Journal of Thermal Analysis and Calorimetry, Vol. 66 (2001) 273–280

THERMODYNAMIC ANALYSIS OF CERAMICS PRODUCTION IN SASSUOLO (ITALY) FROM A SUSTAINABILITY VIEWPOINT

S. Bastianoni, V. Niccolucci and M. P. Picchi*

Department of Chemical and Biosystems Sciences, University of Siena, Pian dei Mantellini 44, 53100 Siena, Italy

Abstract

We present a thermodynamic analysis of the sustainable use of resources in the province of Modena, focusing the attention on the district of Sassuolo. The methodology that is used is the emergy evaluation. The analysis shows that the Sassuolo district represents the peak of non-sustainability of the whole area, with a huge consumption of non-renewable primary resources, both imported and local. The role of the ceramic tile industry is relevant in the consumption of energy and materials. Different types of factories for ceramics production are compared, representing a good sample of different methods of production. Emergy analysis shows which of these has higher levels of sustainability with respect to the others.

Keywords: ceramic tiles, emergy analysis, province of Modena, sustainability

Introduction

Our style life is no more compatible with the cycles of nature: the use of resources and the discharge of waste proceed at a rate, which overshoots the carrying capacity of the Earth.

Sustainable development since its introduction has become a universal policy goal and a matter of endless debate. The assessment of sustainability requires integrated and complementary approaches to understand deeper the complex network of interactions occurring between humans and the environment. Thermodynamics, and especially the 2nd law, is a key point of sustainability.

The concept of emergy can be used to test one of the principles of sustainability defined by Daly, namely, that a process is sustainable only if the resources consumed are used at a rate that does not exceed the rate at which they are renewed [1]. Odum defined emergy as the quantity of solar energy necessary (directly or indirectly) to obtain a product or energy flow in a given process [2]. Solar energy is the common basis of all energy flows occurring in the biosphere. The greater the emergy flow nec-

* Author for correspondence: Phone: +39-0577-232005, Fax: +39-0577-232004, E-mail: vniccolucci@unisi.it

1418–2874/2001/ $ 5.00

Akadémiai Kiadó, Budapest
Kluwer Academic Publishers, Dordrecht

essary to sustain a process, the greater the quantity of solar energy consumed or in other words, the greater the environmental cost. Hence emergy is the memory of all the solar energy consumed during the process. Emergy is measured in Joules, but not indistinct Joules, solar energy Joules, that Odum called sej [2].

Solar transformity is the solar energy directly or indirectly necessary to obtain one unit (Joule) of another type of energy. For systems with the same output, such as different ceramic tiles production, the lower the transformity, the higher the efficiency of the system in the production is [3].

This approach provides indicators of the efficiency of processes and of environmental stress. We can distinguish between renewable (R) and the non-renewable (N) resources, and between local (L) (natural) and imported inputs (F) of the total emergy of the output (Y).

The emergy yield ratio (EYR) is the emergy of an output (Y) divided by the emergy of those inputs from the economic sector (i.e. not provided for free by the environment) (F):

$$EYR=\frac{R+N+F}{F}=\frac{Y}{F}$$

A high value of the EYR implies a high capacity of the process to exploit resources supplied gratis by the environment [3].

The environmental loading ratio (ELR) is the ratio of purchased and non-renewable indigenous emergy to renewable environmental emergy:

$$ELR=\frac{N+F}{R}$$

A high value of the ELR, often due to a high technological level in the use of resources, indicates high environmental stress, because local environmental cycles are overloaded. The term stress is therefore intended in an overall sense: for example, environmental damage caused by intensive agriculture is the sum of specific damage due to the combustion of fossil fuels, soil erosion, chemical pesticides, and so forth [4].

This approach can be used for assessments both for production systems and for systems at a territorial level. The administration of the province of Modena (Italy) asked for an emergy evaluation of its territory, which is divided into seven districts, each one composed by several communes. The aim of the study was to point out the situations requiring more attention and interventions to lead towards a higher level of sustainability.

Results and discussion

Emergy evaluation of the province of Modena and the case of the Sassuolo district

The emergy evaluation of the province of Modena shows non-homogeneous results among seven districts [5]. However the district of Sassuolo is the one with worst figures in all the aspects considered by emergy analysis. We can say that the Sassuolo district represents a 'peak' of unsustainability, for the large use of non-renewable inputs both local (*N*) and imported (*F*).

The district of Sassuolo is composed by the communes of Sassuolo, Fiorano, Formigine and Maranello. It is the main industrial pole of the province. The ratio between the emergy exported out of the province and the one imported is around 2.5, a very high value in general and more than twice the value of the provincial average. It is also the area with the highest *ELR*, 129.25, meaning that, in this district, almost 130 times more non-renewable than renewable resources are used [5]. This value is almost five times higher than the provincial average. The industrial pole is mainly composed by ceramic tiles industries. More than 120 factories of this type are operating within the district. They extract from the territory huge quantities of clay and other materials, and importing even more from outside Italy. The final products, ceramic tiles, are then exported all around the world.

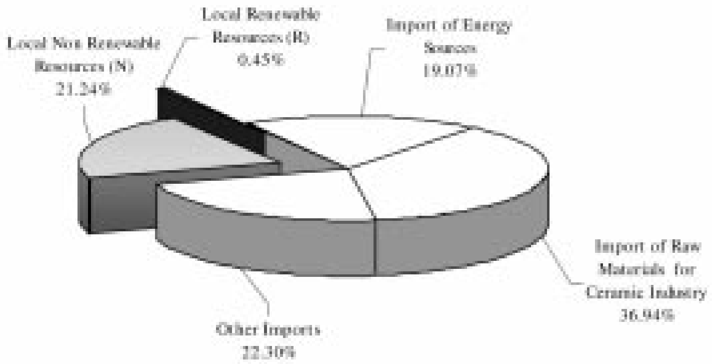

Fig. 1 Emergy inputs to the Sassuolo district. The imported inputs (white part of the diagram) are separated in energy sources, raw material for ceramic industry and other imported inputs

The import related to the ceramic industry represents around 40% of the total emergy of the imported goods of the district, that are dominant with respect to local

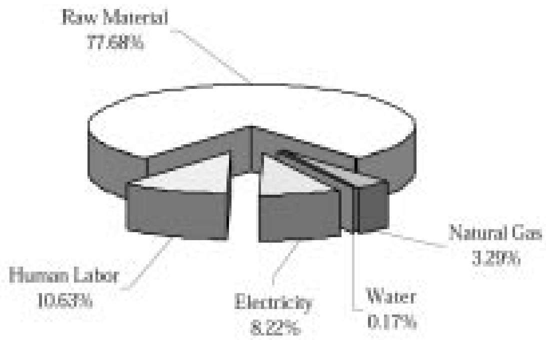

Fig. 2 Distribution of inputs for ceramic industries (total in the Sassuolo district) in emergy terms

renewable and non-renewable inputs (Fig. 1). Globally, within the whole ceramic sector of this area, almost 80% of the emergy required for tiles production is due to raw materials (Fig. 2).

The district of Sassuolo can be seen as a transformer of imported emergy in manufactured goods to be exported. Only less than 50% of the imported emergy is actually used within the district.

In the long run this system cannot be sustainable, since it consumes other places' and its own non-renewable resources very rapidly. In this way, on the one hand, there is a tendency to use up all the resources which should remain available also for future generations, on the other hand it is strongly based on the import from other countries, causing a structural fragility of the system.

These results have implied a more detailed study on the ceramic tile industry, to better understand what kind of alternative technologies and types of production are closer to the requirements for sustainability.

The ceramic tile industry

The province of Modena and the association of the ceramic producers ('Assopiastrelle') have selected three factories, representing three types of production, in order to evaluate the degree of correctness in the resource use in such systems.

Here the focus was not on the problems related to the quantity and quality of emissions or pollutants. On their control the Sassuolo district has reached a very high level, and the authorities are carefully monitoring the whole area.

The three sample factories are different for the quantity and type of ceramics produced and for the way they are produced (with or without recycle).

In Fig. 3 a diagram of one of the factories under study is represented. Tiles production is divided into two parts: the first one in which raw materials form the mixture; the second one for the production of tiles.

In Table 1 the emergy evaluation of one of the sample factories is reported. Emergy, being an extensive function, can be obtained summing the emergy contribution of each input to the system. Each contribution to emergy (fourth column of Table 1) is obtained by multiplying the data in second column by the transformity in third column.

For how the transformities used in Table 1 were obtained, see the references listed in each row.

Transformity of the final product (ceramic tiles), solar emergy and the other emergy related indicators were calculated. All the tables and their footnotes are available upon request to the authors of this paper.

Factory #1 has a very advanced technology for the production of single firing tiles. This is the biggest plant among those examined and uses huge quantities of raw materials coming from other countries (feldspar from Turkey and clay from France and Germany), that implies also a high use of fuels for transportation. This factory is also selling around 41% of the mixture for ceramic tiles.

Table 1 Emergy evaluation of ceramic tile production (Factory #1)

#	Item		Unit	Solar transf./ sej/unit	Ref. per transf.	Solar em./10^{16} sej/year	Type*
Transport of the raw material to the farm							
1	Diesel	$7.23\cdot10^{13}$	J	$6.60\cdot10^{4}$	6	477.18	N, F
Phase 1: mixture production							
2	Raw material						
	Clay	$1.18\cdot10^{11}$	g	$2.00\cdot10^{9}$	3	23600.00	N, F
	Feldspar	$1.04\cdot10^{11}$	g	$1.00\cdot10^{9}$	6	10400.00	N, F
	Sand	$1.80\cdot10^{10}$	g	$1.00\cdot10^{9}$	6	1800.00	N, F
3	Natural gas	$5.97\cdot10^{14}$	J	$4.80\cdot10^{4}$	6	2866.84	N, F
4	Electricity	$5.76\cdot10^{13}$	J	$2.00\cdot10^{5}$	6	1152.00	N, F
5	Diesel and lubricants	$2.67\cdot10^{12}$	J	$6.60\cdot10^{4}$	6	17.62	N, F
6	Water	$5.90\cdot10^{10}$	g	$1.25\cdot10^{6}$	8	7.38	N, 33% F
7	Human labor	$2.93\cdot10^{10}$	J	$7.38\cdot10^{6}$	4	21.62	10% R, F
8	Machinery	$1.31\cdot10^{6}$	$	$1.46\cdot10^{12}$	3	191.63	N, F
9	Mixture	$2.79\cdot10^{11}$	g	$1.45\cdot10^{9}$		40534.27	
Phase 2: ceramic tile production							
10	Raw material						
	Mixture	$1.14\cdot10^{11}$	g	$1.45\cdot10^{9}$		16562.39	N, F
	Glaze and chemicals	$1.57\cdot10^{9}$	g	$3.80\cdot10^{8}$	6	59.66	N, F
	Others	$3.67\cdot10^{9}$	g	$1.00\cdot10^{9}$	6	367.00	N, F
11	Natural gas	$1.78\cdot10^{14}$	J	$4.80\cdot10^{4}$	6	856.76	N, F
12	Electricity	$2.81\cdot10^{13}$	J	$2.00\cdot10^{5}$	6	561.60	N, F
13	Diesel and lubricants	$1.34\cdot10^{12}$	J	$6.60\cdot10^{4}$	6	8.81	N, F
14	Water	$5.90\cdot10^{10}$	g	$1.25\cdot10^{6}$	8	7.38	N, 33% F
15	Human labor	$1.17\cdot10^{11}$	J	$7.38\cdot10^{6}$	4	86.50	10% R, F
16	Machinery	$2.56\cdot10^{8}$	g	$6.70\cdot10^{9}$	7	171.52	N, F
17	Lime	$8.50\cdot10^{7}$	g	$3.80\cdot10^{8}$	6	3.23	N, F
Local renewable resources (10% of item 15)						8.65	
Local non-renewable resources (66% of item 14)						4.87	
Purchased resources (sum of items 10-17, with 90% of 15 and 33% of 14)						18671.25	
Total emergy used for the ceramic tile production						18684.77	
Product							
18	Tiles	$5.78\cdot10^{6}$	m^2 prod.	$3.23\cdot10^{13}$			
		$1.04\cdot10^{11}$	g	$1.80\cdot10^{9}$			

*R – renewable resource, N – non-renewable resource, L – local resource, F – resource purchased from outside

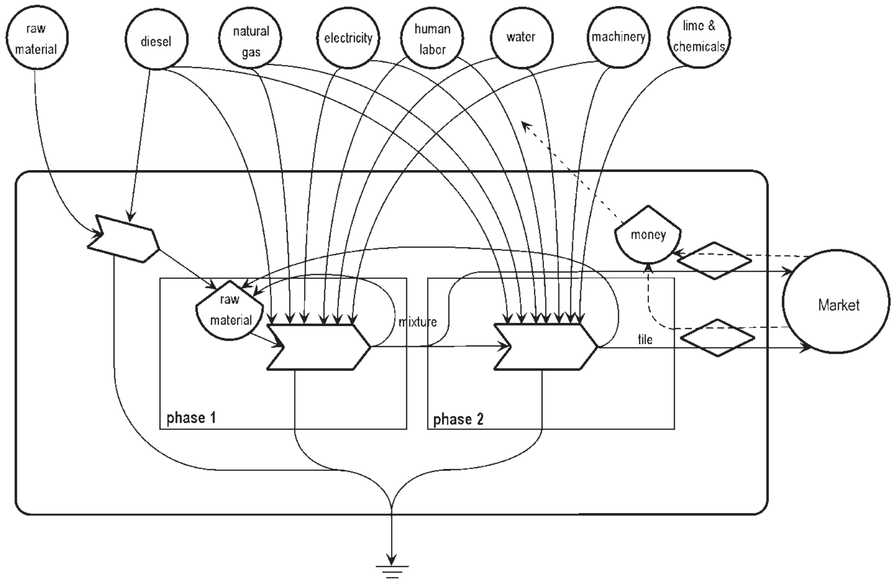

Fig. 3 Energy system diagram of ceramic tile production (Factory #1)

Factory #2 also produces single firing tiles, but is different from the previous one for the size of the plant and for the quantity of tiles obtained. Almost all the raw materials are imported from outside Italy, traded via sea from Turkey and Ukraine. The most interesting point is that factory #2 uses only natural gas as a fuel, co-generating the electricity needed for the productive process.

Factory #3 produces porcelain stoneware. Around 50% of the imports are from other Italian regions.

Looking at the details of the emergy evaluation of the three productive processes, we can point out that the importance of transportation, with respect to the total emergy of the mixture, is relatively higher in factory #1 (2.5%), while in factory #3 it is 1.5% and in factory #2 is below 1%. Anyway all these figures are low compared to the raw material that represent the dominant part of the whole process (88% of the emergy of the mixture and 78% of the total emergy needed for tile production).

The difference between the two factories that produce single firing (#1 and #2) and the one producing porcelain stoneware (#3) is that factory #3 needs relatively more raw material for the production of a unit tile. This implies a higher transformity (Table 2). Porcelain stoneware is anyway a higher level product, and the lower efficiency of production is compensated by a higher cost for the buyer.

The lowest transformity (highest efficiency) is obtained by factory #2 (Table 2), where the use of energy is more rational. Furthermore, the use of natural gas is a relevant and positive fact (with respect to the use of oil derived fuels) also from the viewpoint of the production of CO_2, that is sensibly less, considering the same energy output.

Table 2 Comparison of the emergy evaluation of the three sample factories for ceramic tile production

	Unit	Factory #1	Factory #2	Factory #3
		Single firing	Single firing	Porcelain stoneware
Tile production	g	$1.04 \cdot 10^{11}$	$5.40 \cdot 10^{10}$	$7.70 \cdot 10^{10}$
	m^2	$5.78 \cdot 10^{6}$	$3.00 \cdot 10^{6}$	$3.50 \cdot 10^{6}$
Emergy	sej	$1.87 \cdot 10^{20}$	$8.77 \cdot 10^{19}$	$1.61 \cdot 10^{20}$
Transformity	sej m^{-2}	$3.23 \cdot 10^{13}$	$2.92 \cdot 10^{13}$	$4.60 \cdot 10^{13}$
	sej g^{-1}	$1.80 \cdot 10^{9}$	$1.62 \cdot 10^{9}$	$2.09 \cdot 10^{9}$
EYR		1.0007	1.0010	1.0013
ELR		2159	1013	1247

Values of *EYR* are all very close to one, meaning that for these factories, relatively very few inputs of local origin are used. The differences are not significant.

ELR are very high and justify the high number of the whole Sassuolo district. Also for this aspect factory #2 is the best of the three alternatives, while factory #1 has a value of *ELR* that is more than double. Factory #3 is closer to #2 than to #1.

Conclusions

This study has been devoted to the assessment and discussion of the level of sustainability within the province of Modena (Italy). The study was then focused on a particular aspect (ceramic tile production) that causes negative results in the district of Sassuolo. The area is economically based on this type of industry, which globally can be seen as not sustainable in the long run, for the use of local and imported non-renewable resources.

Further study should be performed to explore the possibility of recycle of materials in order to diminish the dependency from non-renewable imported goods.

Using the emergy approach we were then able to determine which, of the alternative proposed for ceramic tile production, is the best from a sustainability viewpoint. The co-production of heat and electricity using natural gas is to be preferred, since it gives higher efficiency, lower use of non-renewable resources and environmental impacts, both on a local level (pollution) and on a global one (greenhouse effect).

* * *

We wish to thank Prof. Enzo Tiezzi and Nadia Marchettini and Dr. Marcello Porcelli for useful suggestions and stimulating discussions. We also thank Dr. Eriuccio Nora (of the province of Modena administration) for his continuous help in data gathering and for his knowledge of the systems.

References

1 H. E. Daly, Ecological Economics, 2 (1990) 1.
2 H. T. Odum, Science, 242 (1988) 1132.

3 H. T. Odum, Environmental Accounting, Emergy and Environmental Decision Making; J. Wiley and Sons Inc., New York 1996, p. 370.
4 S. Ulgiati, H. T. Odum and S. Bastianoni, Ecological Modelling, 73 (1994) 215.
5 S. Bastianoni, M. Porcelli and E. Tiezzi, in Ecosystems and sustainable development II (Advanced in Ecosystems Sciences), C. A. Brebbia, J. L. Uso, Eds, WIT Press, Southampton, UK 1999, p. 81.
6 H. T. Odum, in Ecological Physical Chemistry, C. Rossi and E. Tiezzi Eds, Elsevier Science Publisher, The Netherlands, Amsterdam 1991, p. 25.
7 M. T. Brown and J. Arding, Transformity working paper. Center for Wetlands, University of Florida, USA, Gainesville 1991.
8 S. Bastianoni, M. T. Brown, N. Marchettini and S. Ulgiati, in Biomass for Energy, Environment, Agriculture and Industry, Charter, Ph., A. A. C. Beenackers and G. Grassi Eds, UK 1995, p. 2300.