Nordic Concrete Research – Publ. No. NCR 59 – ISSUE 2 / 2018 – Article 4, pp. 45-58

ISSN online 2545-2819
ISSN print 0800-6377

Received: Sept. 24, 2018
DOI: 10.2478/ncr-2018-0014
Revision received: Nov. 18, 2018
Accepted: Nov. 28, 2018

Rice Husk Resource for Energy and Cementitious Products with Low CO_2 Contributions

Otto During, M.Sc.
RISE Built Environment
Stockholm, Sweden
otto.during@ri.se

Silu Bhochhibhoya, Ph.D.
Department of Construction Management and Engineering
Univeristy of Twente
Enschede, The Netherlands
s.bhochhibhoya@utwente.nl

Ramesh Kumar Maskey, Ph.D., Professor
Kathmandu University
Dhulikhel, Nepal
maskey@ku.edu.np

Rajendra Joshi, Ph.D., Associat Professor
Department of Chemical Science and Engineering
Kathmandu University
Dhulikhel, Nepal
rajendra.joshi@ku.edu.np

ABSTRACT
Rice Husk Ash (RHA) is a well-known supplementary cementitious materials (SCMs) that can be used for concrete with reduced CO_2 contributions. In 2016, only Nepal produced 5.2 million tonnes rice that gave about 1.14 million tonnes rice husk. The rice husk can also be used directly in a cement kiln as a fuel. This study analysis the potential CO_2 reductions from three scenarios and emphasis strengths, weaknesses, opportunities and treats in the production systems for initiate a decision process with possibilities to get an industry project financed from the green climate found. The highest CO_2 benefits were from rice husk used in a cement kiln were half of the yearly rice husk production in Nepal could reduce the climate impact with 808000 tonnes CO_2.

Key words: Carbon emission reduction, rice husk ash supplementary cementitious material, concrete, sustainable.

1. INTRODUCTION

The global market for cement and concrete is increasing with the increasing population. It is the second biggest traded commodity in the world. There are two aspects of CO_2 emission from the cement production: (*i*) the chemical reaction involved in the production of the main component of cement, clinker, as carbonates are decomposed into oxides and (*ii*) CO_2 emission from the combustion of fossil fuels [1]. The demand for cement, especially in the developing countries, is expected to double within the next 20 years [2]. Hence, the need to reduce the carbon dioxide emissions associated with the production of cement is one of the major concerns of the cement and concrete industry. The use of supplementary cementitious materials (SCMs) is one of the effective solutions to counteract this effect [3-5]. Agricultural-based SCMs such as rice husk ash (RHA) can be a solution for many developing countries such as Nepal, whereby a large percentage of the economic workforce is focused on agriculture rather than industry.

Rice husks are agricultural by-products of paddy farming, which are not suitable for use as livestock feeding due to their lack of protein content. Hence, they are categorized as waste material and disposed in landfills. Worldwide production of rice husks amounts to approximately 100 million tonnes per year [6]. The combustion of the husks yields approximately 25% of ash [8- 9]. Research has shown that incineration of the husks under controlled conditions in temperatures not exceeding 700°C generates silica with the high amorphous content of approximately 90% or more [7], [8].

- RHA is a cheap waste material with no higher value for alternative use.
- RHA requires less energy than cement for its production
- The use of RHA as cement replacing materials reduces the carbon footprint.
- Optimizing RHA as a SCM also benefits the environment from eliminating the disposal of wastes onto land.

Rice husk is not new when it comes to transferring of low carbon technique to developing countries. The Clean Development Mechanisms, (CDM) in the Kyoto protocol have been used for many projects in India where rice husk is used for production of electricity and Certified Emission Reductions (CER). The amount of the CERs has been calculated according to the baseline for CO_2 emissions from electricity production in India. In CDM projects the CO_2 reductions have been focused on energy and not cement replacement.

This study aims to increase the use of Rice Husk Ash (RHA) in developing countries (with Nepal as a research example) for minimizing CO_2 emissions and increasing the use of local waste and other local materials. This study also aims to investigate a paradigm shift to produce concrete without Portland cement by looking at the antique way of producing concrete. The scenarios are followed below:

1. Rice husk for production of slaked lime and pozzolans as RHA and metakaolin for total substitution of Ordinary Portland Cement as binder.
2. Rice husk for production of heat and electricity and the pozzolan RHA for partly substitution of Ordinary Portland Cement as binder.
3. Rice husk for substituting fossil fuel in a cement kiln.

2. METHOD

Projects in developing countries, leading to reduction of CO_2, can get financing from the green climate fund coupled to the international climate convention. To be able to achieve money from the climate found the receiving country must have a plan how it will reduce the climate impact describing in the *Intended Nationally Determined Contributions* and the project shall be a way to implement some parts of the plan. Then the developing country contacts a member country of the climate convention to ask for financing from the fund. For starting a broad discussion in an early stage and not get locked to specific solutions too early, this paper provides a screening climate assessment and point out strength, weakness, opportunities and threat in the product systems lifecycles for three scenarios, SWOT analysis. The SWOT analysis is a starting point for a discussion for selecting of one of the scenarios, the questions are lifted by the writers for be discussed before a decision. The main focus shall be on strength and weakness in the selection process, but opportunities and threats could be lifted up to the level of strength and weakness if a deeper analysis will be done in these fields.

In the first scenario climate reductions are calculated by comparing a concrete produced from rice husk without any Portland cement with a compressive strength at 20 MPa with a standard concrete produced with Portland cement with the same strength. In the second scenario RHA are used as a supplementary material in concrete and the exchange factor are approximately the same as for silica fume, 1 part of RHA can replace 2 parts of cement. In scenario three the climate benefit is calculated by rice husk replacing fossil coal for production of cement. The upstream activities from Rice cultivation to Central Rice Husk storage are the same in al scenarios but the aspects of local or central activities are taken in account in the SWOT analysis, see appendix C.

3. SCENARIO 1: ROMAN CONCRETE AND POWER AND HEAT PRODUCTION

The rice husk is incinerated in a Fluidized Bed Combustion (FBC). Low temperature and good mixing in presence with air are preferred for getting a reactive ash with low rest carbon. RHA are added to the concrete as a pozzolan and even another pozzolan are added, metakaolin. There is tree reason why we add metakaolin: *i)* metakaolin is an aluminosilicate and the Roman concrete are known to include alumina and *ii)* metakaolin increase the reaction velocity and also *iii)* for not put in too much RHA and avoid low workability. The process produces both heat and electricity that can be used in the process for milling rice, grinding limestone, calcinate limestone, dehydrate kaolin to metakaolin, and curing concrete if a concrete element production is integrated at the site. The Roman concrete has the compressive strength 20 MPa [9].

Table 1 – Mix design for 1 m^3 modified Roman concrete

Material	Mass [kg]
Rice Husk Ash (m_{RHA}]	110
Slaked lime ($m_{Ca(OH)2)}$	200
Superplasticizer	2
Metakaolin	110
Water	230
Aggregates	1808

The chemical composition of RHA are described by Habeeb G A and Mahmud H B, 2010 [10]. High silica and low alkali and rest carbon (LOI) make RHA to a good pozzolan. Roman concrete from the antique were made of slaked lime and volcanic ash as binders. In this study we use the same recipe but instead of volcanic ash we use metakaolin (for increase heat development) and RHA for strong pozzolanic reaction. As RHA have a very big surface there is superplasticizer added to the recipe for increase in workability without increasing the water/cement ratio.

Table 2 – Chemical and physical properties of RHA.

Oxid composition	RHA [% by mass]
SiO_2	88.32
Al_2O_3	0.46
Fe_2O_3	0.67
CaO	0.67
MgO	0.44
Na_2O_3	0.12
K_2O	2.91
LOI	5.81
Specific gravity	2.11

The reference concrete recipe is chosen for giving the same compressive strength 20 MPa with Ordinary Portland Cement (OPC).

Table 3 – Mix design for the reference standard concrete.

Material	Mass [kg]
Cement	240
Water	170
Aggregates	1910

3.1 Energy production

Low heating value of rice husk: LHV_{husk}=13 GJ/tonne.
The energy (E) in the half of the production is

$$E = RH_{50} \times LHV_{\mathrm{husk}} \tag{1}$$

E = 570 000 x 13 = 7400 TJ

The energy production in a 100 MW FBC is
7400 x 0.30/3600 = 0.61 TWh electricity and
7400 x 0.6/3600 = 1.23 TWh heat energy used for the process.

3.2 Product system

The system includes activities from raw materials to the product, a low to medium strength concrete. A concrete industry is integrated in the system for increasing the quality of the products and use energy from the process. Blue arrows are symbols for material flows and read arrows are symbols for energy flows were dotted arrows are for heat, see Figure 1.

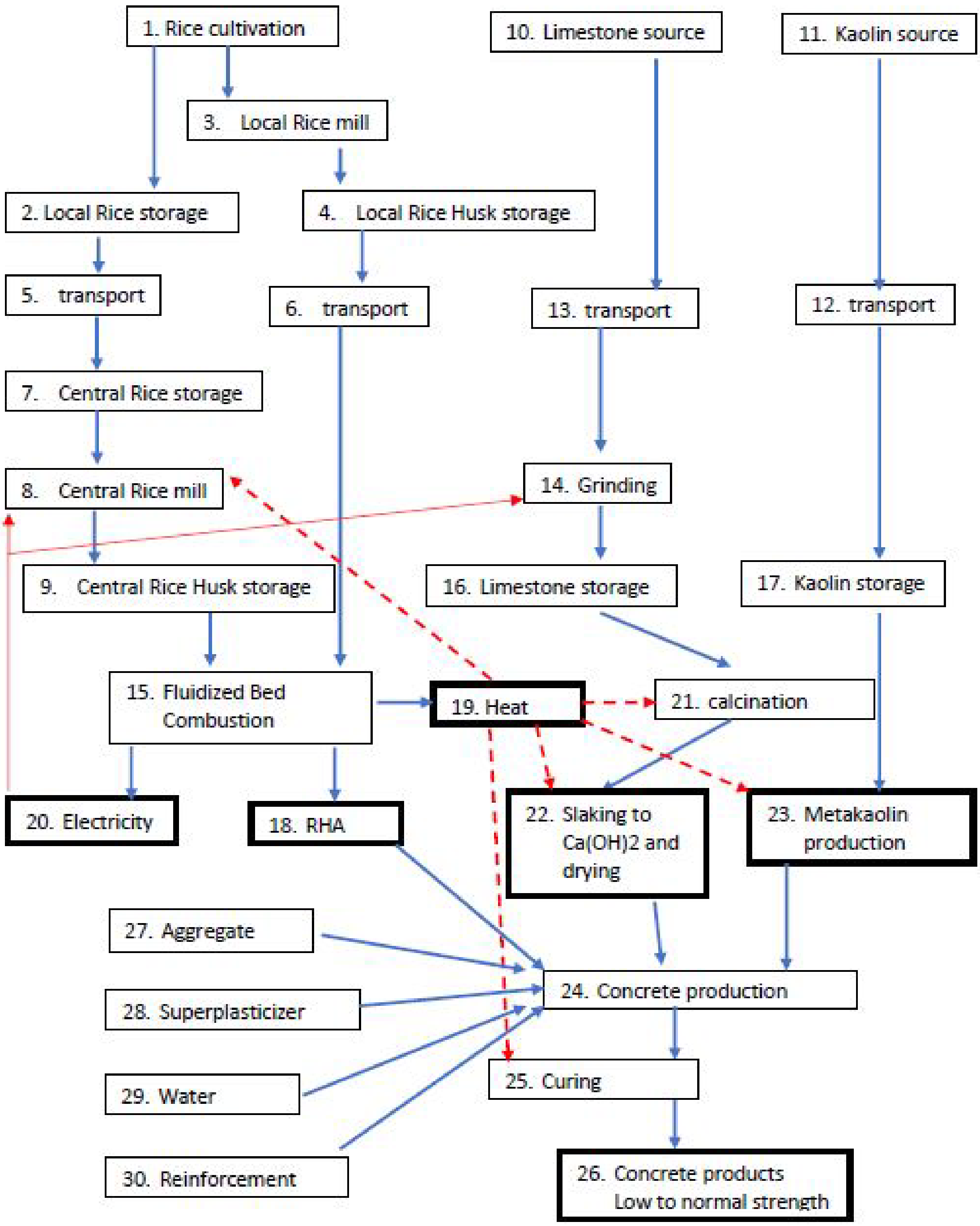

Figure 1 – Scenario 1 Product system of producing modified Roman concrete.

3.3 Climate calculation

Production of electricity and heat from the FBC will not be significant under baseline for Nepal as common energy sources are hydropower and biofuels. But in certain amount, new energy in urban areas could replace ineffective stoves and heating systems that will lower the climate impact but most significantly make the contribution to the local air conditions by low NOx-technique. The basic information and climate calculation scenario are mentioned in Appendices A and B.

More significant reductions on climate impact comes from cement replacement. If 50% of rice husk in Nepal were used, the half of the husk production (RH_{50}) can be calculated as:

$$RH_{50} = 0.5 \times R_{\text{prod}} \times RH_{\text{content}} \tag{2}$$

where R_{prod} is the total production of paddy rice in Nepal and RH_{content} is the rice husk content in paddy rice. RH_{50} = 0.5 x 5.2 x 0.22 = 0.57 million tonnes RH.

The rice husk ash from half of rice production (RHA_{50}) can be calculated as:

$$RHA_{50} = RH_{50} \times DM \times RHA_{\text{content}} \tag{3}$$

where RHA_{content} is the ash amount in dry rice husk and DM is dry matter in rice husk.
RHA_{50} = 570 000 x 0.88 x 0.25 = 125 000 tonnes RHA.

The CO_2 reductions of 1 tonne RHA ($CO_{2,\text{red}}$) is 1.29 tonnes CO_2, see appendix A.
The CO_2 reduction capacity ($CO_{2,\text{R}}$) for scenario 1 of using 50 % of annual rice husk in Nepal is:

$$CO_{2,\text{R}} = RHA_{50} \times CO_{2,\text{red}} \tag{4}$$

$CO_{2,\text{R}}$ = 125 000 x 1.29 = 161 000 tonnes CO_2/ year

4. SCENARIO 2: SUPPLEMENTARY CEMENTITIOUS MATERIAL (SCM) AND POWER AND HEAT PRODUCTION

The rice husk is incinerated in a Fluidized Bed Combustion (FBC). Low temperature and good mixing with air are preferred for getting a reactive ash with low rest carbon. The process produces both heat and electricity and the pozzolan RHA for partly substitution of cement.

4.1 Climate calculation

If 50% of rice husk were used for the production of RHA, the RHA_{50} = 125 000 tonnes. As RHA have very similar properties as Silica Fume. We assume that the replacement factor is 2. 1 kg RHA substitutes 2 kg cement. 125 000 tonnes RHA substitute 250 000 tonnes cement. The CO_2 reduction capacity for scenario 2 of using 50 % of annual rice husk in Nepal is the amount of replaced cement x emission factor for cement in Nepal (see appendix B) is 2 x 125 000 x 1.09 = 272 000 tonnes CO_2/ year. The silica production is in the range of what could be used as 10 % SCM in 2.5 million tonnes concrete/year in Nepal. But export or other products could be good alternatives.

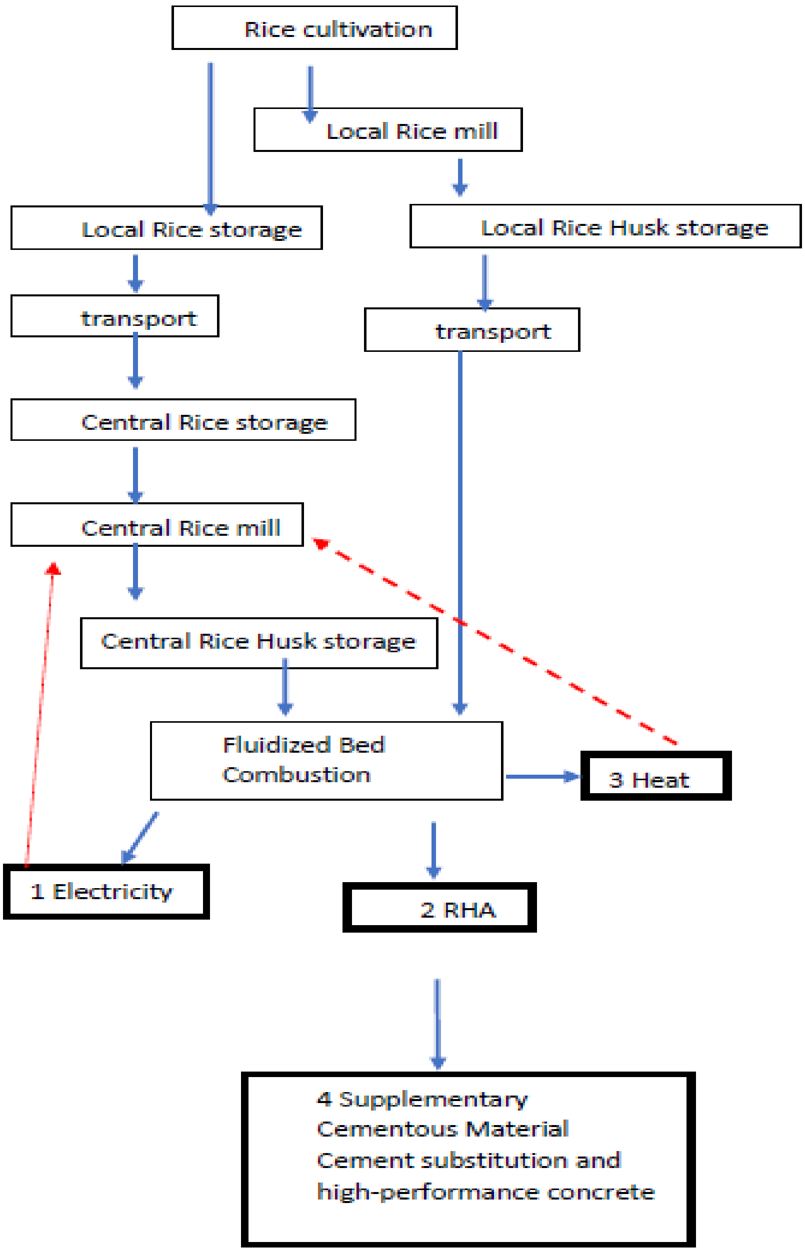

Figure 2 – Scenario 2 Product system for production of Energy and RHA and as a SCM.

4.2 Product system

The system includes activities from raw materials to the product, RHA. Blue arrows are symbols for material flows and read arrows are symbols for energy flows were dotted arrows are for heat, see Figure 2.

4.3 Energy production

The energy production in a 100 MW FBC if half of the rice production reused is 0.61 TWh electricity and 1.23 TWh Heat, see calculation Scenario 1.

5 SCENARIO 3: CEMENT PRODUCTION WITH RH AS FUEL AND SILICA SOURCE

The rice husk is used in a cement kiln for substituting fossil coal. To some content the RHA also substitute other silica sources for the production but no benefits are calculated for this.

5.1 Product system

The system includes activities from raw materials to the product, OPC Blue arrows are symbols for material flows, see Figure 3.

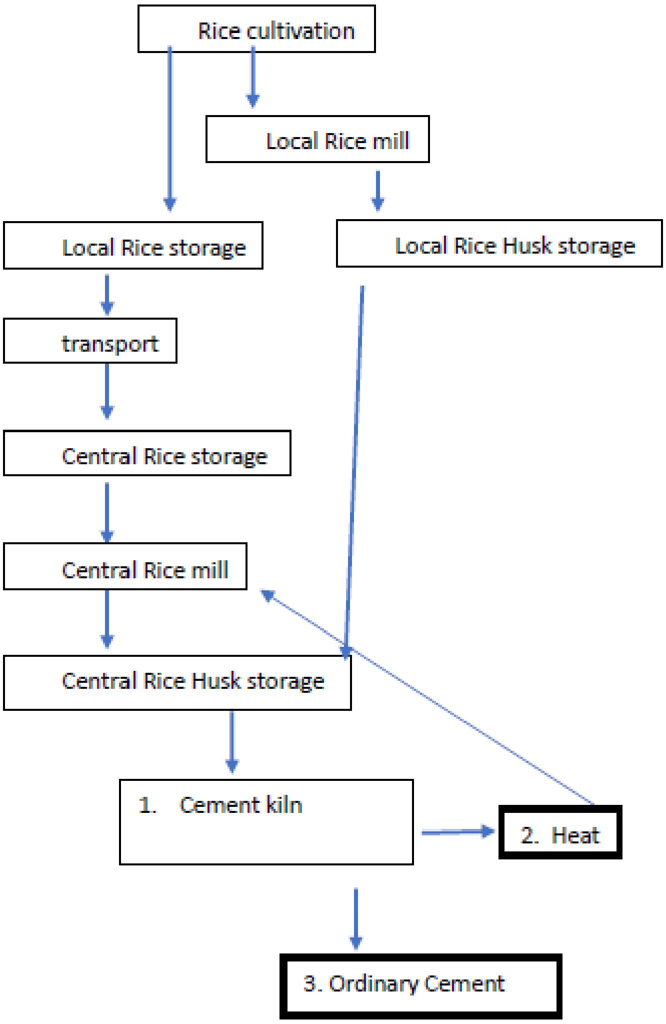

Figure 3 – Scenario 3, Rice husk as fuel in a rotary kiln for cement production.

5.2 Climate calculation

We assume that 50% of rice husk were used for the production of rice husk ash. RH_{50} = 570 000 tonnes, see scenario 1. The energy content is the amount multiplied with low heating value. The energy is 570 000 x 13 = 7 410 000 GJ.

In Nepal the average energy use for cement production is 5.4 GJ/tonne a cement. The cement production (C_3) of 7 410 000 GJ is 7 410 000 / 5.4 = 1.37 million tonnes. The CO_2 reduction capacity for scenario 3 of using 50 % of annual rice husk in Nepal is:

$CO_{2\ \mathrm{red}} = m_{\mathrm{CO2,c}}$ x C_3 = 0.59 x 1370 000 = 808 000 tonnes CO_2/ year.

The silica content in RH is 90 %. The amount of silica is 125 000 x 0.9 = 112 000 tonnes silica. In the cement production there is an input of 180 kg silica/tonne cement. The silica corresponds to 112 000 / 0.18 = 625 000 tonnes cement. If half of production of RH in Nepal were used in the national cement production, the RH stays for 625 / (0.7 x 2500) x 100 = 35% of the silica content in the cement.

6. CONCLUSIONS

In scenario 1 the CO_2 reduction capacity for the Roman concrete and power and heat production of using 50% of annual rice husk in Nepal is 161 000 tonnes CO_2/year whereas, in scenario 2 the CO_2 reduction from Supplementary Cementitious Material (SCM) and power and heat production, of using 50% of annual rice husk in Nepal is 272000 tonnes CO_2/year. The potential energy production of using 50% of RH in a 100 MW FBC is estimated to be 0.61 TWh electricity and 1.23 TWh heat per year. For the cement production with RH as fuel and silicon source in scenario 3, the CO_2 reduction capacity using 50% of annual rice husk in Nepal is 808 000 tonnes CO_2/ year. The climate assessments show that scenario 3 have most climate benefits, see Figure 4.

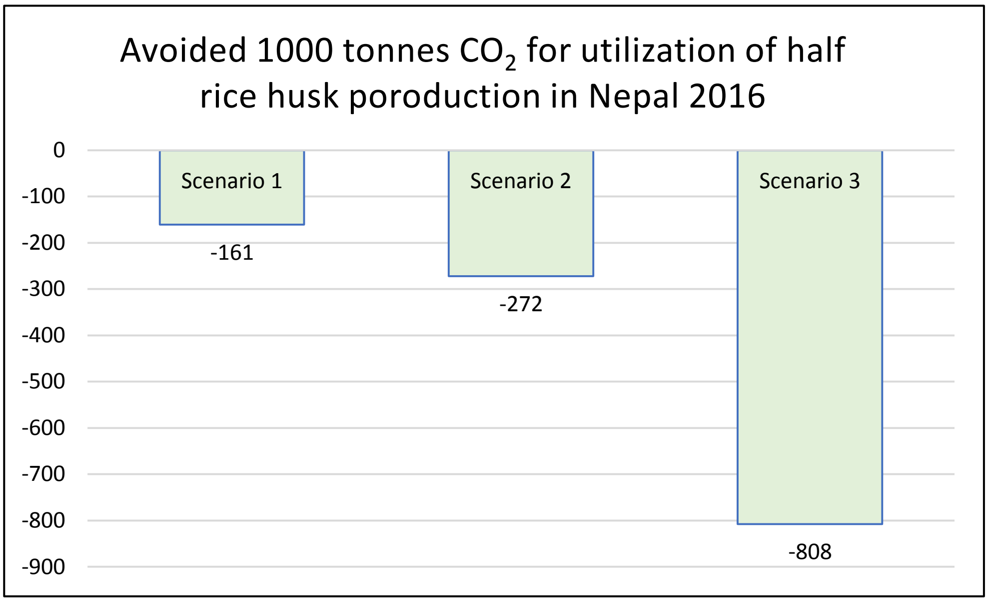

Figure 4 – Avoided CO_2 emissions.

The SWOT analysis, see appendix C, point out many benefits with scenario 2. There the most important strength is the electricity production from biofuel that is goal in Nepal's plan for reducing climate impact.

7. DISCUSSION

The demand for cement, especially in the developing countries, is expected to double within the next 20 years. Hence, the need to reduce the carbon emissions associated with the production of cement is one of the major concerns of the cement and concrete industry. This paper focuses on different scenario for utilizing rice husk resource in Nepal for carbon neutral mineral products.

If the result will be applied for another country it is important to take in account that the result is calculated for a baseline with an energy use for cement production at 5.4 MJ/ton cement which is quite high and with electricity production from hydro power and biofuel. Therefor the scenario 2 and to some extent even scenario 1 will have more avoided CO_2 in a country that use fossil fuels for electricity production. The baseline for electricity production for Nepal is calculated for big scale energy production, if we instead look at small stoves in homes in the capital of Nepal, they often are fired with coal. It is possible that a new large-scale production of heat and power to some extent will replace the stoves in the hoses. This will both increase the avoided emissions for scenario 2 and give a significant positive contribution to the air quality in the city. The use of RHA as pozzolan and substituting cement give a high strength concrete and are quite easy to do [10]. In future research a cost analysis and identification of opportunities and threats could be studied.

REFERENCES

1. Andrew R M: "Global CO_2 Emissions from Cement Production," *Earth Syst. Sci. Data*, Oslo, Norway, No. 10, 2017, 195-217, 2017.
2. Herzog T and Billings B: "Navigating the Numbers," World Resource Institute, 2005.
3. Schneider M, Romer M, Tschudin M, and Bolio H, "Sustainable Cement Production - Present and Future," *Cem. Concr. Res*., Vol. 41, No. 7, 2011, pp. 642–650.
4. Wray P, "Straight Talk with Karen Scrivener on Cements, CO_2 and Sustainable Development," *Am. Ceram. Soc. Bull*., Vol. 91, June-July 2012, pp. 47-50.
5. Baumert K A, Herzog T, Pershing J, and Billings H, "Navigating the Numbers Greenhouse Gas Data and International Climate Policy," Libr. Congr. Control Number, 2005.
6. Food and Agriculture Organization of the United Nations, "FAO Rice Market Monitor Food," Rome, Italy, 2015.
7. Rao K and Anusha P P R T, "Stabilization of Expansive Soil with Rice Husk, Lime and Gypsum – An Experimental Study," *Int. J. Eng. Sci. Technol.*, 2011, pp. 8076–808.
8. Malhotra V.M. and Mehta P.K., Pozzolanic and Cementitious Materials. Gordon and Breach, Amsterdam, The Netherlands, 1996.
9. Pages L: "Low Carbon Emission Cement Using Bio Origin Pozzolan," *Degree Project* FEI , RISE Swedish Cement & Concrete Research Institute, Stockholm, Sweden, 2018.
10. Habeeb G A and Mahmud H B, "Study on Properties of Rice Husk Ash and Its Use as Cement Replacement Material", *Materials Research*, Vol. 13, No. 2, 2010, pp. 185-190.

APPENDIX A

Input data to the analysis:

Production of milled rice in world: 500 million tonnes/year
Production of paddy rice (husk+ rice) in Nepal (R_{prod}): 5.2 million tonnes (2016)
% RH of rice (RH_{content}): 22%
Moist content in rice husk: 12%
RHA of rice husk: 25%
Silicon dioxide of rice husk ash: 90%
Carbon of rice husk: part organic of RH: 0.71and part C of organic: 0.4 gives 0.284
Density of rice husk: 86-114 kg/m^3
Low heating value of rice husk: 13 MJ/kg, dry content 88%
Thermal efficiency of large 100 MW fluidized bed combustion: 60%
Electricity efficiency of large 100 MW fluidized bed combustion: 30%
Thermal efficiency of local 10 MW combustion: 40%
Electricity efficiency of local 10 MW combustion: 20%
Heat used for production of 1 tonne cement: 5.4 GJ, most wet kilns
Power used for production of 1 tonne cement: 148 kWh
Silica used for production of 1 tonne cement: 180 kg
Part of CaO by weight in cement: $x_{\text{CaO}} = 0.64$
CO_2 emission from 1 MJ coal: 110 g CO_2
CO_2 emission from 1 kWh electricity in Nepal: 5 g CO_2, hydropower
CO2 emission from 40 tonnes full packed lorry: 60 g CO_2/tonnes, km
CO_2 emission from 40 tonnes 30% packed lorry: 180 g CO_2/tonnes, km
Cement consumption in Nepal: 2.5 million tonnes/year. In 2010, 30% import from India.

APPENDIX B

Climate calculation Scenario 1

Molar weight $(OH)_2$, $M_{(OH)2}$ = 34
Molar weight Ca, M_{Ca} = 40
Molar weight CO_2, M_{CO2} = 44
Molar weight CaO, M_{CaO} = 56
Energy (coal) used for cement production in Nepal: E_{cement} = 5.4 GJ/tonne
CO_2 emissions from coal combustion: e_{coal} = 0.11 kg CO_2/MJ
CaO content in cement: x_{CaO} = 0.64 kg/kg

<u>Production of 1 m^3 Roman concrete</u>
Lime production: 200 kg
RHA use: m_{RHA} =110 kg
Calcination of limestone when heated: $CaCO_3 = CaO + CO_2$
Slaking quick lime: $CaO + H_2O = Ca(OH)_2$ (slaked lime)
For one part slaked lime there is production of one part CO_2 due to calcination.

CO_2 emission (m_{CO2}) from production of lime for 1 m^3 Roman concrete:
$m_{CO2} = m_{Ca(OH)2}$ x $M_{CO2}/M_{(CaOH)2)}$
(1)m_{CO2} = 200 x 44 / 74 = 119 kg CO_2/m^3 concrete

<u>Production Standard concrete</u>
The most significant climate impact is the 240 kg cement use with Nepal conditions
CO_2 from cement production comes from fossil fuel used (5.4 MJ/kg) and calcination
CO_2 from fuel: $m_{CO2,c} = E_{cement}$ x e_{coal} = 5.4 x 0.11 = 0.59 kg CO_2/kg cement

CO_2 release from calcination. $CaCO_3 = CaO+CO_2$
CO_2calcination = x_{CaO} x (M_{CO2}/ M_{CaO})
CO_2calcination = 0.64 x (44/56) = 0.5 kg CO_2/kg cement
The CO_2 emissions from a typical cement in Nepal
$CO_{2,cem,Nepal}$ = 0.5 +0.59 = 1.09 kg CO_2/kg cement
Total CO_2 emissions for 1 m3 concrete with 240 kg cement
(2) $m_{CO2} = m_{cem} * CO_{2,cem,Nepal}$ = 240 x 1.09 = 261 kg CO_2/m^3 concrete.

Climate impact reduction: $CO_{2\ red} = m_{CO2\ (2)} - m_{CO2\ (1)}$ = 261-119 = 142 kg CO_2/m^3 concrete
Climate reduction for 1 kg RHA: $CO_{2,red/kg} = CO_{2,red}/m_{RHA}$ = 142/110 = 1.29 kg CO_2/kg RHA

APPENDIX C

Activity	SWOT Analysis	Scenario 1	2	3
	Strengths	**1**	**2**	**3**
Rice cultivation	1140 000 tonnes of RH in Nepal make it to a big national resource.	1	2	3
Rice cultivation	Over 100 million tonnes of RH in the world. The world potential for CO_2 reductions are big.	1	2	3
Local rice storage	Local storage secure food near the population.	1	2	3
Local rice husk storage	Local storage relieves the central production site.	1	2	3
Fluidized Bed Combustion, FBC	Temperature could be below 700°C to produce amorphous silicon dioxide - Low temperature give low NOx emissions.	1	2	
Lime Stone Resources	Resources available in Nepal.	1		
Kaolin Resources	Some resources available in Nepal if we will use metakaolin in the concrete mix.	1		
RHA	RHA could be used in many applications as a silicon source	1	2	
RHA	Very high content of amorphous silica in RHA make it good as a pozzolan.	1	2	
Electricity / Heat	The potential energy production of using 50% of RH in a 100 MW FBC are estimated to be 0.61 TWh electricity and 1.23 TWh heat per year.		2	
Electricity	Included in Nepal Goal in Intended Nationally Determined Contributions. Help to industrialize the country and provide low CO_2 energy.		2	
Electricity	Could be used for grinding and milling.	1	2	
Heat	Could be used for production of metakaolin, lime, rice processing, curing concrete etc.	1		
Heat	Could be used for rice processing and with district heating households and industry etc.		2	
Heat	Could be used for district heating etc.		2	3
Cement kiln	Known technique, Product standards, Building Standard, Silica comes with the fuel.			3
Ordinary cement	Standard product.			3
	Weaknesses			
Rice cultivation	Methane emission under anaerobe conditions contribute to global warming.	1	2	3
Local rice mill	Effective use of energy from rice husk is not so easy.	1	2	3
Local rice husk storage	Low density on RH demands large buildings for dry storage.	1	2	3
Transports	Long transports could lead to high climate impact and higher cost - Load capacity for rice husk in a big lorry is just 30% of max weight capacity. It is restricted by the low density. This gives about 180 g CO_2/ (tonne, km).	1	2	3
RHA	Workability of concrete decrease. Superplasticizer could be needed.	1	2	
	Opportunities			
Rice cultivation	Avoid anaerobic conditions in cultivation. Use rice with high silica content in husk.	1	2	3
Transports	If possible use train and non-fossil transport systems.	1	2	3
RHA	Pure silica could be produced for a lot of applications. Recycling of silica minimizes waste.		2	
Cement kiln	Potentially lower temperature is needed to produce clinker when rice husk is used as silica source.			3
	Threats			
Transports	A hilly country could make transports difficult and increase the energy and cost.	1	2	3
RHA	Rest carbon from insufficient incineration could inhibit superplasticizer and contribute to a dark concrete. The low albedo increases global warming. Lack of standard for RHA in concrete.	1	2	