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Energy and environmental analysis of marble productive sites: "by phases" and "by single process" combined approach.

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Abstract

The approach on which the in force Community eco-label scheme of marble relies (EU Decision 607/2009) is questioned, as a contribution to the on-going revision process of the associated ecological criteria. An alternative approach able to provide a more realistic image of the marble producing site's energy and environmental performances is also argued. The proposed approach considers the marble production in terms not only of life cycle phases (as the Decision does) but of unit operations and/or machineries (as the typical assessment methodologies of production processes do). An application of this proposal on a marble producing site located in Sicily.

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Keywords: Community eco-label criteria; marble; natural stones; quarrying; energy and mass balance; life cycle phase.

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1. Introduction

The European Union (EU) is strongly committed to reducing its final energy consumption mainly to improve both its energy security and reduce its greenhouse gases emissions. The great amount of energy required by buildings, which are, in fact, responsible for approximately 40% of total final energy consumption in the EU – 28 [1] has therefore focused a great attention on this sector by the EU. To promote the reduction of the buildings' energy consumption and improve their energy efficiency, many EU Directives were issued. Among these directives, the followings are two of the most important: the 2002/91/EU [2] and the 2010/31/EU EPBD recast [3] on the energy performance of buildings.

Also, properties of materials and components (and their manufacturing processes) typically used in buildings are rapidly changing, particularly because they have to respect these new Standards and Directives on energy efficiency and environmental protection. Specifically, new criteria aimed at certifying the environmental and energy excellence of single building materials and components have been established. Among the building materials, attention has been focused on marble as well as natural stones for which the Community eco-label awarding criteria have been established by the European Commission [4].

These criteria will be discussed here. This discussion will make reference to some currently available scientific studies that address the energy and environmental performance of marble manufacturing as well, but propose further methods to assess the energy and environmental quality of this production process. Specifically, a possible integration of the approach followed in these studies within the current criteria scheme for awarding a Community eco-label to marble is proposed here. This integration might provide an even more realistic and comprehensive assessment of the quality of marble, and in turn a better certification of its environmental excellence.

After the analysis of the approach proposed by the Decision, essentially belonging to a "by-components" methodology, where the components are single phases from cradle to gate, the possibility of moving to a sort of a "hybrid by-components" approach will be argued by considering the production process of marble in terms not only of life cycle phases in their wholeness but also of unit operations and/or machineries. Such hybrid approach that puts together the approach proposed within the Decision and that one of the typical mass and energy balances, allows getting a wider set of indicators concerning the performance of the product working chain.

An application of the proposed scheme, will be carried out by considering a marble producing site located in Sicily that is representative of the extraction and processing activities of marble [5]. As the aim of this application is to provide an example, only the extraction has been here considered.

2. The Community eco-label and its environmental criteria for awarding marble

The Decision 607/2009 [4] establishing the ecological criteria for the award of the Community eco-label to hard coverings is comprised of 10 criteria. Seven criteria out of ten refer to the following life cycle phases: raw material extraction, manufacture (processing and finishing), packaging, and use phase. It is considered the management of waste deriving from quarrying and finishing operations, but the end of life of the hard coverings is not included among the criteria. The remaining three criteria are instead not strictly related to the life cycle of a hard covering rather to the fitness for use, information on the packaging and/or on the documentation accompanying the product, and information appearing on the eco-label.

The Decision divides hard coverings into two classes: "natural" (among which, marble, granite, etc.) and "processed" (among which, agglomerated stones, terrazzo tiles, ceramic tiles, etc.) products. While the last three criteria are applicable for both types of products, only some of the first 7 criteria can be applied to natural products (and so to marble), that is: criterion 1 "raw material extraction"; criterion 2 "raw material selection"; criterion 3 "finishing operations"; criterion 5 "waste management"; criterion 7 "packaging".

Please consider that criterion 5, "waste management", does not refer to the end of life stage of marble products rather to waste from quarry and finishing activities, because it essentially states that applicants should provide a documentation about waste management from quarry and laboratory.

As it can be observed, some relevant stages of the marble productive chain are neglected in the Decision. In fact, the manufacture phase - comprising cutting and finishing activities – is, actually, considered only partially since only impacts of finishing activities are evaluated. Criterion 4, "production process", which indicates energy and water requirements and sets specific limits to the liquid and air emissions generated during processing operations, is actually designed only for processed products. It has not to be overlooked that cutting operations of marble blocks in sawmill require a great amount of energy [6] that in turn may imply air pollutant emissions that could be greater than those caused by quarrying and finishing operations, as shown, for example, in [7]. Another component that is neglected is transportation of products along the "cradle to gate" line. This latter is indeed source of pollutant emissions that sometimes might become relevant and not negligible in the assessment of the environmental management of marble. However, a more accurate description of the limits and concerns regarding the real practicability of these criteria for the award of the Community eco-label to marble products is presented in [7]. In addition, some criticisms have been risen on the good adaptability of these criteria to the real situation in natural stone quarrying [8].

In addition, criteria are proposed by productive phase and not by single machine. In fact, criterion 1, "raw material extraction", which refers to all the activities occurring in quarry, indicates a procedure to calculate a weighted score for the quarrying activity and establishes a minimum score that the quarry should achieve to be eligible for the EU eco-label award. Indicators to assess the quarry's performance concern water recycling ratio, quarry impact ratio, natural resource waste, air quality, water quality, and noise. Criterion 2, "raw material selection", referring to the production process, provides a list of risky substances and requires the absence of these substances in the raw materials that are used in the production process. Criterion 3, "finishing operations", which refers to all the activities occurring in the laboratory, sets specific limits to the solid, liquid and air emissions generated during finishing operations. Finally, criterion 7, "packaging", referring to the kind of paperboard used for packaging, provides features that the paperboard used for packaging should be designed with. In other words, based on the analysis of the features of the single criteria, a kind of "by phases" approach (holistic) seems to be implemented in the Decision without particularly taking into account the single machines, which the single phase is comprised of.

3. Further criteria to assess the energy and environmental quality of marble

As previously stated, several criteria are included in the Decision for a Community eco-label award for hard coverings that consider the main segments of the marble working chain. Each section of the productive line of marble examined by the Decision is seemingly treated as "a whole" whose performances are analysed by a "by phases" approach, as previously observed. Actually, each part of the chain involves various machines and tools, with very different energy consumption and environmental performances. Indeed, current marble-related scientific literature tends to present also data that are distinguished by unit operations and/or single machines, particularly in the case of energy analyses. In this regard, interesting data are presented in the study carried out by [6], in which researchers adopt a typical "by single machinery" approach. They have assessed the energy and environmental condition of a typical medium-sized marble small-to-medium enterprise (SME) in the marble production sector in Greece. They present the energy consumed for raw block extraction (cutting with diamond wire saw), the energy consumed for transportation of blocks from quarry to processing plant, and the energy consumed by each single machinery used in the processing plant. A similar approach is seemingly adopted in [9]. They have performed a comparative Life Cycle Assessment between two flooring materials: ceramic and marble tiles. To accomplish this task, researchers present energy consumption data for unit operations of pre-production (i.e. activities occurred in quarry), production (i.e. activities occurred in sawmill and laboratory) of 1 m^2 of marble tile. Data concerning the use and disposal are presented as well. In the case of pre-production, values related to a single unit operation called "marble extraction" and transport are provided (without giving any data on the further quarry operations such as sectioning and cutting of the blocks into transportable size), while in the case of production, values related to the unit operations (i.e. raw blocks cutting, standard blocks cutting, and polishing –buffing) are presented. Other authors [5] follow the same approach. In fact, in the case of quarrying operations they provide an analysis by single unit operation, distinguishing among extraction, squaring, and transportation of product, spoils, and scraps. On the other hand, in the case of sawmill and finishing plant, they present input and output data per each single machine, both in terms of energy and material resources.

This approach, which is seemingly followed by most marble-related studies, might derive from the two following factors: *1)* for energy and environmental analyses of marble the mostly applied methodology is the Life Cycle

Assessment [10; 11]; *2)* this kind of analyses on marble are quite often carried out in order to identify hot spots of the analysed products and/or processes. As regards the first point, since the LCA requires to provide a detailed inventory of each life cycle phase, a deep (or at least as much accurate as possible) knowledge of all energy and resources in and out flows, which are involved in each single machine and/or unit process within each phase, is needed. As regards the second point, in order of identifying the critical points within a productive chain, the most suitable approach appears to be the "by single tool" one; a "by phase" kind of approach, as the Decision one does, would indeed not be able to identify the critical points.

4. "By phases" and hybrid approaches

As stated earlier, in the Decision the approach is by components where these are the single phases of the life cycle. There is no input/output analyses in energy and environmental terms or, better, only some environmental output are assessed. In fact, the Decision in its current configuration does not contemplate the energy consumption associated to each operation performed in quarry and laboratory.

In Figure 1 the approach implemented in the Decision is illustrated.

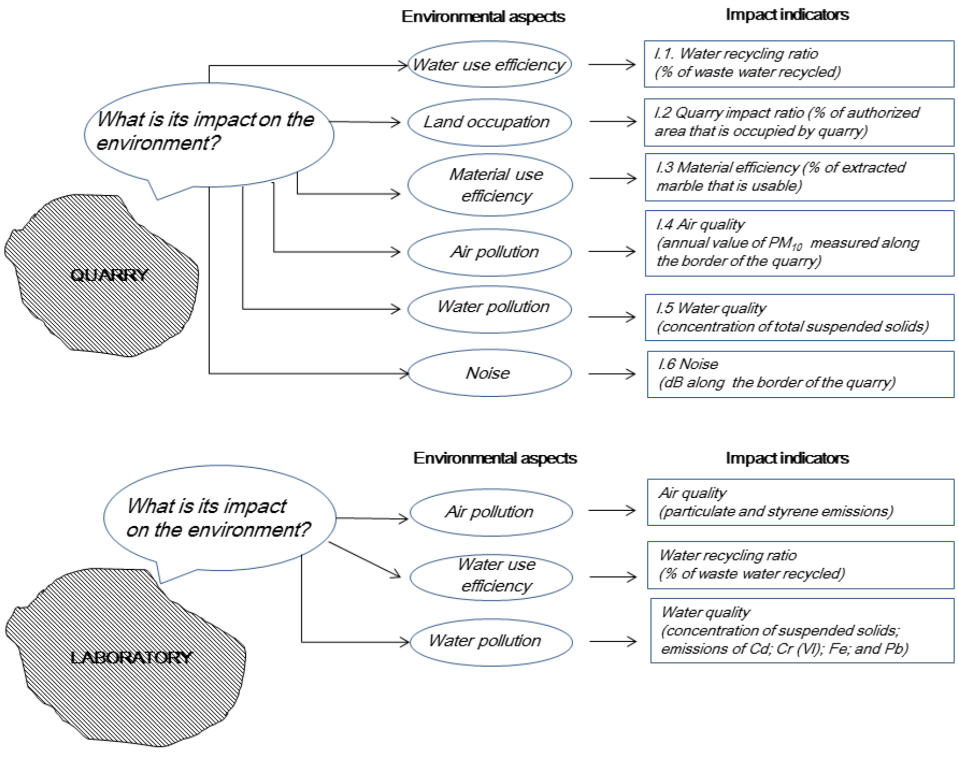

Fig. 1. "By phase" approach of the EU Decision for awarding an EU eco-label to hard coverings.

As it can be observed, for each considered phase (only the extraction and finishing considered in the Decision) a classical balance between input and output is not required. In addition, no energy consumption–related criteria are present. On the contrary, in the previously cited studies, although the approach is still by components, where each component is the single process and/or the single machine, for each of them, energy and mass input and output are assessed.

The previously described approaches (that is that of the Decision and that of literature) belong to a "by-components" vision of the production process of marble, in the sense that its whole performance is seen as the summation of the single contributions of the performances of each component comprising it, which could be either phase ("by phase approach") or unit operation ("by single process approach").

Interestingly, these two approaches, used together, might capture a great part of the energy and environmental impacts of the marble productive chain (as well as of any other natural stone). Their integration, in fact, would be able to provide a certainly more realistic and comprehensive image of the energy and environmental quality of this production process. The "by single process" approach, if on one hand could be used to obtain the same parameters required by the Decision, on the other hand, scaling down to the level of each component of the phase, allows to obtain further indicators concerning particularly the energy consumption. This aspect will be deeper analyzed in the following. This would result particularly relevant especially in the case of the EU eco-label, as it is a brand that certifies the environmental excellence of a product or service.

5. Application of the "hybrid by components" approach to a case-study

In order to evaluate the feasibility of the above mentioned hybrid approach, in the following, we perform an in-field application to a quarry site. For this purpose, we refer to the marble producing area of Custonaci's district (Trapani). In this area, both quarrying and processing activities occur. There are present approximately 158 quarries, of which 78 are working while 80 are abandoned. Almost 90% of the total amount of Sicilian marble production comes from this producing area, which indeed represents the greatest expression of the mining activity in the island [12]. Different types of marble are produced in the Custonaci's district, among which "Perlato di Sicilia" is the most famous and commercialized Sicilian marble in many European and Middle East countries and now in North America and Japan too. In this application, particularly we will make a reference to an enterprise that commercializes the "Perlato di Sicilia", referring to its quarrying operations.

5.1. The "quarry" phase

The excavation of the "Perlato di Sicilia" marble essentially comprises three steps: *1)* cutting of a big "slice" of rock (this operation is carried out using a diamond wire that is constantly cooled down by water and moved by electric sewers); *2)* removal and tipping of this "slice" onto the quarry area (this operation is executed by widening the cut through explosive); *3)* squaring of the "slice" in blocks according to standard sizes that are suitable for being loaded onto proper trucks and being transported to the next processing plants (this operation is carried out using diamond wire saws). In Figure 2 the sequence of these three steps is shown.

Fig. 2. Illustration of the three steps of the excavation of "Perlato di Sicilia".

At the end of these operations, squared blocks, semi-squared blocks, and shapeless blocks are produced. These blocks are then loaded on trucks by means of bulldozers and transported to the processing plants.

The equipment used in quarry basically consists of electric tools and operating machines. As regards the sources of energy used, both primary and secondary energy is consumed, as well as water that is continuously used to cool down the diamond wire while the sawing is being executed. Specifically, the main equipment present in quarry are electric tools (drills for vertical and horizontal holes; diamond wire saws) and operating machines (bulldozers and excavators). The energy sources involved in the operations are fossil fuels (diesel oil feeding the vehicles that are aimed at moving blocks within the quarry area) and electric energy (running the drill and the diamond wire saw). As for the materials, mainly explosive (used to expand the cut carried out with the diamond wire saw) and water (used to cool down the diamond wire).

5.2. Moving towards a hybrid approach

As above pointed out, an excellence brand should properly take into account several aspects of the environmental and energy performances of a marble producing site. On purpose, the knowledge of the balances of mass and energy involved in each single process would be needed. In the case of the extraction phase in quarry, the main unit operations are two: cutting and squaring. In Figure 3 the energy and resources budgets involved in these two activities are illustrated for the analyzed quarrying site.

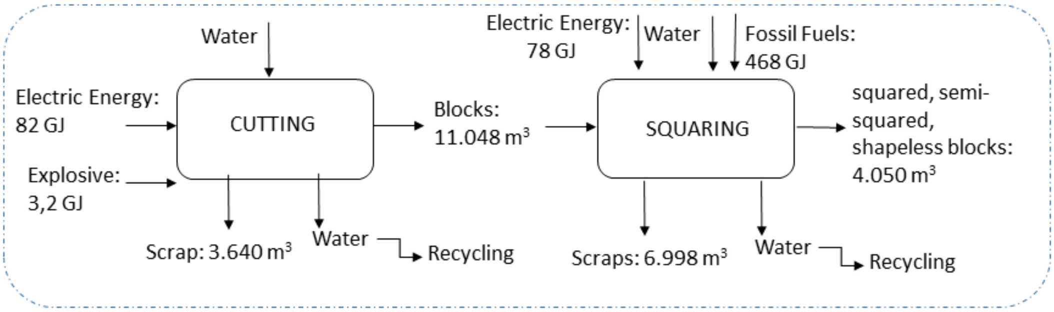

Fig. 3. Resources and energy budgets involved in quarry (on an annual base).

As it can be observed, the squaring process produces both squared, semi-squared, and shapeless blocks (that will undergo further processing) and material that is landfilled (that in the presented quarry accounts for 37% and 63% of the of the material extracted in the quarry, respectively).

Table 1 is a “map” of the information, i.e. parameters, that is possible to obtain using the hybrid approach. As it can be seen, the “by single process” approach allows not only to achieve a more detailed knowledge of the quarry’s performance but also to provide data that are needed to calculate some indicators required by the Decision in order of assessing the quarry’s performance. This is the case of the indicator “water recycling ratio”, for which data on the amount of water consumed during cutting and squaring operations, as well as on the amount of wastewater produced by these two operations, need to be estimated. Likewise, in order to calculate the material use efficiency of the quarry through the indicator “material efficiency”, as required by the Decision, data on the amount of squared, semi-squared, and shapeless blocks produced by the squaring operation, as well as on the amount of solid waste produced (scraps) in cutting and in squaring, need to be estimated. The “by single process” approach, on the other hand, would introduce new important indicators to be assessed, not contemplated by the Decision in force that would enable having a more corresponding image of the real quarry’s performance.

This is the case of the parameters on the electric energy consumption during both cutting and squaring operations, on the explosive consumption during cutting and on fossil fuel consumption during squaring.

When considering only the production of a marble building component, some concerns, in fact, have been arisen because both quarrying and processing activities demand significant amounts of energy and impact the environment [6; 13; 14; 15].

6. Discussion

The considerations arisen in this paper lie in the open debate on the revision of the Decision for an EU eco-label for hard coverings, and could therefore constitute a contribution to it. As stated above, these two approaches, if used together, could capture a great part of the environmental and energy impacts of the productive chain of marble (as well as of any other natural stone). Their integration would be able to provide a certainly more realistic and comprehensive image of the energy and environmental quality of this production process, in order of defining an excellence brand, more corresponding with the real site's performances.

Table 1. Quarry evaluation by using a "hybrid by components" approach.

Assessment approach	Unit operations	Energy and environmental aspects	Indicators/Parameters to be assessed
Assessment of the phase in its wholeness ("by single phase" approach)		Water use efficiency	% of waste water recycled
		Land occupation	% of authorized area that is occupied by quarry
		Material use efficiency	% of extracted marble that is usable
		Air pollution	Annual value of PM10 measured along the border of the quarry (e.g. mg/Nm^3)
		Water pollution	Concentration of suspended solids (e.g. mg/l)
		Noise	dB along the border of the quarry
Assessment of the single processes constituting each phase ("by single process" approach)	Cutting of the "slice" of rock and removal and tipping of this "slice" onto the quarry area.	Energy input	Electric energy consumption (e.g. GJ/year)
		Material input	Explosive consumption (e.g. ton explosive/year or GJ/year)
			Water consumption (e.g. m^3water/year)
		Material output	Amount of blocks produced (e.g. m3/year)
			Wastewater production (e.g. m^3water/year)
			Solid waste production (scraps) (e.g. m^3/year)
	Squaring of the "slice" in blocks.	Energy input	Electric energy consumption (GJ/year)
		Material input	Water consumption (m^3water/year)
			Fossil fuel consumption (ton Diesel oil/year)
		Material output	Amount of squared, semi-squared, and shapeless blocks produced (e.g. m^3/year)
			Wastewater produced (e.g. m^3water/year)
			Solid waste production (scraps) (e.g. m^3/year)

However, it is evident that a combined approach is more complex than a "by phases" approach, because it would require a more detailed knowledge of the production process. Anyway, it has not to be overlooked that an environmental excellence brand of a product and/or a service is in context. Therefore, criteria, on the base of which establishing whether attributing this excellence brand, should cover at least also the energy consumptions.

In addition, a hybrid approach would also allow not only satisfying an excellence brand but would represent an operative tool to single out intervention priorities aimed at improving the energy and environmental performances of the sites. The EU eco-label, in fact, being based on criteria by phases, might lead to an audit that would not enable to establish a priority of interventions on single machines or single "working islands", in order to improve the energy efficiency of the productive chain, unlike a combined approach.

It seems worth to remind that this paper proposes a tentative scheme of a hybrid approach according to which mass and energy balances of single processes and/or single machines could be included within an EU eco-label scheme for natural stones. However, it is also evident that including energy and mass balances in the evaluation procedure would imply the definition of benchmarks for the energy and resources consumptions, whose establishment would certainly require further and more extensive analyses.

7. Conclusion

This paper intends to provide a contribution to the revision process of the EU Decision of 9th July 2009 establishing criteria for the award of the Community eco-label to hard coverings, presently under revision.

The current European approach for certifying the environmental excellence of hard coverings, particularly of marble, can be qualified as by components one, where the production process is considered as one phase and it includes instead extraction and finishing phases. In addition, the cutting phase occurring in sawmill does not seem to be considered. According to such an approach, on one hand, neglecting all the energy spent on cutting extracted marble blocks can constitute a serious limitation in having the real site's performances. On the other hand, such an approach will likely lead not to single out hot spots along the working chain and thus establishing intervention priorities.

In this work, an alternative approach combining the approach of the Decision and that of current assessing methodologies has been presented, which considers the production process as constituted by unit operations and machineries. This vision leads to a "hybrid by components" approach, in which components are phases, each of them with its unit operations. Compared to the EU Decision approach, this seems to be more comprehensive, and could allow at the same time to establish a priority of intervention on single machinery o unit operations, in order of improving the energy efficiency of the entire manufacturing.

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