normal, medium and high growth, respectively. Hence, the elastic growth is considered valid and is used in the modeling and scenario analysis.

3.4. Scenario Assumption

The Long-range Energy Alternatives Planning system (LEAP)[3] modeling framework is used for the scenario based modeling and analysis of potential energy savings and CO_2 emissions reduction. The scenarios have been projected up to

2 Calculated from the primary data

3 LEAP is a scenario-based energy-environment modeling tool of which scenarios are based on "comprehensive accounting of how energy is consumed converted and produced" [34]

2030. To analyze the impact of different energy efficiency and carbon reduction measures and policies, three scenarios are constructed consisting of Business as Usual (BAU) scenario, Energy Efficiency (EFF) scenario and GHG Mitigation (MIT) scenario. Scenarios have been defined on the basis of various national and international level goals and targets [19].

The BAU scenario has been considered as reference scenario without any policy intervention for energy efficiency improvement and GHG mitigation. The efficiency scenario is constructed with the objective to observe the energy consumption pattern with energy efficiency measure determined by benchmarking. On the contrary, Mitigation scenario observes the effect on GHG emission due to the inclusion of energy efficiency measures, use of alternative fuel and reduction of clinker to cement.

An average of 36 kWh of electricity can be produced per MT clinker through WHR power generation [9]. The electricity generation through WHR is calculated to forecast the electricity produced by the cement industries. Electricity production is assumed to be utilized by the industries so as to reduce the dependency on electricity supplied from the grid supply.

The average emission factor of 73.3 ton CO_2 per TJ for alternative fuels is assumed, which indicates the use of alternative fuel could reduce about 23% of overall CO_2 emissions as compared to burning bituminous coal of which assumed emission factor is 94.5 ton CO_2 per TJ [32]. The cement process emission is calculated as 0.547 ton CO_2 per clinker production [33].

3.5. General Assumption and Base Year

The following were the assumptions for the reference case (BAU) scenario

- The base year is considered to be 2014.
- The major energy intensive fuels like electricity from grid and diesel gen-sets were considered for electrical energy.
- Furnace oil and Coal bituminous or coke is considered for thermal energy.
- The calculated value of final energy demand in the base year 2014 is 5.42 PJ.

3.6. Growth Scenario

Growth scenario is created to access the energy consumption and environment emission in various growth rate of cement demand. The cement demand was determined in different growth scenarios as found out by the Eq. (2). The growth scenario is simply the representation of baseline scenario (i.e. 2014) projected up to 2030. This scenario does not incorporate efficiency improvement and emission reduction measures.

Growth scenario is categorized as Business as Usual, Medium Growth and High Growth. Each scenario resembles the energy consumption and environment emission at 4.45%, 5.5% and 7.45% growth rate of GDP (constant 2005 US$). Also, the Clinker to Cement (CC) ratio is assumed to be reduced from 0.88 in 2014 to 0.75 by 2030 [19], for all scenarios.

3.7. Efficiency Scenario

Efficiency (EFF) scenario is constructed to access the potential in reduction of energy consumption and emission by implementing the efficiency improvement measures.

This scenario presumes the efficiency improvement of cement industries by the implication of efficiency measures and reaches the best practice value of specific energy intensity. At present, different energy efficiency programs are being carried out in cement industries, with assistances from different national and international organization. Hence, it is assumed that efficiency programs will also be made viable in future; ultimately bring the efficiency to international best practice standard. Also, in future, new commissioning industries are assumed to be installed with the basic amenities of standard best practice values. It is therefore, plausible to assume that the best practice values of specific electrical energy and specific thermal energy would reach the international standard value with the succession of time. Table 4 and 5 shows the assumed gradual efficiency improvement in Specific Energy Consumption (SEC) fuel. In the efficiency scenario, the shaft kiln technology has been considered to be phased out by 2020, due to its low production volume and quality.

Since, there are three growth scenarios, corresponding to each growth scenario there will be an efficient scenario. Hence, three efficiency scenarios corresponding to three growth rates are considered.

Table 4. *Assumed efficiency improvement in SEC (fuel energy).*

Scenario	Technology	Final energy intensity by technology (GJ/MT clinker)			
		2014	2020	2025	2030
Efficiency	Rotary Kiln	4.54	4.0	3.6	3.4
	Shaft Kiln	7.9	7.9	0	0

Table 5. *Assumed efficiency improvement in SEC (electricity).*

Scenario	Technology	Final energy intensity by technology (kWh/MT cement)		
		2014	2020	2030
Efficiency	Rotary Kiln	125.5	90	90
	Shaft Kiln	214.2	0	0
	Clinker Based	48.68	35	35

3.8. Mitigation Scenario

CO_2 Mitigation (MIT) scenario analyzes the effect of substituting coal by alternative fuel in cement industries and also the penetration of waste heat recovery for power generation. This scenario considers all the efficiency measures, aforementioned in section 3.7. This scenario is developed with the opined objective of curtailing emission from cement industries, as targeted in the international level [19].

Table 6, 7 and 8 shows the penetration of alternative fuel, Waste Heat Recovery for Power Generation (WHRPG) and fuel efficiency. The penetration of WHRPG and alternative fuel is not considered in Growth and Efficiency scenario.

Table 6. *Assumed penetration of alternative fuels (in % of coal substitution).*

Scenario	2014	2015	2020	2025	2030
MIT	0	1	5	11	21

Table 7. *Assumed Penetration of Waste Heat Recovery for Power Generation (% of clinker production).*

Scenario	2014	2020	2025	2030
MIT	0	20	60	100

Table 8. *Fuel energy intensity at Base Year and Projected Years.*

Scenario(s)	Technology	Final energy intensity by technology (GJ/t clinker)			
		2014[4]	2015	2020	2030
BAU, MG and HG	Rotary Kiln	4.54	4.54	4.54	4.54
	Shaft Kiln	7.9	7.9	7.9	7.9
MIT	Rotary Kiln	4.54	4.0	3.6	3.4
	Shaft Kiln	7.9	7.9	N/A	N/A

4. Result and Analysis

4.1. Benchmarking Result

The domestic benchmarking of the rotary kiln technology has been performed and the template generated incorporates different process flow of the cement industry. Special focuses were given to the rotary kiln technology. Since, all plant do not produce cement the energy per unit clinker basis is formulated.

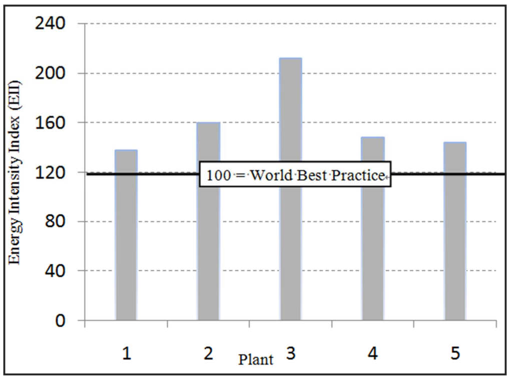

Figure 3. *Energy Intensity Index (EII) benchmarking of surveyed plant.*

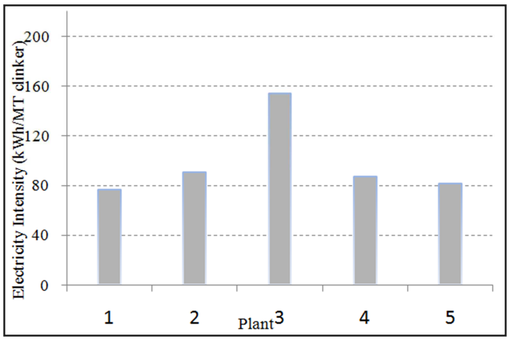

Figure 4. *Electricity Intensity in surveyed plant.*

4 Calculated from the primary data

The difference between the actual plant and its corresponding best-practice technology illustrates the technical potential for energy improvement. In order to compare the 5 plants, an energy intensity index (Eq. 1) is used to illustrate the distance between best practice and the plants improvement opportunity.

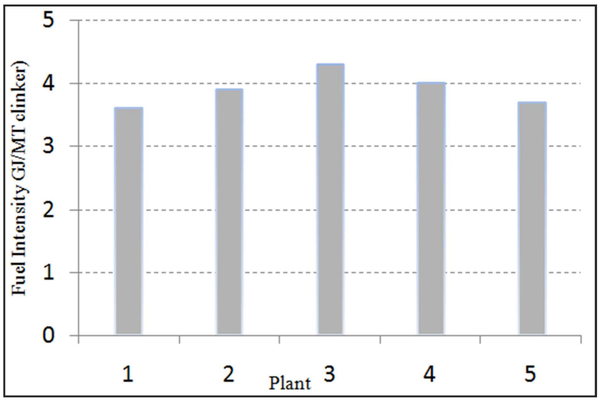

Figure 5. *Fuel Energy Intensity in surveyed plants.*

Fig. 3 shows the EII score for the 5 plants compared to the world best practice based on primary energy use. All 5 plants scored above the 100 value which hints the opportunity for efficiency improvement above the 100 value. Plant 1 scores the lowest value (138) suggesting 28% of technical potential saving. Likewise, Plant 3 scores the highest value (212) suggesting 53% of technical potential saving.

Fig. 4 and 5 shows the electricity intensity and fuel energy intensity of clinker production. The average values have been used for the scenario analysis. Plant one has the lowest electricity energy consumption of 79 kWh/MT clinker. Plant three has the highest electricity energy consumption of 154 kWh/MT clinker. Considering the cement grinding, the average electricity energy consumption for rotary kiln is 125.5 kWh/MT cement. Likewise, the average energy consumption for VSK is 214.2 kWh/MT cement.

Fig. 5 explains the fuel energy intensity in rotary kiln plants. The lowest fuel intensity is found in Plant one with 3.9 GJ/MT clinker. Similarly the highest fuel energy intensity is found in Plant 3 with 6.54 GJ/MT clinker. The average of the plant is found to be 4.54 GJ/MT clinker. Similarly for the energy consumption VSK plant is found to be 7.9 GJ/MT clinker.

In clinker based industries, the average electricity energy consumed for clinker grinding is 48.68 kWh/MT of cement.

4.2. Result of Growth Scenario

4.2.1. Energy Demand Projection

The energy demand for the base year 2014 is 5.4 PJ. The final energy demand would increase to 22.86 PJ, 31.26 PJ and 55.97 PJ in 2030, under BAU, MG and HG respectively.

The cumulative energy demand for BAU, MG and HG scenario would be 216.89 PJ, 263.43 PJ and 386.19 PJ respectively. Compared to the BAU scenario, the cumulative energy demand would be increase by 21.46% for MG scenario and 78% for HG scenario. The energy demand projection for growth scenario is shown in Fig. 6.

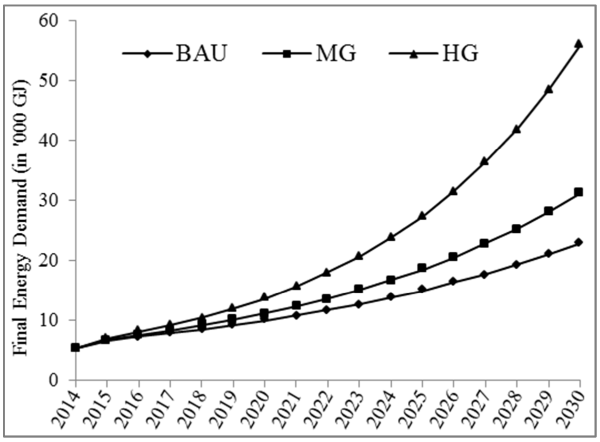

Figure 6. *Final Energy Demand Projection in BAU, MG and HG scenarios (2014-2030).*

4.2.2. Emission Projection

Likewise, the CO_2 emission for the base year 2014 is 365.40 thousand MT. The final CO_2 emission would increase to 1,540.70 thousand MT, 2,292.90 thousand MT and 4,105.60 thousand MT in 2030, under BAU, MG and HG respectively. The cumulative energy for BAU, MG and HG scenario would be 15.91 million MT, 19.32 million MT and 28.33 million MT, respectively. Compared to the BAU scenario, the cumulative emission would rise by 21.46% for MG scenario and 78.00% for HG scenario, which is in exact match with the energy consumption. The emission projection for growth scenario is shown in Fig. 7.

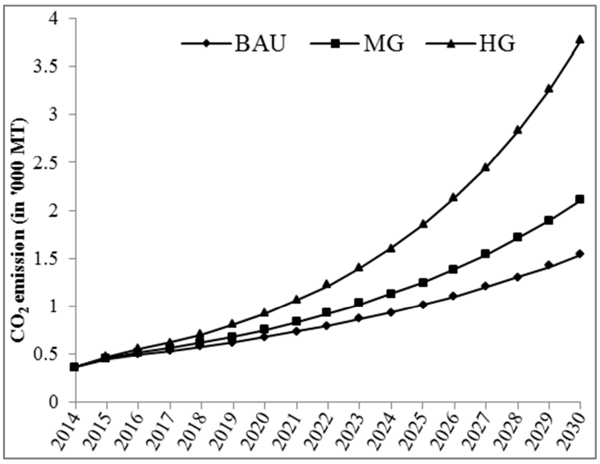

Figure 7. *CO_2 emissions in BAU, MG and HG scenarios (2014-2030).*

4.3. Result of Efficiency Scenario

The efficiency scenario is constructed as an efficiency improvement in technology employed in cement industries. The scenario can be studied as an efficiency improvement in the three growth scenario. In other words, efficiency scenario studies the effect of technological improvement in three growth scenario viz. EFF BAU, EFF MG and EFF HG scenario.

The EFF BAU, EFF MG and EFF HG scenario projects the total cumulative final energy demand to be at 191.58 PJ, 229.87 PJ and 280.32 PJ, respectively. Compared to the BAU scenario, under EFF BAU scenario, 11.67% of total cumulative energy consumption can be reduced. Likewise, in between MG and EFF MG scenarios, 12.74% of total cumulative energy can be conserved. Finally, EFF HG scenario, 27.42% of energy can be conserved compared to HG scenario.

The energy demand projections in efficiency scenario as compared with their corresponding growth scenario are shown in Fig. 8.

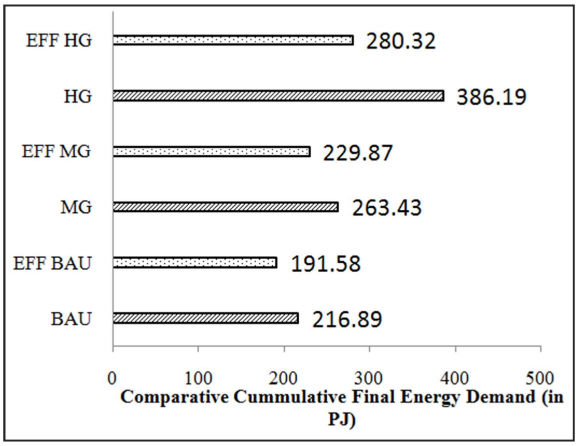

Figure 8. *Final Energy Demand in Efficiency Scenario (2014-2030).*

4.4. Result of Mitigation Scenario

The MIT BAU, MIT MG and MIT HG scenario projects the total cumulative CO_2 emissions to be at 9.70, 11.60, and 16.61 million MT, respectively. Compared to the BAU scenario, in MIT, 33.64% of total cumulative emission can be reduced. Likewise, between MG and MIT MG scenario, 34.59% of CO_2 emission can be mitigated. Finally, under MIT HG scenario, 36.20% of CO_2 emission can be reduced as compared to HG scenario.

The reduction in emission can be credited to the use of alternative fuel and phase-out of high energy intensive cement industries, Vertical Shaft Kiln Technologies.

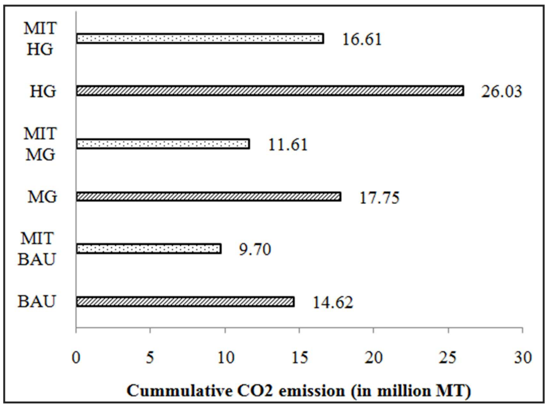

Figure 9. *Cumulative CO_2 emission comparison between respective Growth and Mitigation Scenarios (2014-2030).*

The emission projection scenarios compared with their corresponding growth scenarios is shown in Fig. 9, for BAU, MG and HG scenarios, respectively.

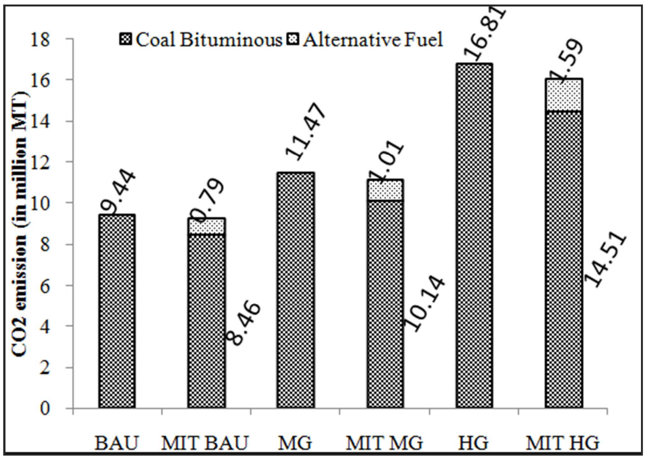

Figure 10. *Cumulative CO_2 emissions- substitution of Coal Bituminous with Alternative Fuel in all scenarios (2014 -2030).*

Similarly, the substitution of coal bituminous with alternative fuel has a positive impact on the reduction of CO_2 emission. Up to 4% of the total emission can be reduced, as noticed in Fig. 10.

4.5. Effect of Penetration of Waste Heat Recovery for Power Generation (WHRPG)

WHRPG is considered only in the mitigation scenarios. The production of electricity, by WHRPG in the limestone based industries is considered from 2020.

Considering scarcity of electricity in present context along with the future energy supply security, WHRPG can contribute to the power generation through waste heat studied combined with the growth scenario viz. BAU, MG and HG.

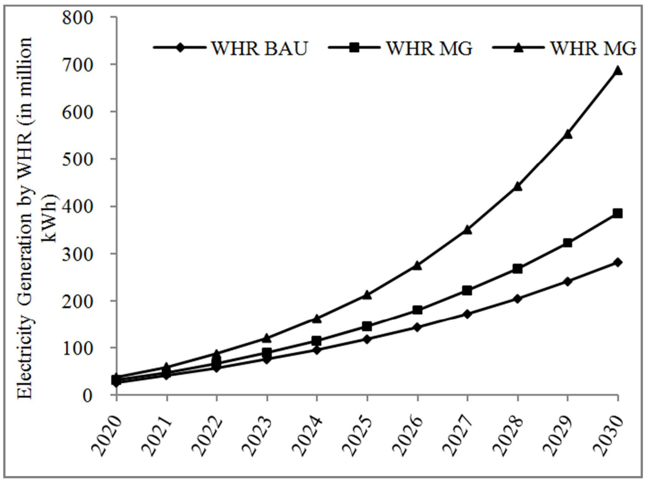

Figure 11. *Electricity Generation by WHRPG in WHR BAU, WHR MG and WHR HG scenarios (2020-2030).*

The subsequent growth of the production of electricity from waste heat in different growth scenarios can be accounted to the higher production of clinker. With the assumed penetration of WHRPG, for three growth scenarios, in BAU scenario cumulative of 1,446.31 GWh of electricity can be generated. Similarly, under MG and HG scenarios, 1,860.99 GWh and 2,988.35 GWh of electricity can be generated. This subsequently accounts for, around 20% of total cumulative electricity demand in cement industry.

Considering the current average electricity tariff of Nepalese Rupees (NRs.) 6.3 per kWh the total amount saving in BAU is NRs. 9.11 billion. Similarly, in MG and HG the total saving can be attained to be NRs. 11.72 billion and NRs. 18.83 billion.

4.6. Conclusion and Recommendations

In context of Nepal, the output of cement has shown a continuous growth during 1990 to 2014. The increase of the domestic demand and it fulfillment, in future perspective, expects more cement industries to commence. The growth in cement demand is studied in growth scenario as business as usual, medium growth and high growth. These growths are associated with 4.45%, 5.5% and 7.45% of GDP growth, respectively.

Log-linear regression method was used to determine the relation between value addition (VA) associated with the manufacturing industries and the end use cement demand. The elasticity of demand for cement industry was determined to be 2.16. Year 2014 estimates production capacity of cement being 2.46 million metric ton which is expected to reach 10.375 million MT in 2030, with a cumulative cement demand of 96 million MT, from 2015 to 2030 in normal (BAU) growth rate scenario. Similarly, the cement demand would rise to 14.88 million MT in 2030 with cumulative demand of 117.14 million MT, in Medium Growth (MG) rate scenario. In case of high growth rate scenario, the cement demand rises from 2.4 million MT in 2014 to 25.41 million MT, with cumulative of 172.9 million MT.

Long-range Energy Alternatives Planning system (LEAP) modeling tool was used to conduct the scenario based analysis projected for base year of 2014 up to 2030. Scenarios have been defined on the basis of various national and international level goals and objectives, which include the energy efficiency measures, waste heat recovery and use of alternative fuels.

Corresponding to the growth scenarios, energy demand were studied under the efficiency (EFF) scenario and the environmental effects were studied under mitigation (MIT) scenario. Hence, overall nine different scenarios were analyzed.

The energy demand for the base year 2014 is 5.4 PJ. The final energy demand would increase to 22.86 PJ, 31.26 PJ and 55.97 PJ in 2030, under BAU, MG and HG respectively. The cumulative energy demand for BAU, MG and HG scenario would be 216.89 PJ, 263.43 PJ and 386.19 PJ respectively. Compared to the BAU scenario, the cumulative energy demand would be increased by 21.46% under MG scenario and 78.00% under HG scenario.

Likewise, the CO_2 emission for the base year 2014 is 365.40 thousand MT. The annual CO_2 emission would increase to

1,540.70 thousand MT, 2,292.90 thousand MT and 4,105.60 thousand MT in 2030, under BAU, MG and HG respectively. The cumulative energy for BAU, MG and HG scenario would be 15.91, 19.32 and 28.33 million MT, respectively. Compared to the BAU scenario, the cumulative emission would rise by 21.46% for MG scenario and 78.00% for HG scenario, which is in exact match with the energy consumption.

The EFF BAU, EFF MG and EFF HG scenario projects the total cumulative final energy demand to be at 191.58 PJ, 229.87 PJ and 280.32 PJ, respectively. Compared to the BAU scenario, in EFF BAU scenario, 11.67% of total cumulative energy consumption can be reduced. Likewise, in MG and EFF MG scenario, 12.74% of total cumulative energy can be conserved. Finally, under EFF HG scenario, 27.42% of energy can be conserved compared to HG scenario.

Under MIT BAU, MIT MG and MIT HG scenario projects the total cumulative CO_2 emissions would be 9.70, 11.60, and 16.61 million MT, respectively. Compared to the BAU scenario, in MIT, 33.64% of total cumulative emission can be reduced. Likewise, between MG and MIT MG scenario, 34.59% of CO_2 emission can be mitigated. Finally, under MIT HG scenario, 36.20% of CO_2 emission can be reduced as compared to HG scenario.

The subsequent growth of the production of electricity from waste heat in different growth (WHRPG) scenarios can be accounted to the higher production of clinker. With the assumed penetration of WHRPG, for three growth scenarios, under BAU scenario cumulative of 1,446.31 GWh of electricity can be generated. Similarly, in MG and HG scenario, 1,860.99 GWh and 2,988.35 GWh of electricity can be generated. This subsequently accounts for, around 20% of total cumulative electricity demand in cement industry. Considering the current average electricity tariff of Nepalese Rupees (NRs.) 6.30 per kWh the total amount saving in BAU is estimated to be NRs. 9.11 billion. Similarly, in MG and HG the total saving can be attained as high as NRs. 11.72 billion and NRs. 18.83 billion, respectively.

Hence, the study opines on the following policy reformation to be implemented in cement industries of Nepal

- Categorization of energy efficiency measures at various stages of cement process, so as to meet the international best practice standards.
- Phase wise implementation of efficiency improvement and low carbon footprint programs.
- Identification and management of indigenous alternative fuel sources that can be used in cement industries to improve energy supply security.
- Formulation and implementation of the effective mechanisms for promoting the above policy intervention options in the existing industrial, energy and climate change related policies of the country.

References

[1] WECS, "Energy Sector Synopsis Report," Water and Energy Commission Secretariat (WECS), Kathmandu, Nepal, 2010.

[2] Ministry of Finance, GoN, "Economic Survey," Kathmandu, 2014.

[3] TEPC (Trade and Export Promotion Center), GoN, [Online]. Available: http://208.67.23.5/~itsoftc/projects/tepc/commoditywise.php. [Accessed 12 October 2013].

[4] N. A. Madlool, R. Saidur, M. S. Hossain and N. A. Rahim, "A critical review on energy use and savings in the cement industries," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 2042-2060, 2011.

[5] J. Wang, Y. Dai and L. Gao, "Exergy analyses and parametric optimization for different cogeneration power plants in cement industry," *Applied Energy,* vol. 86, no. 6, pp. 941-8, 2009.

[6] M. K. Singhi and R. Bhargava, "Sustainable Indian cement industry. In: Workshop on International comparison of Industrial Energy," 2010.

[7] G. G. Mejeoumov, "Improved cement quality and grinding efficiency by means of closed mill circuit modeling," 2007.

[8] L. M. Junior, "Sustainable development and the cement," 2003.

[9] K. Jing, Z. Nina, F. David, P. Lynn and Z. Nan, "Potential energy savings and CO_2 emissions reduction of China's cement industry," *Energy Policy,* vol. 45, pp. 739-751, 2012.

[10] A. S. Nastaran Ansari, "A system dynamics model for analyzing energy consumption and CO_2 emission in Iranian cement industry under various production and export scenarios," *Energy Policy,* vol. 58, pp. 75-89, 2013.

[11] F. Atabi, M. S. Ahadi and K. Bahramian, "Scenario analysis of the potential for CO_2 emission reduction in the Iranian cement industry," *World Renewable Energy Congress,* pp. 740-746, 2011.

[12] E. Worrell, C. Galitsky and P. Lynn, "Energy Efficiency Imporvement Opportunities for the Cement Industry," Berkeley, CA, 2008.

[13] L. A. Greening, G. Boyd and J. M. Roop, "Modeling of industrial energy consumption: An introduction and context," *Energy Economics,* vol. 29, no. 4, pp. 599-608, 2007.

[14] A. Hasanbeigi, C. Menke and L. Price, "The CO_2 abatement cost curve for the Thailand cement industry," *Journal of Cleaner Production,* vol. 18, no. 15, pp. 1509-1518, 2010.

[15] S. O. Ogbeide, "Developing an optimization model for CO_2 reduction in cement production process," *Journal of Engineering Science and Technology Review,* vol. 3 (1), pp. 85-88, 2010.

[16] Q. Tan, W. Zongguo and J. Chen, "Goal and technology path of CO_2 mitigation in China's cement industry: from the perspective of co-benefit," *Journal of Cleaner Production,* 2015.

[17] W. R. Morrow III, A. Hasanbeigi, J. Sathaye and T. Xu, "Assessment of energy efficiency improvement and CO_2 emission reduction potentials in India's cement and iron & steel industries," *Journal of Cleaner Production,* vol. 65, pp. 131-141, 2014.

[18] A. M. Castañón, S. García-Granda, A. Guerrero, M. P. Loreno and S. Angulo, "Energy and enviromental savings via optimisation of the production process at a Spanish cement factory," *Journal of Cleaner Production,* vol. 98, pp. 47-52, 2015.

[19] IEA/WBCSD, "Cement Technology Roadmap: Carbon emission reduction up to 2050," 2009.

[20] E. Mokrzycki and A. Uliasz-Bochenczyk, "Alternative fuels for the cement industry," *Applied Energy,* vol. 74, pp. 95-100, 2003.

[21] Zhejiang Energy Research Institute, "Waste Heat Recovery for Power Generation in Dry Cement Production," 2004.

[22] UNFCC, "Vikram Cement (VC): Energy efficiency improvemet by upgrading of preheater in cement manufacturing. CDM project design document," 2007.

[23] UNFCCC, "Siam Cement (Ta Luang) Waste Heat Power Generation Project, Thailand. CDM project design document," 2008.

[24] UNFCC, "Hebei Quzhai Cement 9000 kW Wase Heat Recovery Project - CDM PDD," 2007.

[25] GIZ, "Baseline Study of Selected Sector Industries to assess the potentials for more efficient use of energy," GIZ, Kathmandu, 2012.

[26] EPA (United States Environmental Protection Agency), "Available and emerging technologies for reducing greenhouse gas emission from the portland cement industry," 2010.

[27] A. Hasanbeigi, L. Price, H. Lu and W. Lan, "Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China: A case study of 16 cement plants," *Energy,* vol. 35, pp. 3461-3473, 2010.

[28] S. R. Shakya and R. M. Shrestha, "Transport sector electrification in a hydropwer resource rich developing country: Energy security, environmental and climate change co-benefits," *Energy for Sustainable Development,* vol. 15, pp. 147-159, 2011.

[29] R. M. Shrestha and S. Rajbhandari, "Energy and environment implications of carbon emission reduction targets: case of Kathmandu Valley, Nepal," *Energy Policy,* vol. 38, pp. 4818-27, 2010.

[30] TERI, "National Energy Map for India: Technology Vision 2030," Delhi, 2006.

[31] The World Bank, [Online]. Available: http://data.worldbank.org/indicator/NV.IND.MANF.KD. [Accessed 14 12 2014].

[32] PCC, "IPCC Guidelines for national Greenhouse Gas Inventories," 2006.

[33] CSI, "CO_2 Accounting and Reporting Standard for the Cement Industry, Version 2," 2005.

[34] SEI, 2011. [Online]. Available: http://www.energycommunity.org/documents/Leap2011UserGuideEnglish.pdf. [Accessed 2012].