App. Envi. Res. 38 (3): 15-26

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/aer

Application of Life Cycle Assessment Method for Environmental Impact Assessment of Fired Brick Production Plant in Thailand

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Article History
Submitted: 26 April 2016/ Accepted: 20 June 2016/ Published online: 17 October 2016

Abstract

In many Asian countries, fired bricks are produced by burning raw bricks in a rudimenttary clamp kiln without pollution control mechanisms, a practice which contributes to several kinds of environmental impact. This research investigated the inputs and outputs associated with production of fired bricks using the rice husk-fuelled clamp kiln. Data collected included raw material use, energy, products, emissions and kiln temperatures. To quantify environmental impacts, the consequential-focused life cycle assessment (LCA) approach was adopted. The impacts were assessed in terms of fuel substitution as the acquisition of another fuel was required to substitute for electricity. The findings indicated that the clamp kiln technology produced low CO_2 emissions per unit of production and per unit of energy input, despite poor specific energy consumption. The LCA analysis indicated that the use of rice husk was the major contributor to environmental impact, and that abiotic depletion of fossil fuels represented the environmental hotspot. To improve combustion efficiency, the clamp kilns should be either insulated or replaced with more efficient kiln technology, in conjunction with the use of rice husk.

Keywords: Life cycle assessment; Clamp kiln; Fired brick; Cradle to grave; Rice husk

Introduction

In modern buildings, construction materials such as. bricks and cement are the major contributor to the building's overall environmental impact throughout its life cycle [1]. This is significant since fired clay bricks are an essential construction material for construction of buildings all over the globe [2]. In Asia, annual consumption of fired bricks is as high as 1,300 billion bricks [3]. In Thailand, fired bricks accounted for 13% of the total demand for construction materials in 2008 and were second to concrete in terms of volume [4].

Currently, production of fired bricks can be classified into two types according to the burning process: continuous and intermittent. In the continuous burning process, the kilns typically deployed are, e.g., the fixed chimney bulls trench kiln (FC-BTK), natural draught zigzag kiln, high draught zigzag kiln, vertical shaft brick kiln (VSBK), Hoffman kiln, and tunnel kiln. In contrast, the intermittent burning process use clamp kilns or downdraught kilns [2]. The main contributors to the environmental impact for all kiln types, as reported by UNEP [2], is air pollution including carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM) and black carbon.

The environmental burden of fired brick production is dependent on the type of fuel and kiln used [5-6]. To produce a fired brick requires an energy input of 0.5-5 MJ/kg of brick [7-8], and the most common energy sources are coal, pet coke and biomass [5, 7, 9]. Ubiquitous in most Asian countries, including China, India and Thailand, clamp kilns remain the dominant kiln type [2-3, 5, 9-10]. Descriptively, clamp kilns consist of a rectangular chamber with uncovered top for intermittent feeding of fuel. In some Asian countries, e.g. Afghanistan, India, Nepal, Pakistan and Vietnam, rice husk is the main fuel source [11-13].

In Thailand, there are at present 730 fired brick factories of varying sizes, 90% of which utilize clamp kilns without any pollution control mechanism in place [14]. Although many Asian countries, including Thailand, have stressed the importance of reducing carbon emissions in order to reach national environmental and climate change goals [15-19], environmental data are seriously lacking, particularly those relevant to manufacturing, including fired bricks. Specifically, to reduce carbon emissions and produce more eco-friendly fired bricks, environmental assessment information pertinent to production of fired bricks is needed.

Prior research on the environmental impacts of air emissions from different brick kiln technologies documented that the zigzag kilns and VS-BK emitted lower CO_2 per kg of fired brick than other kiln types [11, 13]. Koroneos and Dompros [20] conducted an environmental life cycle assessment (LCA) of fired bricks produced using the continuous burning process using pet coke as the energy source in Greece, while Kumbhar and Kulkarni [5] carried out the same assessment for brick production using the clamp kiln technology fuelled by bagasse and coal. As expected, the findings of both studies revealed that fuel was the major contributor to environmental impact, and that the highest impact was acidification due to use of low grade fuels [5, 20]. Nonetheless, no research has investigated fired brick production using the clamp kiln technology and rice husk as the energy source, which is the predominant mode of fired brick production employed in a number of Asian countries, including Thailand.

In LCA, there are two principal models for the life cycle inventory (LCI), which is the straightforward accounting of everything involved in the system of interest: the attributional and consequential models. In general, the attributional approach, which is embedded into a static technosphere and uses average data for co-products [21-22], is more widely utilized than the consequential model, which is embedded into a dynamic technosphere and uses marginal data for co-products [21-24]. However, the dynamic nature and close link between building material production and economic policy as well as consumer demand [25-26] render the consequential model more relevant to research into the environmental impact of construction materials and processes.

The objectives of this research are (i) to gather primary data on production of fired bricks in Thailand and to apply the consequential-focused LCA concept to assess the environmental impacts, using rice husk as the energy source in the clamp kiln; and (ii) to compare the environmenttal impacts of various production processes.

Methodology

The brick-making process involves mixing, drying and burning. In Thailand, fired bricks are made by baking raw bricks in a rudimentary clamp kiln fuelled by rice husk for 6-8 days. The time variation is due to the weather and kiln size. The emissions from a fired brick factory are attributable to the fuels used (diesel and rice husk) and electricity.

This research investigated four conventional rice husk-fuelled fired brick plants in central Thailand, a region with a high concentration of fired brick factories. The selected brick factories produce the same product via the same process, but using different machinery. The first factory is located in the province of Ayutthaya and employs only one machine for moulding, with the remaining production processes carried out manually. The second factory is located in the province of Angthong and uses a special manual method for quick drying of raw brick. The remaining two factories are located in the province of Singburi and use the same machinery: a mini excavator, a forklift and a wheel loader. Data collection was carried out from August to December 2013.

1) Measurement

Data on temperatures and air emissions total suspended particulates (TSP), total volatile organic compound (TVOC) and nitrogen dioxide (NO_2) were systematically collected. Temperatures were measured three times daily (morning, afternoon and evening) for the entire baking period (6-8 days) at nine pre-determined openings on one side of the clamp kiln (Figure 1). In the temperature measurement, a K-type thermocouple was successively inserted into the nine openings. TSP was measured every 24 hr using a high volume air sampler and analysed by the gravimetric method [27]. The measurements of TVOC and NO_2 were carried out three times daily for the entire baking period using a Pro-check 5000 portable gas detector.

Weather data were obtained from the Thai Meteorological Department. In this study, the overall performance assessment of the clamp kilns was based upon the actual emissions data. In addition, data on raw material inputs and product outputs (excluding air emissions) of the life cycle inventory (LCI) were collected from the four brick factories for further analysis of environmental impacts.

2) Data analysis

In this research, the scope of the environmental impact assessment is of cradle to gate, encompassing biomass production, raw material transport and mixing, drying of raw bricks and the firing of the bricks. The selected functional unit is 1 square meter of brick wall, comprising 121 bricks. The standard size of one fired brick is 14×6.5×4 cm [28]. Emissions data from rice husk combustion were based on the actual input data (Figure 2) and by extrapolation with reference to the findings in Chungsangunsit, Gheewala [29], who studied the air emissions from electricity generation using rice husk as the energy source in a closed system.

Based on the consequential model, rice husk is a co-product from the milling of rice and could be deployed as a substitute fuel in place of petroleum-based and renewable fuels/energy to generate electricity. In Thailand, the government promotes the use of biomass in the production of electricity, with rice husk as the principal substitute energy source for petroleum-based fossil fuels in power plants [30]. Based on the conversion factor published by Thailand's Department of Alternative Energy Development and Efficiency [31], the usage of rice husk per one functional unit of fired bricks (121 bricks) is equivalent to electricity production of 12.50 kWh.

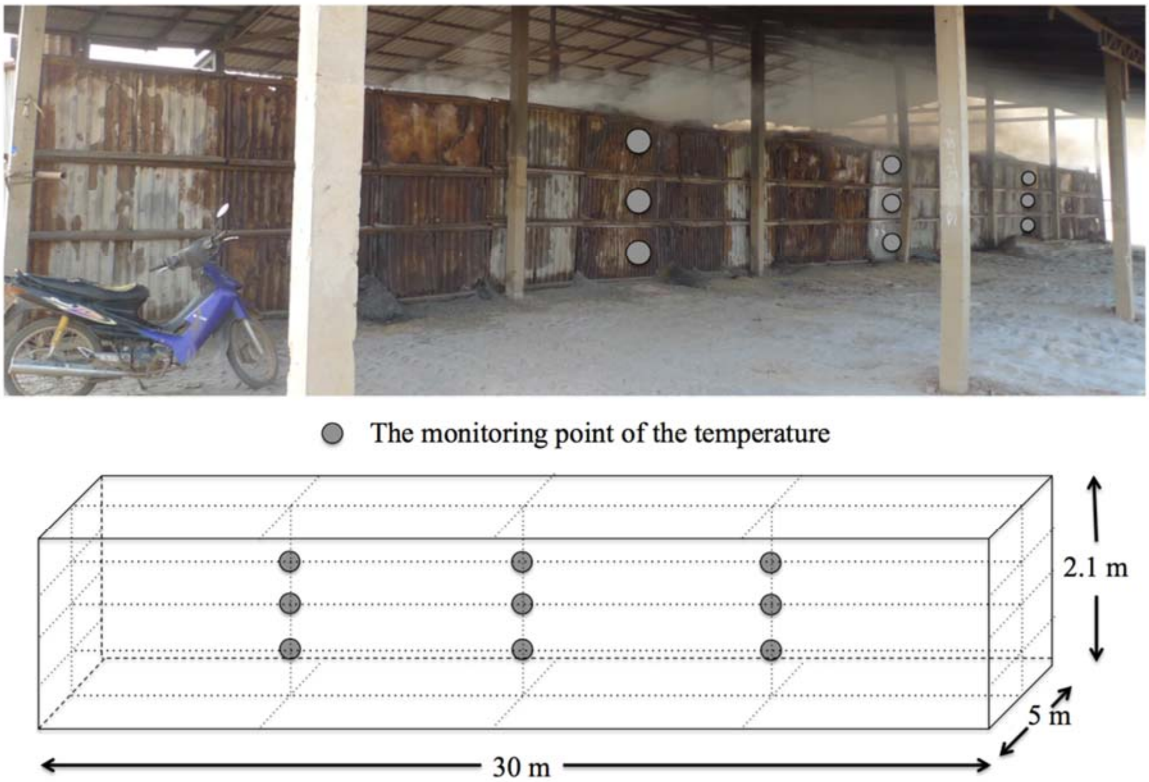

Figure 1 A photograph image of a clamp kiln and the geometry of the kiln with the positions of nine openings for temperature measurement

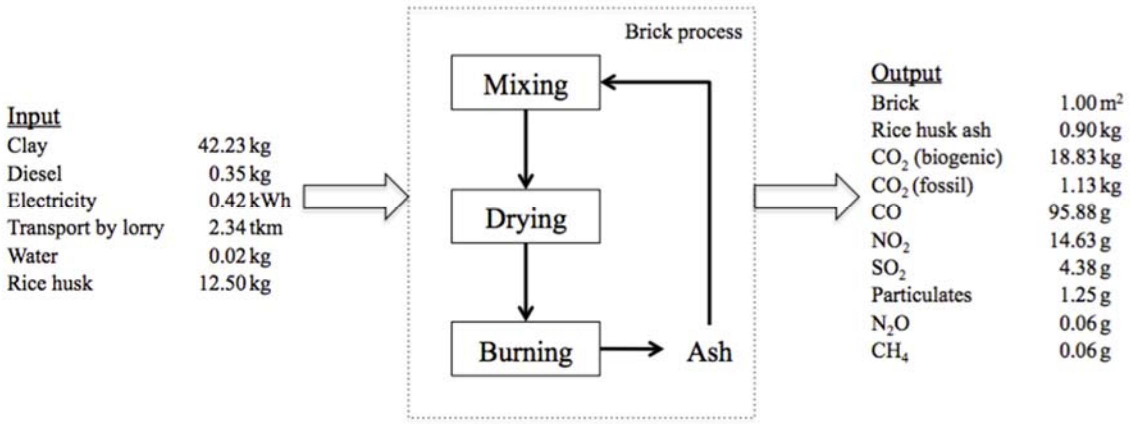

Figure 2 The input and output from the rice husk-powered clamp kiln fired brick production

The principal product and by-product of the fired brick production are respectively the bricks and rice husk ash. In the brick-making process using a clamp kiln, half of the rice husk ash from the production process is reused as raw material for the subsequent production of bricks. In addition, prior research noted the use of rice husk ash in fertilizers since a ton of rice husk ash contains 0.25 kg of potassium [32-33]. Thus, in the LCI calculation, this research assumed that the remainder of rice husk ash (50%) is used as potassium fertilizer in agriculture.

The life cycle impact assessment (LCIA) was carried out by the CML-IA method using Sima-Pro 8 and Ecoinvent to determine environmental impacts in terms of abiotic depletion, abiotic depletion (fossil fuels), global warming, photo-chemical oxidation, acidification and eutrophication. All the environmental impacts were normalized to identify any hotspots. The findings were compared to those of Koroneos and Dompros [20], whose original scope ranged from 'cradle to grave'. A modification was made to their research scope to correspond to the analysis scope of this research (cradle to gate) and the impacts were recalculated based on the consequential-focused LCIA method using their original input and output data.

For the sensitivity analysis of LCA, the shift from the clamp kiln technology to VSBK is an economically and environmentally viable solution to improving the combustion efficiency and at the same time lowering the air emissions [13]. The environmental impacts were recalculated with the same input and output data (i.e. those belonging to the four brick factories), except for the amount of fuel use per square meter of brick wall which was decreased.

Results and Discussion

1) Primary data

Figure 3 illustrates average hourly temperatures and average daily concentrations of air emissions for the entire brick baking period. The temperature profiles measured at the nine openings indicated the non-uniform temperatures inside the kilns, as shown in Figure 3a. The variations were largely attributable to the loss of heat to the surroundings through the uncovered top and the kiln walls which were constructed from corrugated metal sheets [2]. In addition to the kiln's poor performance with regard to the combustion and brick production efficiencies Utama, McLellan [1], the temperature non-uniformity exacerbates the levels of air emissions. To address, the kiln walls should be insulated with plasters or by using heat-resistant brick walls to keep the heat loss to a minimum [2, 10].

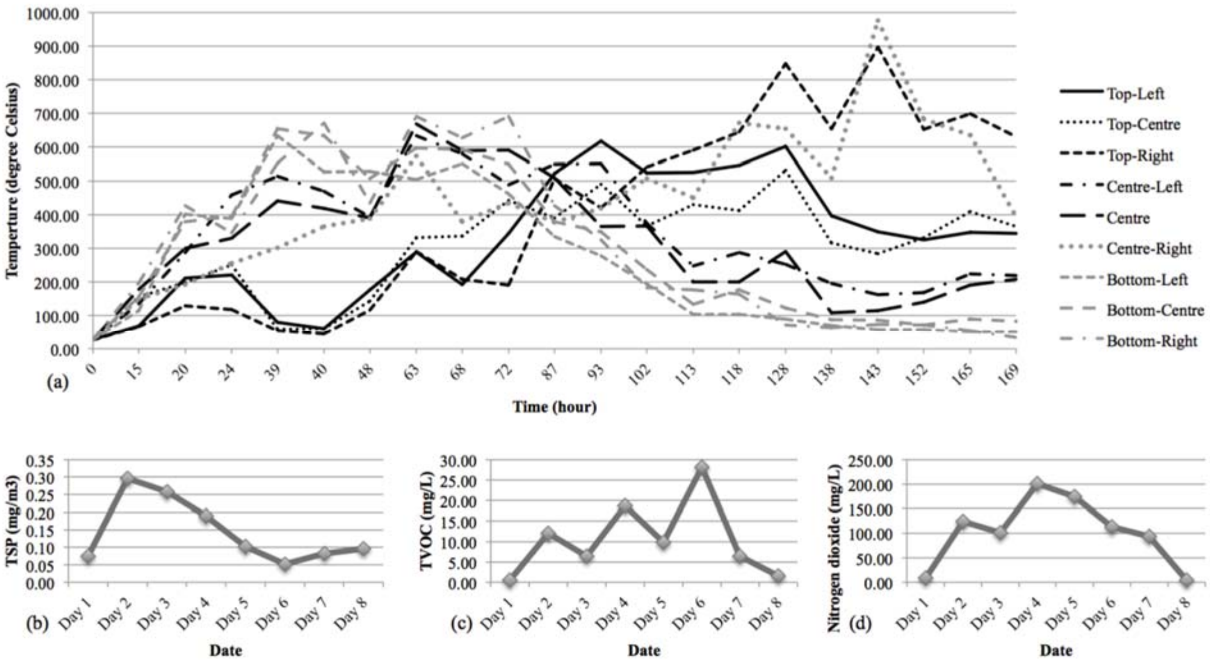

Figure 3 The profiles of: (a) average hourly temperatures at nine different openings, (b) average daily TSP emissions concentrations, (c) TVOC and (d) NO_2

For the emissions data, the average concentrations of TSP, TVOC and NO_2 were respectively 0.14 mg/m^3, 10.42 mg/L and 102.51 mg/L. At present, Thailand has no standards on air emissions specific to the brick production and to the clamp kiln in particular. In this research, the maximum TSP emissions concentration of 0.51 mg/m^3 is significantly lower, in comparison with the TSP emissions standard for biomass-based power plants of below 120 mg/ m^3 [34]. The TVOC levels nevertheless indicated the incomplete combustion of the clamp kiln. According to Chungsangunsit et al. [29], rice husk typically contains 42.2% carbon and 0.7% nitrogen. To reduce TVOC emissions, the combustion performance of the kilns needs to be improved. In addition, fuels with lower nitrogen content, e.g. rice straw and leaf litter [35], should be used to reduce NO_2 emissions. Figure 4 compares energy consumption for three energy sources, i.e. rice husk, diesel and electricity, in the fired brick production. The results revealed that combustion of rice husk provided the maximum energy.

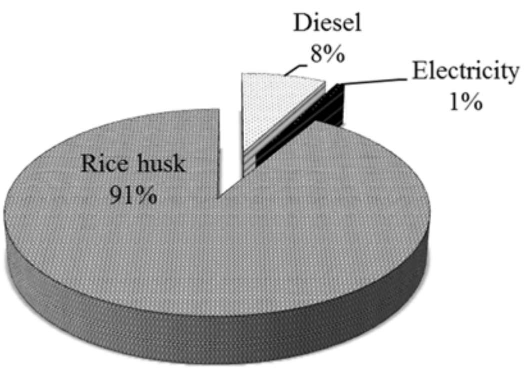

Figure 4 The proportion of energy consumption in from the rice husk-powered clamp kiln fired brick production

In this research, gaseous emissions from the production process were carbon dioxide (CO_2) (biogenic), CO_2 (fossil), carbon monoxide (CO), NO_2, sulfur dioxide (SO_2), particulates, dinitrogen oxide (N_2O) and methane (CH_4), in the amounts, on average, of 18.83 kg, 1.13 kg, 95.88 g, 14.63 g, 4.38 g, 1.25 g, 0.06 g and 0.06 g per square meter of brick wall, respectively. As shown in Table 1, the energy input requirements (the specific energy consumption) for the production of fired bricks using different fuels and kiln technologies were lower than that of this research (3.14 MJ/kg fired brick). However, the use of rice husk as fuel in the clamp kiln in the fired brick production produced lower levels of CO_2 emissions per energy input, while the Greek fired brick production process produced less particulate and CO [20]. To address the issue of high specific energy consumption per kg fired brick, the combustion performance should be enhanced and heat loss reduced. The improvement would contribute to a lower energy input per kg fired brick and lower emissions per energy input. Nevertheless, the clamp kilns are a low-efficiency type of kiln [12-13], given that heat loss from could be reduced up to 58% by switching to VSBK [13], whereby the specific energy consumption would be reduced to 1.94 MJ/kg fired brick and rice husk use would decrease to 0.084 kg per kg fired brick or 5.25 kg per square meter of brick wall.

2) Environmental impacts

The environmental impacts of fired brick production of the four brick factories were assessed in terms of abiotic depletion (fossil fuels), global warming, acidification, eutrophication, photochemical oxidation and abiotic depletion. Table 2 presents the respective average values of these impacts: 136.25 MJ, 11.14 kg CO_2 eq, 0.0561 kg SO_2 eq, 0.0397 kg PO_4^- eq, 0.0049 kg C_2H_4 eq and 2.76×10^{-6} kg Sb eq. All four factories showed similar environmental impacts, with the fourth showing the largest impacts (Table 2) due to its high use of diesel and the greatest distance from the clay site to factory for this factory.

Table 1 The comparison of efficiencies in terms of emissions and energy consumption by kiln and fuel types

Type of kiln	Type of fuel	Emissions per product (g/kg fired brick)				Specific energy consumption (MJ/kg fired brick)	Emissions per energy input (g/MJ)			
		CO_2	Black carbon	PM	CO		CO_2	Black carbon	PM	CO
FCBTK[1]	Mixed fuel	131.00	0.13	1.18	2.00	1.30	100.77	0.10	0.908	1.538
Natural Draught Zigzag Kiln[1]	Mixed fuel	105.00	0.01	0.22	0.29	1.06	99.06	0.01	0.208	0.274
High Draught Zigzag Kiln[1]	Mixed fuel	105.00	0.02	0.24	1.62	1.03	101.94	0.02	0.233	1.573
VSBK[1]	Coal	70.50	0.00	0.15	1.84	0.80	88.13	0.00	0.188	2.300
VSBK in India[2]	Coal	118.00	NA	0.09	4.14	0.93	126.00	NA	0.100	4.390
VSBK in Vietnam[2]	Coal	79.00	NA	0.12	1.59	0.54	146.00	NA	0.220	2.930
Hybrid Hoffman Kiln[1]	Coal	100.00	NA	0.29	NA	1.20	83.33	NA	0.242	NA
Tunnel Kiln[1]	Mixed fuel	166.30	0.00	0.24	3.31	1.40	118.79	0.00	0.171	2.364
Down Draught Kiln (DDK) [1]	Mixed fuel	282.40	0.29	1.56	5.78	2.97	95.08	0.10	0.525	1.946
Greece brick factory[3]	Pet-coke	201.78	NA	0.01	0.02	1.98	102.16	NA	0.005	0.012
This study (CO_2 emissions only from fossil fuel)	Rice husk	18.08	NA	0.02	1.53	3.14	5.75	NA	0.006	0.487

Remarks: [1] UNEP [2]
[2] Rajarathnam, Athalye [11]
[3] Koroneos and Dompros [20]
NA denotes "not available".

Table 2 Comparison between the normalized results of the impact categories of Koroneos and Dompros [20] and this research study

Category		**This research**[1]					**Koroneos and Dompros**[2,*] **[20]**
Impact category	Unit	1st Factory	2nd Factory	3rd Factory	4th Factory	Average	
Abiotic depletion (fossil fuels)	MJ	126.00	116.00	142.00	161.00	136.25	495.00
Global warming (GWP100a)	kg CO_2 eq	10.60	9.75	11.40	12.80	11.14	47.10
Acidification	kg SO_2 eq	0.0571	0.0508	0.0555	0.0609	0.0561	0.4870
Eutrophication	kg PO_4^- eq	0.0412	0.0364	0.0389	0.0423	0.0397	36.20
Photochemical oxidation	kg C_2H_4 eq	0.0052	0.0045	0.0049	0.0053	0.0049	0.0288
Abiotic depletion	kg Sb eq	2.66×10^{-6}	2.37×10^{-6}	2.80×10^{-6}	3.21×10^{-6}	2.76×10^{-6}	5.06×10^{-6}

Remark:
[1] Study location and fuel used were Thailand and rice husk, respectively
[2] Study location and fuel used were Greece and pet-coke, respectively
[*] normalized to cradle to gate to correspond to the scope of this research
- LCIA method used and scope of both studies were CML-IA and cradle to gate

Figure 5 provided the results of environmental impact categories and environmental impact contribution of each factory. The main contributor of the environmental impacts for all factories, except photochemical oxidation, was the use of rice husk in the production of fired bricks, which is a diversion of the energy source for electricity generation to the fired bricks production. Meanwhile, baking bricks in the kiln was largely responsible for photochemical oxidation. Table 2, which compares the findings of this research with Koroneos and Dompros [20], demonstrates that our environmental impacts were generally lower, suggesting that the environmental impacts of rice husk were less than those of pet coke. However, the global warming impact of this research (0.378 kg/ kg of brick) was higher than that of unfired clay brick (0.00176 kg/kg of brick) found by Christo- forou, Kylili [8].

Based on the sensitivity analysis, the environmental impacts after switching from clamp kiln technology to VSBK in terms of abiotic depletion (fossil fuels), global warming, acidification, eutrophication, photochemical oxidation and abiotic depletion were, respectively, 90.24 MJ (33.77%), 7.21 kg CO_2 eq (35.26%), 0.0402 kg SO_2 eq (28.31%), 0.0252 kg PO_4^- eq (36.60%), 0.0043 kg C_2H_4 eq (12.63%) and 1.83×10^{-6} kg Sb eq (33.54%), where the values in parentheses represent the percentage of reduced impacts when compared with the clamp kiln technology.

In Figure 6, the normalized values of abiotic depletion (fossil fuels), global warming, eutrophication, acidification, photochemical oxidation and abiotic depletion were 3.58×10^{-13}, 2.67×10^{-13}, 2.51×10^{-13}, 2.35×10^{-13}, 1.35×10^{-13} and 1.32×10^{-14}, respectively. The normalization results revealed that the environmental hotspot of the fired brick production using the clamp kiln technology was the abiotic depletion of fossil fuels.

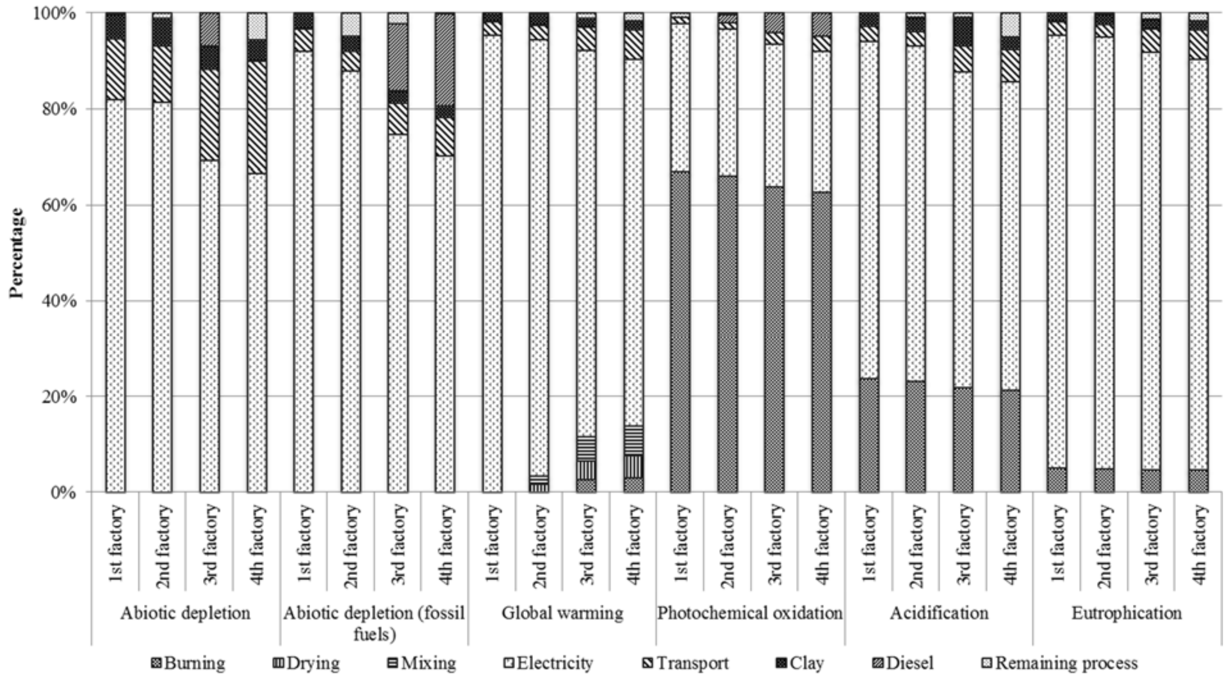

Figure 5 The results of impact categories of the rice husk-powered clamp kiln fired brick production

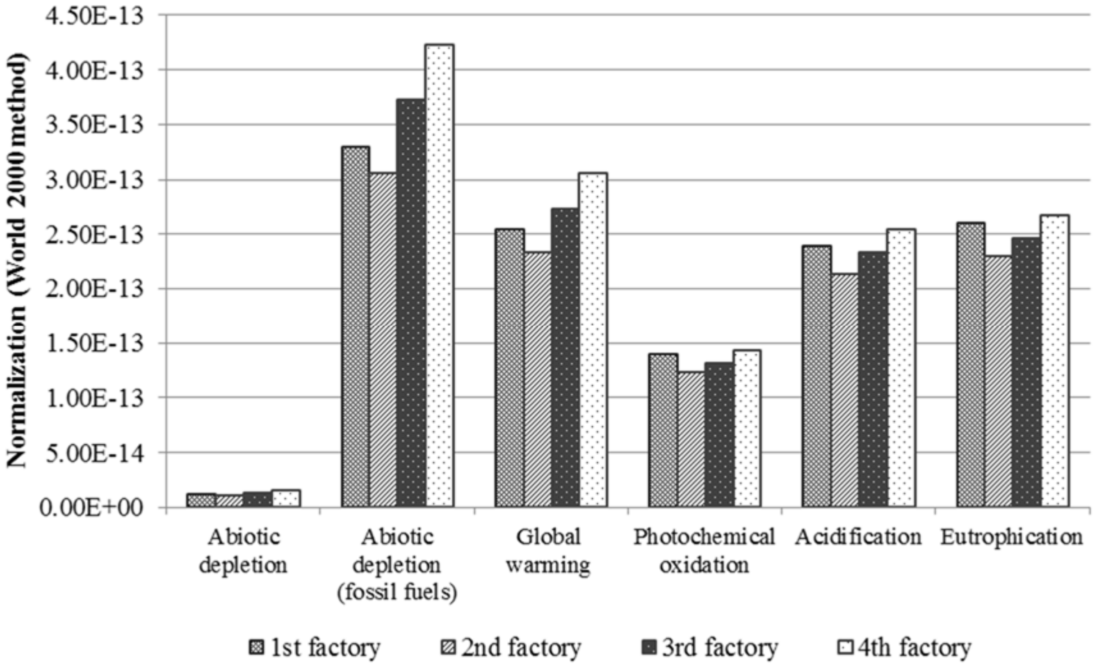

Figure 6 The normalized values of environmental impacts of the rice husk-powered clamp kiln fired brick production

Conclusions

This research points to incomplete combustion using clamp kiln technology to produce fired bricks, as manifested by the non-uniform temperature profiles inside the kiln. The findings also indicate that, despite the high energy input requirement (i.e. specific energy consumption) per kg fired brick, CO_2 emissions per production and per energy input of the clamp kiln technology with rice husk as fuel were minimal. The main contributor to the environmental impacts (apart from photochemical oxidation) was the use of rice husk in brick production, which represents a diversion of the energy source for electricity production to production of fired bricks. Meanwhile, burning bricks was largely responsible for photochemical oxidation. Thus, the improvement of kiln performance with insulation, together with utilization of rice husk, would contribute to a lower energy input requirement per kg fired brick and also lower emissions per energy input. Future research should attempt to identify brick manufacturing techniques that achieve better fuel efficiency and lead to fewer environmental impacts.

Acknowledgments

The authors would like to express their deep gratitude to the Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0175/2553) for the financial support, without which this research would not have materialized. Sincere appreciation also goes to Associate Professor Massimo Pizzol, Ph.D., for expert advice on life cycle assessment.

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