THE ECONOMIC DIMENSION OF SUSTAINABILITY: NEW PERSPECTIVES FROM A CERAMIC TILE MANUFACTURING CONTEXT[1]

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ABSTRACT

Circular economy practices are especially interesting for the ceramic sector, which is an energy- and raw materials-intensive industry. Even with a remarkably positive

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impact on the environment, circular practices must be sustainable in socioeconomic terms. Appropriate assessment tools are therefore needed in order to implement sustainability in the business models of ceramic producers.

For this purpose, the Life Cycle Sustainability Assessment Framework (LCSA) is one of the most widely adopted methodologies in the evaluation of sustainability and it enables each of the three pillars of sustainability: environmental, economic and social to be considered. Life Cycle Costing (LCC) is the economic assessment tool of the LCSA. The literature underlines the existence of at least two categories of LCC. Conventional LCC is a pure economic assessment of the costs incurred by the company in the different phases of the product life cycle. Environmental LCC considers the life-cycle costs of a product incurred by the actors involved, including externalities that are expected to be internalized. Nevertheless, for decision making, LCC is generally considered as a mere extension of the environmental sustainability assessment and it continues to have significant limitations as the economic pillar of sustainability. It has an unclear system of boundary definition and, therefore, it does not include different perspectives of the economic agents involved.

The aim of this research is to overcome the above mentioned LCC limits, offering a new approach to the economic dimension of sustainability, starting from the ceramic tile-manufacturing context. To do so, a new comprehensive LCC calculation tool for the ceramic sector will be presented. Along the entire ceramic supply chain, the most relevant and measurable circular practices will be selected and included in this new tool, considering the whole ceramic manufacturing supply chain. The tool will consider both internal costs and externalities and it will offer the opportunity to compare different scenarios with different levels of sustainability practices, assessing their feasibility in economic terms.

The analysis should provide, through an operative case, an illustration of the implementation of a broad LCC definition in a manufacturing reality. The research opens up new avenues for future economic assessments of sustainability in manufacturing processes, even in sectors different from the ceramic one.

1. INTRODUCTION

The European Commission stresses that the circular economy will boost the European Union's (EU) competitiveness by protecting businesses against resource scarcity and price volatility (Domenech and Bahn-Walkowiak, 2019). This school of thought thus pursues a regenerative economic model to overcome the current models of growth and resource consumption (Pinheiro and Jugend, 2019). The circular economy proposes a radical systemic change aimed at eco-design, economy of functionality, reuse, repair, remanufacturing, and industrial symbiosis (Baldassarre et al., 2019).

Implementing such changes requires companies to deeply transform the ways they create value. From linear models that create added value through manufacturing processes based on the flow of materials (Andrews, 2015) to circular models capable of capturing the value of waste in order to maintain a constant flow of value in many different supply chains in order to reduce the depletion of resources (Bressanelli et al. 2018). The industrial system, at the end of the production and consumption cycle, must develop the capacity to absorb and reuse waste and slag. Accordingly, the circular economy refers to a development model where the waste of one company becomes the raw material of another (Singh and Ordoñez, 2016), in other words, it is a model that regenerates itself.

Firms, especially those intensive in the use of energy and natural resources (such as the ceramics industry) are intended to think of new products, production and sales systems capable of integrating more agents of the value chain in the task of maintaining the reverse circulation of resources for less resource deterioration (García-Muiña et al., 2018). This in turn requires them to have effective and reliable information systems that allow them to make appropriate decisions within this new competitive framework. This means being able to quantify the sustainability of the various possible options in terms of environmental, financial and social acceptability.

The Life Cycle Sustainability Assessment framework, expressed as LCSA= LCA+LCC+SLCA (Klöpffer, 2008), is one of the most widely used tools to measure sustainability of products and processes. Actually, LCA (Life Cycle Assessment) and LCC (Life Cycle Costing) are being performed together in an attempt to broaden the concept of LCSA (Heijungs et al., 2013). In this regard, both approaches contribute to the documentation of product-related business processes, serving as instruments of business control, facilitating decision process and making companies aware of economic and ecological impacts. Furthermore, they are system modelling, so they help to set systems boundaries and relevant data collection. However, there is still a lack of holistic studies reporting the effective use of these tools (Cinelli et al., 2013). Therefore, more conceptualisation and methodological foundation are needed in order to properly define the sustainability problem and connect the different methods and models (Cinelli et al., 2013). In fact, today's economy is demanding new ways of achieving sustainability, i.e. on the Triple-Bottom-Line, beyond the separate valuation of environmental, social and economic aspects (Bradley et al., 2018).

Furthermore, the LCSA framework falls short of analysis of the added value of business models (Scheepens et al. 2016). It is precisely in this aspect where the circular economy approach can contribute most, whose main innovation lies in reflecting on the ways of capturing value from what would be considered waste in a linear value generation approach (Ghisellini, Ripa and Ulgiati, 2018).

Whereas LCA is already a standardized method (ISO 14044, 2006), accepted across various industries (Bradley et al., 2018) and widely used to investigate the potential environmental impacts of products and processes (Klöpffer and Grahl, 2014), LCC and SLCA (Social Life Cycle Assessment) lack consensus and definition and thus broad practical implementation (Broberg and Fornell, 2017; Neugebauer et al., 2015).

A recent report on the state of the art in LCC published by the ICLEI (Local Governments for Sustainability, European Secretariat, 2018) stated that, although LCC is a top strategy in Sustainable Public Procurement in Europe, there is still a clear trend of non-application of its methods into procurement procedures. Among the most important challenges that this report highlights when using the LCC as a sustainability assessment tool are: the complexity of environmental issues and the selection dilemma between environmental versus cost effective alternatives.

The LCC technique is designed to present decision options according to the different stages of a life cycle and for different cost estimates. Therefore, LCC focuses on costs at every stage of the life cycle and should answer the questions: How much does the process cost? What economic impacts does it have? (Moreau and Weidema, 2015). The different possibilities of defining a productive system, categorizing costs and identifying the agents that support them determine different modes of calculation and aggregation (Huppes et al., 2004). Therefore, interpretations of the results and alignment with other complementary analysis techniques also depend on these three aspects (Huppes et al., 2004). Nonetheless, apart from the different methods of cost calculation, LCC is a powerful management technique for making effective decisions about costs (NATO RTO, 2009).

The key sustainability literature differentiates two main types of LCC (Hunkeler et al., 2008; Ciroth et al., 2011). Firstly, conventional LCC (C-LCC) incorporates private costs; in other words, it is based on a purely economic assessment that considers the costs of the different phases of the life cycle incurred only by the company. External costs or costs not directly incurred by the producer are not considered.

On the other hand, environmental LCC (E-LCC) considers the life-cycle costs of a product incurred by the actors involved, including externalities that are expected to be internalized (Rebizer and Hunkeler, 2003). For example, if it is expected in the future that a new tax on CO_2 will be enforced or a subsidy granted for engaging unskilled people within the next two years, LCC will reflect these costs and benefits in its calculations (Ciroth et al. 2011).

This analysis is complementary to LCA analysis. In order to operationalize this technique, the economic cost of polluting emissions should be estimated, based for example on the willingness to pay (WTP) of the responsible company, to avoid a worsening of the situation created or to remedy a damage caused, attributing an economic value to the damage (according to the selected categories of damage, for example Human Health, Ecosystem Production Capacity, Abiotic Stock Resource, Biodiversity). It should be taken into consideration that the LCC objective to collect all the costs and impacts of the life-cycle environmental aspects implies significant risks of double-counting when environmental damages are monetized in LCC, which would be counted in the environmental domain, as well as costed in the economic domain (Kloepffer, 2008; Wood and Hertwich, 2013).

Based on the above, it could be said that both LCC techniques are useful to determine the costs derived from the production of a functional unit in a particular system. However, LCC (conventional and environmental) has important limitations related to the unclear system boundary definition and the unresolved internalization approach (Neugebauer et al., 2016).

Thus, a need arises to establish a consistent definition of the production system or identify the system's boundaries[2]. Following the ISO 15686:5 (2017), LCC attempts to capture all cost across the life cycle, in other words, from the beginning until the disposal, end-of-life/status change (also called *from cradle to grave*). Therefore, LCC is based on a linear process that sees the use of raw materials and the generation of production waste that is thrown away (take-make-dispose). Thus, it does not consider other costs besides disposal or end of life (Swarr et al. 2011; ISO 15686:5, 2017), such as renewable and recyclable resources or the recovery of waste from internal processes and from other players in the ceramic industry, which are consistent with the sustainability principles of the circular economy.

The aim of this research is to overcome the above-mentioned LCC limits, offering a new approach to the economic dimension of sustainability, starting from the ceramic tile-manufacturing context. In order to construct our proposal, using the ISO 15686:5 (2017) guidelines as a reference method, we have started from an internal cost-oriented perspective (conventional LCC) and then incorporated the full cost philosophy. This

2 Quantitative description of all flows of materials and energy through the system, both incoming and outgoing (ISO 14044, 2006)

standard represents an important tool in helping to establish a clear terminology and a common methodology for life-cycle costing; to enable its practice, to help to improve decision making and evaluation processes, and to provide the framework for consistent LCC predictions and performance assessment, among others. However, this framework is particularly aimed at predicting and assessing the cost performance of buildings and constructed assets. With this in mind, it has been adapted to the sector by breaking down the costs according to the different steps of the production process in a supply chain perspective. Moreover, aiming at strengthening the sustainable dimension of this technique, some costs related to circular economy practices have been identified in order to foster changes to circular business models.

2. METHODOLOGY

2.1. SYSTEM BOUNDARY

When assessing economic impacts, it is worth considering what is implicit in a final product cost, in other words, along the full production chain, relating LCC to the supply chain may help to distinguish the components of final LCC (Wood and Hertwich, 2013). For this reason, an inventory analysis to identify the input and output flows in the life cycle of the ceramic process is needed.

On the other hand, from a circular approach the limits of the product system must be established from the product's conception, extraction of materials, manufacture, use and end of its useful life until the recovery and introduction into a new process return circulation so that the greatest possible quantity of materials is recovered, reproduced, reused or recycled.

The model displayed in Figure 1, show all the phases of the life cycle of the ceramic product and its relations. It allows determination of the inputs and outputs, forwards and backwards from a circularity approach (cradle to cradle). It also represents the potential relationships with other agents to whom the company may be linked, to close the loops in a possible cradle-to-cradle model.

The manufacturing process begins with the reception and storage of the raw materials that will be used to prepare the ceramic mixture. Before this phase, it is essential to study the strategic alternatives to procurement and transport in order to reduce environmental impacts. For this purpose, collaboration with mining industries is fundamental. For example, through the sharing of storage capacities or by evaluating the different qualities of materials and transport alternatives. In this phase, the options of materials recovery, although desirable, are, in fact, very reduced, so efforts should focus on the reduction of waste and the application of measures for the recovery of soils or ecosystems.

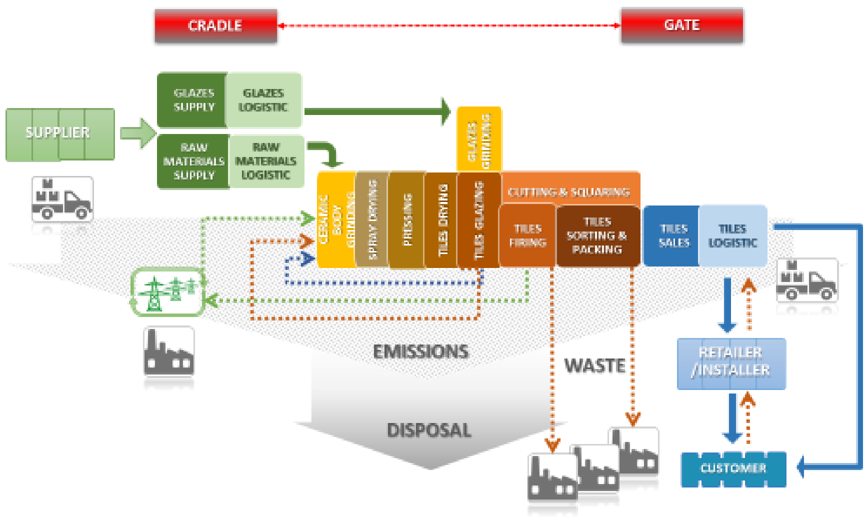

Figure 1. *Ceramic production circular process flow.*

After storage, the raw materials are mixed (with the compositions of the ceramic body being produced) and ground with water in continuous rotary mills until a solids/liquid suspension called slip is obtained. This is then stored in tanks and subsequently spray dried at high temperatures, yielding a very fine and homogeneous powder that is subsequently pressed to achieve a format (square or rectangular) of the desired size. During these phases, which are continuous, design and production constitute alternatives that are directed not only at avoiding the greatest volume of emissions to the atmosphere or of discharges into the waters, but also at achieving the greatest volumes of reuse, not of the intermediate products (broken unfired tiles), but especially of resources such as heat, convertible into electrical energy, or wastewater reuse. The tiles are then coated with a layer of glaze and digitally decorated with special inks to obtain the required graphic design, ready for firing at very high temperatures in cycles of different times.

In these phases, the possibilities of reincorporating flows into the manufacturing system are reduced, due to the special characteristics of the products that are already glazed. The recovery of energy and the search for quality and production alternatives (lean management) that reduce the losses of fired tiles to a minimum are still of special importance. Here, as in the next phase, other companies outside the ceramic value system become important. Either because they can incorporate these materials as raw material for their production processes (reducing consumption and waste of raw materials and natural environments) or because they are specialists in waste treatment. The tiles coming out of the kiln can then follow two paths: they can go directly to the packaging department of the finished product or they can be sent for further processing, which can include cutting of smaller and more modular tiles and/or lapping of the surface to obtain a glossy effect, such as stone materials (marble and granite). In these phases, the minimization of tile losses is once again key, but the choice and possibilities of recycling and recovery of packaging materials through appropriate supplier companies also become important.

At the end, the finished tiles are routed to the different final agents. In these stages, the selling of the product must be thought of in terms of possible alternatives to reduce the impact (transport and storage) and the cost of using the final product. Equally important are the possibilities of systems for repurchasing, recovering or treating waste from the end user or from the retailer.

In all production stages, reliability in production and control systems is essential to reduce product and time losses. These do not only involve a higher cost, but also a greater environmental impact. In addition, the availability of tools to make a sensitivity analysis of the possible alternatives of investment and design of product and production is crucial. The possible symbiosis relationships that are essential for a true circularity of the system and that are already being investigated especially in the ceramic sector are also highlighted[3].

2.2. TIME HORIZON

This variable will affect both the monetary value of the costs to be included in the analysis and the uncertainty when calculating future resource consumption. The difference between current and future values makes it imperative to use discount rates to be applied to cost magnitudes over time. In addition, however, the more or less required choice of longer periods of time in the life cycles of a product increases the sources of uncertainty when quantifying future costs.

The ceramic product has relatively short production periods, typical of manufacturing industries, which are increasingly used to lean systems and are also subject to more frequent changes in tastes and fashion. However, the periods of use (durability) in which the product is being exploited are still quite high. In this sense, choosing a calculation period appropriate to the type of analysis to be carried out is essential to ensure consistent and useful cost data for decision making. On the other hand, and in the search for greater coherence and integration of the LCSA tools. It would be desirable that the period of calculation of life cycle costs could include the same periods used in the environmental assessment or LCA.

3 To find out about possible symbiosis relationships in the Spanish ceramic sector, see Vicent et al. (2018).

2.3. IDENTIFYING COSTS: THE SCOPE OF THE LCC ANALYSIS

The scope of the LCC methodology relates to the type of cost to be taken into account in the analysis. Thus, to identify and allocate those costs it is important to keep in mind that the LCC analysis is aimed at quantifying the life cycle cost of a product to serve as input information into a decision-making process. The set of costs to be considered in LCC analysis goes beyond a mere definition of the most direct consumptions related to the life cycle of a product, since it is also necessary to consider other indirect costs and those associated with compliance with national or international regulations or tax systems. This is reflected in the international reference standard (ISO 15686:5; 2017) which proposes a classification of costs that should be included in a standard analysis for the construction sector as shown in Figure 2.

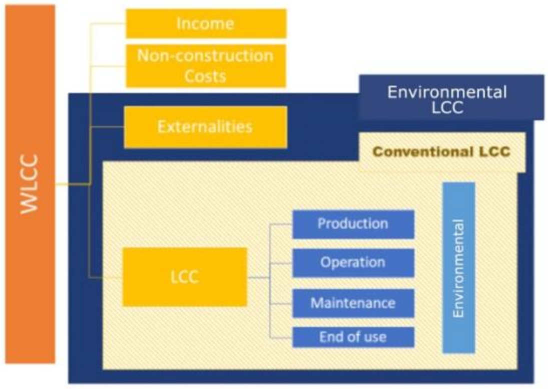

Figure 2. *WLC and LCC elements (ISO 15686:5; 2017).*

This standard (ISO 15686:5; 2017) distinguishes between life cycle cost (conventional LCC) and full life cycle cost. The former only includes those costs that are directly related to production, in addition to considering this process to be a long in time. According to this scheme, to know if a product (building) will be sustainable from an economic point of view, all those costs linked to its production (construction), operation, maintenance and disposal at the end of its useful life have to be included.

Thus, when considering the LCC calculation system of a product, it is not possible to identify those cost savings related to decreased use or greater recovery of resources, which, however, could be true measures of environmental sustainability. Only those costs related to compliance with norms and standards about, for example, pollution or environmental protection are considered and always if they are monetized in terms of taxes or subsidies (environmental costs). Therefore, it does not include any valuation of other externalities as a consequence of production.

In order to be able to include these externalities, the standard proposes the full cost method. This calculation would include the economic valuation of costs or cost savings that may occur throughout the life of the product due to impacts on the environment or on society. In this respect, the standard makes it clear that only those that are likely to be internalised in the future in the form of taxes, fees or subsidies should be included. That is to say, it explicitly recommends not monetizing those externalities whose future influence on the product cost is unknown. This recommendation is important if we consider costing from an accounting approach, since increasing the costs of a good can influence its viability from a purely economic perspective. However, to assess sustainability from a broader point of view, the monetary quantification of externalities should be included, regardless of whether or not they were to be internalised in the future. After all, these impacts can be considered as real losses of value of a good (being more polluting) or greater value of that good (polluting less). In addition, their monetary valuation, for example, based on an LCA analysis, may be more accurate and complete than simply incorporating a current tax, rate or bonus.

One of the difficulties facing the practical application of this methodology in an industry such as porcelain tile is the adaptation of this cost structure to the reality of a continuous production process.

In the ceramic process, some of the costs related to the life cycle of the product are borne by agents other than the company. For example, we can assume that the operation of a good such as ceramic tile is more the activity of an installer than of the company itself, or that the maintenance costs for the product are something that must be borne by the end customer, or even that the costs of dismantling a ceramic flooring could be borne by the customer, the reseller or even the installer. Therefore, knowing who bears the cost of a certain basic activity related to the life cycle of a product is a key aspect in determining the real cost of its sustainability. Thus, if a ceramic company launched on the market a new tile design aimed at reducing the consumption of polishing or cleaning products (to be supported by the customer), it would not only be reducing the monetary cost of maintenance to the customer, but it would also be putting a more sustainable product on the market. An adequate system of sustainability analysis to make these decisions should be able to include these costs regardless of the agent that bears them.

Identifying the costs related to each agent in the value system is not only important for the economic quantification of sustainability but can also be key to undertaking circular economy principles. That is, reverse logistics actions, waste reuse policies or searching for alternative uses of materials throughout the useful life of the product. For example, in order to assess the feasibility of offering retailer or customer programmes for the repurchase of materials, it would be necessary to make an economic assessment of the costs associated with the required investments, as well as the environmental impacts that might occur.

2.4. A MORE COMPREHENSIVE LCC TOOL

Starting from the ceramic tile-manufacturing context and the ISO 15685:6 (2017) as the reference model, the LCC's new comprehensive tool has been built in two sequential models.

First, an aggregation scheme has been explored from a circular flow approach, which is closer to the reality of a continuous productive process. With this first scheme EC-LCC (environmental and circular LCC), the calculation is intended to identify the most relevant circular economy practices in the production process. It also tries to respect the concept of life cycle in the terms in which it is expressed in the international standard and it is intended to be calculated in periods of one year or less.

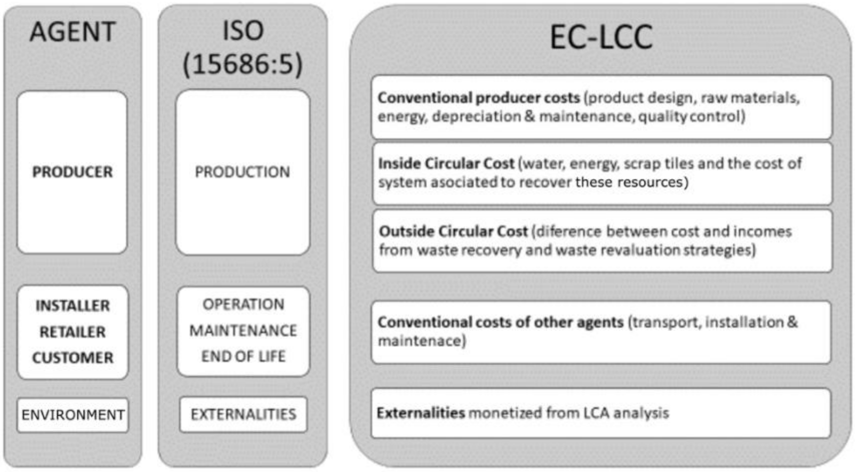

Table 1. *EC-LCC scheme.*

In this sense, an identification of costs based on three criteria is proposed, considering: conventional costs directly associated with the life of the product, eco-circularity cost associated with circular economy practices or principles and externalities obtained from the monetary valuation of impact from emissions and non-recoverable waste.

Product lifetime costs are identified without considering the full cost but only those linked to production, installation, maintenance and end-of-life. In other words, the costs directly associated with design and quality control, the acquisition of materials, labour costs, energy costs and the depreciation, maintenance and repair of productive investments are considered. All this regardless of the agent that bears the costs. Reasonable estimates should be made of the installation, transport and maintenance costs that, due to the characteristics of the product[4], are borne by other agents throughout the entire life cycle.

An Eco-cost is a measure to express the amount of environmental burden of a product on the basis of prevention of that burden: the costs which should be made to reduce the environmental pollution and materials depletion in our world to a level which

[4] These costs should not be considered total installation or maintenance costs that would be borne by the installer or the customer as these will depend on other factors not directly related to the product´s qualities of functionality, durability, weight, fragility, etc., but on the practices or characteristics of those other agents.

is in line with the carrying capacity of our earth (the 'no effect level') (European Commission, 2003; Scheepens et al., 2016).

In this line of thought, so-called eco-circularity, the costs would be all costs generated by investments aimed at developing any of the principles of the circular economy (Ellen MacArthur Foundation, 2017): design out waste and pollution, keep products and materials in use and regenerate natural system. Two cost types are proposed for assessing this. Inside circularity costs, i.e. the costs of resources reused and the systems to do it inside the production process water, pieces of pressed tiles and the recovery of thermal energy in the form of electrical energy, for example). Outside circularity costs, i.e. from practices involving other actors and involving reverse logistics. For example: repurchase policies, recovery of packaging or final product from retailers, installers or customers, sale of recovered materials to companies in other sectors such as cement mortars (Pitarch Roig et al., 2018) or concrete production (Debueno Pradillas et al., 2016). The calculation of these costs should also take into account the potential incomes arising from the recovery of waste of recovered materials that are difficult to remanufacture. These costs must be obtained separately from conventional ones to avoid double counting.

In the case of externalities, the tool would have to be fed by the information from the LCA analysis. Thus, both LCA and LCC need to use a consistent and shared definition of the product system in order to represent all the actors involved (Swarr et al., 2011). Following Ferrari et al. (2019), in order to overcome some of the problems of integrating LCA and LCC, a difference has to be made between production phases that generate costs to the producer and others incurred by other agents within the value system: distributor, installer and user. Keeping the same system boundary definition for LCA y LCC analysis, the environmental externalities could be monetized separately, to some extent avoiding double counting.

The second scheme is the WEC-LCC aggregation model. Although the implementation of the whole life cycle cost of the ISO is not good for this type of productive process – investments and costs are mixed (multiannual investment), the general principles and cost breakdown system of ISO 15686-5: 2017 have been followed with reasonable adaptations for the ceramic tiles production process. To do that, two templates of the Society of Chartered Surveyors Ireland (SCSI) working group on LCC (Kehily and Hore, 2012) have been considered. For this reason, the costs have been included according to the type of asset (investment) associated with the ISO 15686:5 cost structure, keeping a reasonable coherence with the cost classification of the first structure.

As a full cost model (or total cost of ownership), it involves including other incomes and costs not directly related to production but necessary for the business's development. These link the company to its administrative and financial activity and to the tax/legal system. These costs have not been included in the first scheme, which is just related to the productive process (European Commission, 2003; Scheepens et al., 2016).

In this model, the strict application of ISO implies considering each ceramic product as an investment project including assets and incomes, as well as production (operational) costs, which makes it necessary to consider a time horizon of more than one year. The guide to Life Cycle Costing of the working group on sustainability and LCC of the SCSI has been followed to take into account a possible escalation effect for costs and the discount rates to calculate Present Values. However, statistical methods such as Monte Carlo analyses would be recommended when uncertainty about future costs arises.

A representation of the proposed model with the two previous schemes is exhibited in Figure 4.

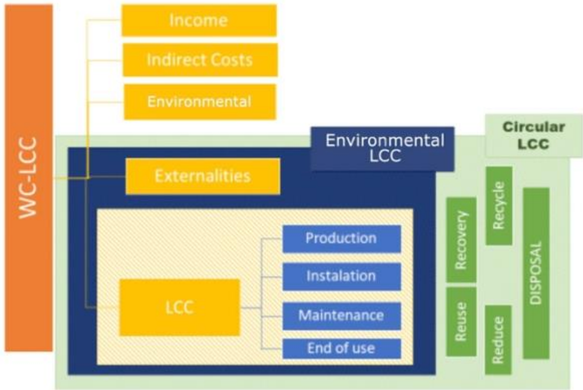

Figure 4. *New economic approach: WEC-LCC elements.*

3. CONCLUSIONS

The two schemes approached have different objectives, but they are complementary. Thus, in the first one, the total cost, considered as an investment appraisal technique, is not taken into account. However, it makes possible to achieve the true value of a product, that is, the measurement of: the resources consumed, the resources recovered and the effects on third parties (externalities) throughout, not so much the life cycle of a product, but the circular value system of the product.

A clear and broad definition of the system boundary to the whole system of value of a product homogenizes the limits of LCA with those of LCC. If environmental impacts (externalities) are also monetized separately for each part of the value system that generates them, then it is possible to know better the origin of the value gains or losses, to some extent avoiding double counting. Whether due to: more eco or recovered materials, better designs, more or better recycling or remanufacturing practices or even cooperation agreements with other companies for the recovery of waste. In this sense, by proposing an identification of the costs generated by efficiency systems that reduce waste (Eco circularity cost), we can quantify efficiency measures aimed at reducing the burden of waste and residues generated by valuing one of the principles of circular economy.

The second approach, building on the previous one, allows a present valuation to be made of the future costs arising from environmentally responsible investments focused on the circular economy, taking into account the structure of the company (indirect costs) and the legal system in which it is embedded (taxes and environmental cost).

In many cases, companies have sustainability actions that are not reflected in their information systems and therefore are not being considered in decision making. Being able to have relevant information on the economic valuation of the harmful effects of production, as well as investments directed towards more circular production models, allows the company to create different decision scenarios truly focused on sustainability. At the same time, growth proposals and/or the incorporation of more or better relationships with other agents that allow more symbiotic models and fewer resource consumers (meso-macro approach), as well as better ecodesign decisions, can be taken into consideration.

The implementation of this new comprehensive model could help companies to better understand the sustainability of their products to: a) make business decisions regarding which products to produce, which circular economy decisions to take and how polluting (or relatively unsustainable) their products are, and b) be able to inform reliably and to be externally comparable (depending on the standardization of the methodology), in order to fulfil the real objectives of transparency and consistency, normally related to intangible returns for the company.

We are aware of some of the limitations that remain unresolved and that open the way for further investigation. Questions such as the uncertainty associated with the assessment of future impacts or the evolution of prices and risks must continue to be studied in order to improve decision-making tools. In the same way, dealing in depth with the valuation of income or intangibles, both of the company and of third parties (social cost) is another of the issues that will allow us to build more sustainable models on more realistic and complete decision bases.

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