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Environmental aspects of substituting bio-synthetic natural gas for natural gas in the brick industry

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Abstract. Firing of bricks is an essential manufacturing process during which the bricks obtain all the necessary properties. Life cycle assessment studies show that this process is also the most energy intensive in the brick manufacturing process and results in the largest environmental impact. Usually kilns are fired with natural gas, therefore substitution of fossil fuel with a renewable energy source is considered one of the most effective approaches for reduction of environmental impact. Bio-synthetic natural gas (bio-SNG) is one of the most feasible substitutes for natural gas and therefore the aim of the study was to compare the environmental impacts of those energy sources.
Comparison of the life cycle of the environmental impact of natural gas and bio-SNG was carried out using the GEMIS (*Global Emission Model for Integrated Systems)* database. Both energy sources were compared on the basis of the life cycle of CO_2 emissions, cumulated energy and material requirement, land use and employment effects.
Results show that by replacing natural gas with bio-SNG, greenhouse gases could be reduced and employment increased. However, cumulated energy, material and land requirement is larger when bio-SNG is used instead of natural gas.

Key words: alternative energy, bio-SNG, brick industry, natural gas.

INTRODUCTION

One of the most specialised steps in the manufacture of bricks is the firing (Venta, 1998) during which the bricks obtain all the necessary properties. Different life cycle assessment studies show that the firing is the most energy intensive of the brick manufacturing processes, most of the energy is used in this production stage (Rose et al., 1978; Moedinger, 2005; Koroneos & Dompros, 2007; Machado et al., 2011; Skele et al., 2011; Oti & Kinuthia, 2012). Furthermore, most of the reported emissions from clay brick production are attributed to the energy used for firing kilns (Oti & Kinuthia, 2012). It is estimated that an air dried brick has 33% less CO_2 equivalents per brick than a traditional kiln fired brick (MacMillan, 2010).

Usually brick kilns are fired with natural gas, although propane, oil, sawdust, coal or combinations of these fuels can also be used (Venta, 1998; Moedinger, 2005). There are many factors affecting the energy consumption in the clay brick manufacturing process. Kiln fuel usage depends on the firing temperature and duration of firing, the type and condition of the kiln, its efficiency, mode of operation (continuous or periodical), type of finished product, and type of and carbon content of the raw materials (Venta, 1998; Machado et al., 2011).

However, through innovative development it has been shown possible for these traditional sources to be successfully replaced by renewable alternatives (Moedinger, 2005). Gomes & Hossain, (2003) indicate that replacement of the technologies (especially if the coal-based technologies would be replaced by natural gas-based technologies) will result in significant reductions in greenhouse gas emission. Similarly natural gas replacement by bio-SNG would also reduce CO_2 emissions (Repele et al., 2012). The brick fired with renewable fuels features the least energy content of all building products available on the market today (Moedinger, 2005).

Therefore, research and comparison of alternative energy sources is necessary and essential. In this paper bio-SNG is analysed and compared with natural gas from an environmental aspect as a potential alternative energy source (a term used to refer to any energy source other than fossil fuels) for the brick industry.

MATERIALS AND METHODS

The study is based on operational data obtained over a year from a brick factory in Latvia. Characteristics of the factory are: production capacity is 135,000 tonnes of ceramic building materials; oven capacity is 160,000 m^3; annual consumption of natural gas is 7,644 thousand m^3; electricity consumption is 4,824 MWh; raw material (clay) consumption is 146,000 tons; annual emissions to air: carbon dioxide – 14,292 tons, carbon monoxide – 89.5 tons, nitrogen oxides – 25.7 tons, sulphur dioxide – 5.9 tons, solids – 3.9 tons (‘A’ category permit, 2012).

Functional unit is 1 tonne of ceramic building materials (bricks).

Comparison of the life cycle environmental impact of natural gas and bio-SNG was carried out using GEMIS (*Global Emission Model for Integrated Systems)* v. 4.8 database. GEMIS was first released in 1989, and is continuously updated and improved (Fritsche & Stetz, 2013). For processes and scenarios GEMIS is used to calculate life cycle impacts, i.e. considering all processes from resource extraction (including primary energy and raw materials) to final material or energy use. Included are also auxiliary energy and material use, materials for construction of energy supply, material and transport systems, as well as direct and indirect employment effects (Fritsche & Stetz, 2013).

GEMIS contains data on direct air emissions (SO_2, NO_x, CO, NH_3 etc.), greenhouse gas emissions (CO_2, CH_4, N_2O), as well as solid wastes, liquid effluents and land use. Emission standards are also included and thus it provides an opportunity to assess whether the combustion process is in compliance with national and international emission standards, and filter the database for suitable processes.

Two scenarios were analysed in this paper: brick factory consumes only natural gas or only bio-SNG. Both energy sources were compared on the basis of such environmental indicators as global warming (CO_2 emissions), resources (cumulated material and cumulated energy requirement, land use) and employment effects.

RESULTS AND DISCUSSION

The following process data were used from the GEMIS database:

- natural gas (based on lower heating value – LHV) and supplied from 'gas-mix-FI-2010', i.e. 90% of natural gas is imported from Russia and 10% from Norway; mixed in Finland;
- bio-SNG from wood chips and wood waste processed for gas-pipeline (LHV) supplied from 'pipeline\bio-SNG-wood-forest-DE-2030', i.e. biogas processed in Germany, reference year 2030.

Since GEMIS database does not contain data on natural gas imported into Latvia, life cycle data on natural gas mix consumed in Finland was used in this study, because natural gas in both Latvia and Finland is imported from Russia. For comparison, data on production of bio-SNG in Germany was used. Process chains for both energy resources are shown in Fig. 1.

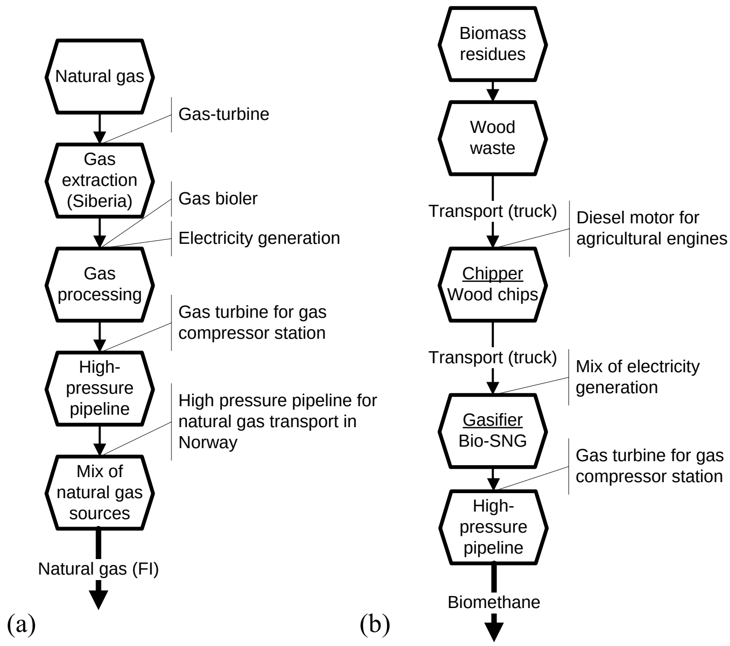

Figure 1. Process chain of (a) natural gas and (b) bio-SNG (GEMIS, 2011).

The following environmental impacts were evaluated (Table 1):

- greenhouse gases: CO_2 equivalent and separately CO_2 emissions – important indicators that describe environmental impact of fuel conversion;
- cumulated energy requirement: shows how much energy is embedded in 1 GJ of fuel energy;
- cumulated material requirement: includes the total consumption of materials throughout product (energy source in this case) life cycle;

- land use: factor that describes how much land is needed to produce a certain amount of energy;
- total employment effects: effects that each energy source has on employment levels.

Table 1 summarises the environmental impact caused by the production of 1 tonne of ceramic building materials at the brick factory in Latvia.

Table 1. The results of the environmental impacts per one tonne of ceramic building materials produced at the brick factory of Latvia

	Natural gas	Bio-SNG
Greenhouse gases [kg]:		
– CO_2 equivalent	33.92	7.71
– CO_2	17.47	7.31
Cumulated energy requirement [GJ], int. al:	2.34	3.06
– non–renewable	2.34	0.10
– renewable	0	2.97
Cumulated material requirement [kg], int. al:	10.28	39.73
– non–renewable	1.48	9.36
– renewable	8.57	29.82
– other	0.24	0.55
Land use [m²]	0.01	0.56
Total employment effects [persons]	$607(10^{-9})$	$989(10^{-7})$

Within GEMIS it is possible to convert emissions of greenhouse gases (GHG) by using their global warming potentials (GWP) into the equivalent quantity of CO_2, so that the emissions of different greenhouse gases can be summed up into the total CO_2 equivalent. All GWP in GEMIS are mass-based, i.e. they give the relative greenhouse effect of 1 kg CO_2. Cumulated energy requirement (CER) is a measure of the total amount of energy resources (primary energies) needed to deliver a product or a service. Cumulated material requirement (CMR) is a quantitative measure of the total amount of raw materials needed to deliver a product or a service. In the calculation for CMR in the category 'other' secondary resources (wastes, residues with the potential for material re-use) are shown. The term 'land use' means the area affected by processes. But the annual land use is calculated, i.e. the life-time of the process is not included. GEMIS also allows fast computation of the direct and indirect job-creating effects as well as the sum of both portions possible. The direct effects are given by jobs in the energy sector and their upstream processes and are stored in the GEMIS database as part of the process information. The indirect effects are calculated from investment, operations and maintenance costs using country-specific input-output tables (Fritsche & Schmidt, 2008).

When choosing fuels, all the criteria that characterise the fuel and all environmental impacts must be carefully considered as each energy source has pros and cons. Scenario analysis was carried out for the replacement of natural gas with bio-SNG.

Fig. 2 shows the comparison of environmental impacts due to substitution of natural gas by bio-SNG assuming that scenario '100% natural gas' is the reference scenario with zero values.

From an environmental point of view one of the most important criteria is emissions of greenhouse gases, and natural gas is the worst alternative in this respect. Compared with bio-SNG, natural gas generates 23% more CO_2 equivalents and 42% more CO_2 emissions. Hence, replacement of natural gas with bio-SNG is fully justified from a global warming perspective.

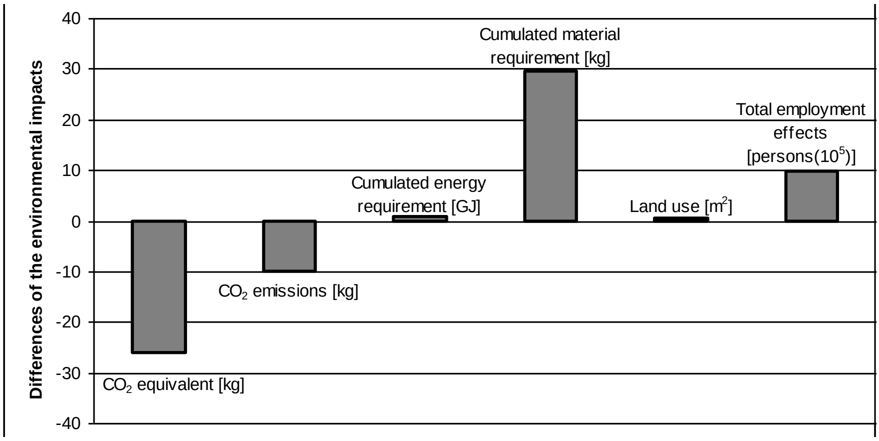

Figure 2. Results of scenario analysis when natural gas is replaced with bio-SNG. Y-axis shows comparison of environmental impacts against '100% natural gas' scenario which is taken with values zero.

The total cumulated energy requirement throughout the whole life cycle in the case of natural gas is 24% less than for bio-SNG. However, it should be taken into account that bio-SNG alternative contains mainly renewable energy (i.e. 97%) contrary to natural gas which is a non-renewable energy source.

Regarding the total life cycle cumulated requirement of materials, bio-SNG appears worse than natural gas by 74% because more non-renewable materials are needed for production and installation of equipment. In the case of natural gas, the share of non-renewable materials in the total CMR is 14% and renewable – 83%, but in the case of bio-SNG the share is respectively 24% and 75%.

In the case of bio-SNG approximately a 60 times bigger land area is affected by all processes to provide the amount of energy, than in the case of natural gas.

The total employment effect in the case of bio-SNG is approximately 163 times bigger than in the case of natural gas. It can be considered as a positive indicator, especially in the circumstances of the economic crisis and high unemployment.

CONCLUSIONS

Results of this research show that when choosing energy sources for industrial production, the criteria based on the life cycle cumulated material and energy consumption, and CO_2 emissions for characterisation of environmental impacts can be used.

It can be concluded that bio-SNG, when used in the brick industry, has an advantage over natural gas from the prospective of global warming potential, cumulated energy consumption and employment, but at a disadvantage in terms of cumulated material consumption and land area required.

When considering a replacement for natural gas with alternative energy sources, a manufacturer, apart from environmental impacts, should also be aware of the required technological changes. Therefore, substitution of natural gas with bio-SNG could be considered as a convenient solution because virtually no technological changes are required.

Further studies are necessary to examine the possibility to substitute natural gas with other alternative energy resources, e.g. bio-ethanol, bio-diesel, biomass, and to compare their environmental impacts also taking advantage of other databases and evaluation methods, in order to find the most suitable solution.

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