HYBRID TOP-DOWN AND BOTTOM-UP FRAMEWORK TO MEASURE PRODUCTS' CIRCULARITY PERFORMANCE

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Abstract

Industrial practitioners are increasingly willing to shift their products and businesses into more circular models. Circular economy paradigm requires optimization of system rather than components. Yet, existing methods and tools, intended to designers, engineers or managers, to assess and improve product circularity potential are both lacking of systemic vision and operational considerations. This research work contributes to fill this gap through the design of a holistic and integrated framework aiming at measuring, improving and monitoring product circularity performance. The developed framework is based on a hybrid top-down - objective-driven - and bottom-up - data-driven - approach including the four building blocks of circular economy defined by Ellen MacArthur Foundation. First mature steps of the proposed framework are detailed and experienced on an industrial case study. Insights for enhanced products' circularity performance measurement and improvement framework are also discussed and lead to further promising research perspectives.

Keywords: Circular economy, Circularity indicators, Sustainability, Design for X (DfX), Case study

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1 INTRODUCTION

Companies are increasingly interested in moving their products and businesses towards a more circular economy to benefit from significant economic and environmental advantages promised by the latter (EMF, 2015). Indeed, even if there is no crystalized definition of circular economy yet, this concept aims at decoupling economic growth from consumption of natural finite resources (EMF, 2013). Thus, an efficient circular economy model could both lead companies to capture additional value from their products and manufacturers to mitigate risks from materials' price volatility and short of supply. Furthermore, according to a study realized by the McKinsey Global Institute (MGI, 2015), adopting circular economy principles could not only benefit Europe environmentally and socially but also generate a net economic benefit of €1.8 trillion by 2030. However, the MGI acknowledges that the results of such numerical finding are indicative, since their models rely on multiple assumptions, and calls therefore for more research. Although the promises of a circular economy seem to be appealing, there are still a lot of challenges in its real implementation. So that the move towards a circular economy operates, companies should be supported in this transition from a linear model to a more circular one.

Meanwhile, the current lack of operational support to help industrial companies assessing, improving and monitoring the circularity of their products, components and materials is a reality (EMF, 2015). Hence, the main motivation of the present study is to contribute in the process of moving from an idealized vision of circular economy to a functional and operational one by giving the means to industrial practitioners (i.e. managers, engineers, designers) to measure, enhance and monitor the circularity of their products. In this light, two research questions have then emerged. First, how to assess the circularity potential of a product - complex or not, industrial or not - during early design and development process? Second, how to measure the circularity performance of a product in use, on the market, in order to redesign the product or to rethink and reshape associated business model? Critical analysis of existing methods and tools assessing products' circularity performance are performed and key limitations are highlighted. As a result, both scientific and industrial communities should be interested in the construction and application of a new and more comprehensive framework providing keys to measure and enhance products' circularity performance.

Contrary to existing methods and tools, the holistic and integrated developed framework - using a hybrid top-down and bottom-up approach - claims to encompass a wider spectrum of circular economy complexity, based on the four building blocks of the circular economy defined by the Ellen MacArthur Foundation (2013). A case study is proposed on a catalytic converter, which contains a non-negligible amount of platinum group metals (PGM) considering as critical raw materials by the European Commission (EC, 2010). The framework highlights promising design guidelines to protect critical resources and thus it assists companies to become more resource sensitive.

The remainder of the paper is structured in the following way. After underlining the need for circularity measurement, existing indicators, methods and tools to assess circularity of products are reviewed in Section 2. Insights to design and develop suitable indicators are also provided in the literature review section. The proposed framework, based on a hybrid approach that combines both top-down and bottom-up analyses to define relevant circularity indicators, is detailed in Section 3. Application of the framework on a real industrial complex product is performed in Section 4. Comparison with existing tools to validate actual contributions of the developed framework is also proposed in Section 4. Finally, reflections to enhance proposed framework and directions for future work are discussed in Section 5.

2 LITERATURE REVIEW

The circular economy concept has been and is still widely discussed in literature. For instance, Ghisellini et al. (2015) have recently provided an extensive review of the circular economy literature of last two decades including the main circular economy features and perspectives: origins, basic principles, advantages and disadvantages, modelling and implementation of the circular economy at different systemic levels, notably at the macro level (i.e. referring to city, region or country implementation) and the meso level (i.e. referring to symbiosis association or inter-enterprise implementation). However, the area of monitoring circularity at a micro level (i.e. at the company level) and at a more micro level (i.e. at the level of products, components and materials) - called here the nano level - has been barely discussed in literature (Saidani et al., 2017). Likewise, according to Lieder and Rashid (2016), the circular economy level of discussion is often decorrelated from product consideration and circulation, that is to say, from the core of circular economy implementation. In order to address particularly this area, corresponding to the level of design engineering, the scope of the present state-of-the-art is then narrow to products' circularity measurement and associated indicators. Meanwhile, even if focus is made on products' circularity, considering whole product value chain (i.e. lifecycle and systemic thinking) is essential to fit with circular economy paradigm. As such, interaction - and inclusion - of nano and micro levels within wider levels of the circular economy implementation will be addressed in the proposed framework. In fact, a systemic vision of the circular economy is required to avoid negative and unintended impact transfers (Arnsperger and Bourg, 2016).

2.1 Measuring circular economy performance at product level

When companies are willing to improve the environmental performance of their products, an environmental assessment is usually performed first - e.g. a life cycle assessment (LCA). Similarly, to identify hotspots and areas of improvement in order to move towards a more circular economy, it would be helpful to assess the potential performance of products' circularity first. Product circularity performance provides additional information than a LCA by focusing on possible ways and mechanisms to close the loops. Yet, there is at present no recognized way of measuring how effective a country or a company is positioned in making the transition to a circular economy, nor holistic monitoring tools for supporting such a process (EMF, 2015). Academic researchers and organisations working on the circular economy concept and application agree on the necessity to measure progress in the transition towards circularity of products. More precisely, to follow and successfully achieve the shift from a linear economy to a circular one, it becomes essential for industrial practitioners such as engineers, designers, and managers to get the right and suitable methods and tools, including indicators, to measure and quantify this progress (Griffiths and Cayzer, 2016). Indeed, indicators are a way to assess change. Moreover, indicators have the ability to summarize the great complexity of our dynamic environment to manage a comprehensive amount of information. It should be therefore relevant to measure the circularity degree of current systems, processes and products to evaluate the remaining distance to achieve a self-sustaining economy, truly circular (Arnsperger and Bourg, 2016). Circular economy indicators are at an initial stage of development and existing ones do not have the capacity to capture the entire circular economy performance of products (Franklin-Johnson et al., 2016). Limitations of existing tools and indicators related to product circularity measurement are summarized in Table 1.

Table 1. Indicators, methods and tools to measure products' circularity and associated limits

Sources	Indicators, Methods and Tools	Identified Limits & Gaps
(Amaya, 2012)	Assessment of the environmental benefits provided by closed-loop strategies (remanufacturing and PSS) for industrial products.	Design methods of PSS associated services (e.g. maintenance and/or remanufacturing) are not covered; Absence of cost model; Lack of transparency about the proposed method.
(Ellen MacArthur Foundation, 2015)	Material Circularity Indicator (MCI)	Materials scale only; Limited to a small spectrum of circular economy complexity (e.g. do not considered whole value chain and the focus is only on two end-of-life options: reuse and recycling).
(Evans and Bocken, 2013)	Circular Economy Toolkit (CET)	Similar to an environmental assessment checklist; Qualitative; Simple trinary choice model in the possible answers; Superficial guidance.
(Franklin-Johnson et al., 2016)	Longevity Indicator: "Resource Duration"	Complementary indicator: the focus is only on eco-effectiveness that do not cover a wide range of circular economy paradigm; Non-monetary.
(Griffiths and Cayzer, 2016)	Circular Economy Indicator Prototype (CEIP)	Single score based on 15 questions, mainly focused on the manufacturing and end-of-life phases; Economics and whole value chain are not covered.

In a nutshell, even if these methods, tools and indicators could provide a first trend of products' performance in the context of circular economy, they are neither considering the entire complexity of the circular economy (e.g. interaction between systemic levels, stakeholders' collaborations through end-of-life value chain, integration of all possible end-of-life options to close the loops, circular business models), nor operational enough for industrial practitioners to design and develop more circular products. The interest of this study lies in the development of a framework including more consistent indicators to assess circularity performance of products that are both relevant for industrial practicioners through operational implementation and in accordance with the circular economy paradigm and complexity. Before starting the construction of such a framework related to products' circularity measurement, let us have a look at methods to design indicators properly in a rigorous and scientific way.

2.2 Material and methods for designing indicators

2.2.1 Definitions and overall recommendations for designing indicators

On the one hand, according to Park and Kremer (2017), there is no widely accepted definition of what constitutes an indicator. However, this paper adopts the view of the OECD (2014) where an indicator is defined as "a quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor". Thus, indicators provide an effective tool for measuring progress and performance. On the other hand, a metric is usually considered, by convention, as a calculated or composite measure or quantitative indicator based upon two or more indicators or measures. Metrics help to put a variable in relation to one or more other dimensions. For better and easier understanding in this paper, we will be talking about indicators, even if they represent a value quantified with standardized units - i.e. a measure - or a composite, multi-dimensional structure of data - i.e. a metric. Even if indicators are widely used in both industrial companies and scientific literature, no methodical standard has been developed yet on how to design indicators. Let us have a look at few insights identified in the scientific literature that deal with the design of indicators. Particularly, Brown (2009) provides generic guidelines for the development and reporting of indicators. This methodology is structured into five stages: establishing the purpose of the indicators; designing the conceptual framework; selecting and designing the indicators; interpreting and reporting the indicators; maintaining and reviewing the indicators. In this light, Brown's methodology will be used as a basis for the developed framework, as detailed in Table 3 in Section 3.

2.2.2 Top-down and bottom-up approaches for designing indicators

Definitions and characteristics of both top-down and bottom-up approaches are available below in Table 2. Little et al. (2016) notice that there is little connection between the two approaches in the indicators construction, notably in the field of sustainability which is largely fragmented. Indeed, the majority of the studies use a top-down approach (Park and Kremer, 2017). However, both approaches have several times been used simultaneously to define sustainably indicators adapted to specific industrial sectors. For instance, Faucheux el al. (2003) developed sustainability indicators that were obtained through an innovative bottom-up top-down approach. They delivered proofs of the feasibility, effectiveness and legitimacy of such hybridization to the development and application of indicator systems. Additionally, this linking of bottom-up and top-down perspectives has an extremely important communication function in the context of indicator system development. Chamaret el al. (2007) have used such a hybrid approach to develop suitable (i.e. transferable, generic and scientifically valid) sustainable development indicators in extraction and mining field. As a bottom-up pattern, they used a participatory approach to both involve users and get practitioners' opinions about desired indicators. Weiland (2006) recommends, for the elaboration of sustainability indicator sets, a combination of a top-down-approach with a bottom-up-approach, and alerts about the limitations of each approach, as shown in Table 2. More recently, Park and Kremer (2017) perform an extensive literature review on previous research on categorization and selection of sustainability indicators and compare both approaches to define and select indicators, as highlighted in Table 2. They suggest the bottom-up approach can complement the prevailing ad hoc categorization of indicators from the top-down approach. Comparison of both approaches and their contributions in the construction of indicators is performed in Table 2.

Table 2. Comparison of top-down and bottom-up approaches to design indicators

Approaches	Top-Down	Bottom-Up
Definitions & Principles	Indicator systems based on applying accepted international classifications of indicators (Faucheux et al., 2013). Criteria or categories are pre-defined in a framework according to theoretical and technical meanings and then allocated indicators in each category based on their perceived theoretical similarities (Park and Kremer, 2017). Goal-driven. Analysis. Decomposition.	Indicator proposals based on local perceptions of issues and significance. Based also on appreciation of the preoccupations expressed by stakeholders (Faucheux et al., 2013). Indicators and categories are created from available data and information (Park and Kremer, 2017). Data-driven. Synthesis. Clustering.
Advantages (+)	Generally defined by experts at high levels (Chamaret el al., 2007). Theoretically cover a comprehensive spectrum of indicators and provide well-defined indicator categories (Park and Kremer, 2017).	Implicated more stakeholders and increased stakeholders' adhesion to indicators (Chamaret el al., 2007). Indicators more useful and usable for practicioners (Park and Kremer, 2017).
Drawbacks & Limits (-)	Lack of legitimacy in the eyes of stakeholders (Chamaret el al., 2007). Do not always respond to the specific circumstances of a sector. Lack of consideration for indicator utility in practice. Risk of considering only problems already known (Weiland, 2006). Often results in redundant and ambiguous indicators across categories (Park and Kremer, 2017).	Risk of not depicting all aspects of the issue comprehensively (Weiland, 2006). Difficulties to link and interpret a large amount of raw data from different stakeholders and markets. Data heterogeneity and variety. Time-consuming.

To date and to the best of our knowledge, the combination of top-down and bottom-up approaches has not been used yet to define and select indicators related to the evaluation of product performance in a context of circular economy. Lieder and Rashid (2016) applied top-down and bottom-up approaches to link in the same framework the macro-level (nations) and micro-level (companies) of circular economy implementation. The top-down approach considered first national effort through society, legislation and policies, while the bottom-up approach focused more on individual company effort through manufacturing industries, competitiveness and profitability. Yet, further considerations on product circularity performance thought the whole value chain were missing. On this basis, a hybrid framework is used to generate products' circularity indicators by combining the strengths of both approaches.

3 PROPOSED FRAMEWORK TO MEASURE CIRCULARITY OF PRODUCTS

3.1 Construction of the proposed framework and associated indicators

To structure the framework and associated indicators construction, the five-stage methodology proposed by Brown (2009) is used as explained in Table 3. Furthermore, as mentioned and justified above, a combination of top-down and bottom-up approaches is used to develop our indicators within a framework to assess products' circularity performance.

Table 3. Five-stage methodology to develop indicators, adapted from Brown (2009)

Stage Number - Name	Description	Application in our case
#1 - Establishing the purpose of the indicators	Identify clearly the target audience and determine the scope of the indicator set.	To support industrial practitioners in the circularity measurement of their products, components and materials.
#2 - Designing the conceptual framework	A conceptual framework provides a formal way of thinking about a topic area. It is a valuable tool for building coherent indicators set.	Hybrid method that combines the strengths of top-down and bottom-up ways to design indicators, ensuring holistic and integrated approach.
#3 - Selecting and designing the indicators	Selection criteria should be used as a tool to evaluate the proposed indicators to ensure they are relevant and measurable.	Framework based on the four building blocks of the circular economy according to Ellen MacArthur Foundation (2013).
#4 - Interpreting and reporting the indicators	A mix of graphs and comments is generally more effective for a public audience than large amounts of texts.	An Excel spreadsheet will be first developed to facilitate dissemination and communication of indicators in an organized, understandable way.
#5 - Maintaining and reviewing the indicators	Open consultation with stakeholders, including technical and subject-matter experts, data providers, the target audience, and other interested groups.	Not mature enough and therefore left for future work: include feedback from a review process to react by making adjustments to the indicators set (empirical validation process).

As explained in Table 3, stages from 1 to 3 are applied in our case, while stages 4 and 5 are left for further work as the proposed framework is at an initial stage of development.

3.1.1 Insights from the top-down approach

The overall product' circularity score at the top level will be derived from sub-scores, based on the Ellen MacArthur Foundation circular economy model and its four building blocks (BB), namely: circular product design; new business model; reverse cycles; enablers and favourable system conditions. These are key building blocks needed on a systemic level to shift business in a more circular direction. In fact, the successful implementation of circular models depends on the combined leveraging of these key building blocks (EMF, 2013). The Ellen MacArthur Foundation circular economy model was chosen because it is one of the most acknowledged in the literature at the moment and it has garnered a wide adoption by both academics and industrial practitioners (EMF, 2015). Also, each building block encompasses a wide spectrum of the circular economy complexity through different systemic levels - macro, meso, micro and nano - of the circular economy implementation. Particularly, to ensure a holistic view during the framework construction, main attributes selected to characterize the building blocks were positioned in regard with the levels of circular economy implementation, as illustrated in Figure 1. Each of the four building blocks basically contributes to close the loop of products and materials in its own way but also needs the support of three remaining building blocks. As an example, a modular product that could be easily disassemble for remanufacturing or upgradability will need an efficient collection system, infrastructures and market interest or regulatory obligations to enter in a proper and effective circular loop. Furthermore, the first building block is, for instance, essential because product design is one of the most important sectors influencing global sustainability. Decisions made during product design and development not only relate to material and manufacturing choices but have also a far-reaching effect on the product's entire life cycle. An efficient circular economy requires the consistent eco-friendly design of products that increases lifetimes, provides the same service with less material requirement, and facilitates repair and resale, product upgrades, modularity and remanufacturing, component reuse, and finally, end-of-life recycling (Hass et al., 2015). Hagelüken et al. (2016), Moreno et al. (2016), the European Commission (EC, 2015), the Ellen MacArthur Foundation (EMF, 2015), etc. outline also many additional factors that could impact circularity of goods, showing each of the four building blocks is a cornerstone for a successful circularity of products, components and materials. Numerous works have indeed been done previously in each of these four building blocks, but often in a separate manner. In fact, main weakness of existing methods, tools, and indicators, reviewed in Section 2, lies in the fact they do not cover these four building blocks simultaneously. The proposed framework is a timely and convenient opportunity to use best insights and practices from literature and to combine the strengths of complementary existing works and reflections to efficiently cover all aspects, or at least a wide spectrum, of products' circularity performance.

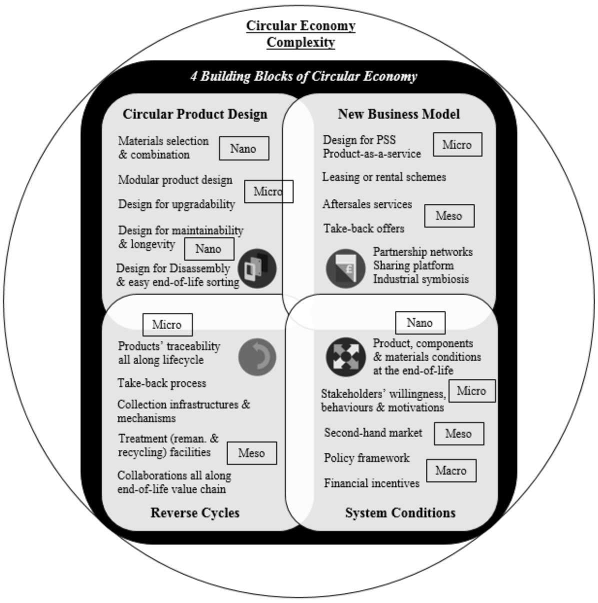

Figure 1. 4 building blocks of the circular economy (EMF, 2013), key associated attributes considered in the framework, and positioning through circular economy systemic levels

3.1.2 Insights from the bottom-up approach

Data-driven approach consists in three main steps, as detailed in Figure 2, and starts with the identification of data providers and stakeholders in order to fit with industrial practices and to be as integrated as possible. Using a lifecycle thinking approach (i.e. pre-life, life and end-of-life stages are considered), data collection and construction are performed regarding not only product features but also markets, business models, existing collaborations, or regulations related to the product. An extract of data collection methods and collectable data types is available in Figure 2. Data collected are used to efficiently evaluate each building block thought associated attributes. Consequently, the question of the transformation of qualitative information, provided by the bottom-up approach, into scores to feed the indicators, developed through the top-down approach, have to be tackled. One simple-yet-effective and intuitive solution is to create scales to translate qualitative statement into values that could be used in quantitative inputs for the indicators. Different conceptual rating scales exist such as Likert scale, Guttman scale, or Bogardus scale (Dawis, 1987). The Bogardus scale and Guttman scale are both cumulative scales, that is to say agreement with any item implies agreement with all preceding items. As such, there are therefore not suitable for our usage. Regarding our context, Likert scale seems to be an effective solution for a systematic and straightforward development of scales. Moreover, Likert scale is the most used and recognized in the design science field. In fact, a Likert item is simply a statement that the respondent is asked to evaluate by giving it a quantitative value. Here, each attribute is assessed through at least one multi-choice question. A score - from 0 to 5 - is given to each possible answer according Likert scales developed and illustrated in Table 4. When several questions are used to assess a single attribute, a non-weighted average is performed to give each attribute a score from 0 to 5. As an illustration, a practical example will be detailed in Section 4.

Table 4. Scoring system associated to Likert scales and items developed

Number of possible answers	**Assigned scores to the possible answers (the higher the contribution to circularity is, the higher the score is)**				
#2	0	5			
#3	0	2.5	5		
#4	0	1.67	3.33	5	
#5	0	1.25	2.5	3.75	5

3.2 Overview of the integrated and holistic framework

An overview of the developed framework - based on the hybrid top-down bottom-up approach - is shown in Figure 2, including different insights provided by the association of both approaches, and adapted to the context of products' performance measurement in the light of circular economy.

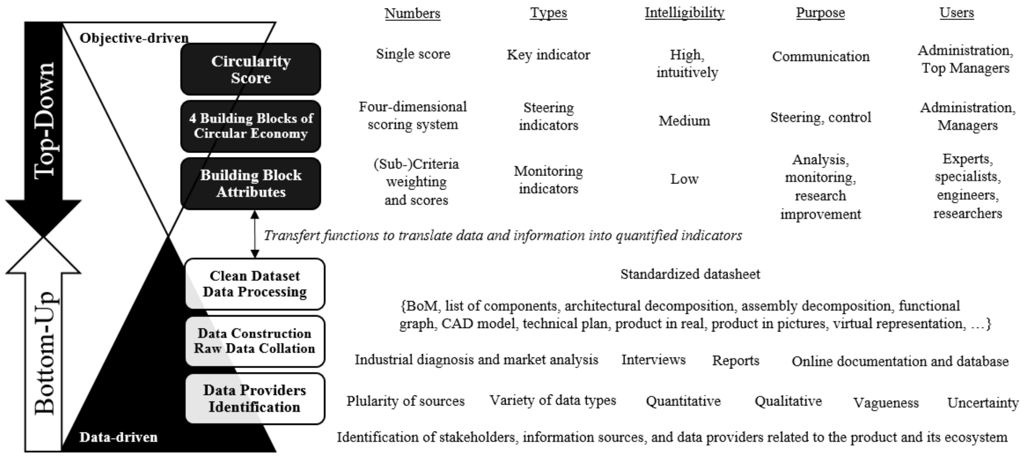

Figure 2. Overview of the framework. Insights from top-down and bottom-up approaches.

4 APPLICATION ON A REAL WORLD INDUSTRIAL PRODUCT

4.1 Case study presentation and context

The product whose circularity performance is measured through the developed framework is a catalytic converter for non-road mobile machinery. It is designed and developed by a large European construction equipments manufacturer. A catalytic converter is a key and mandatory component in motorized vehicles (e.g. cars, heavy-duty vehicles and non-road mobile machinery) which converts toxic pollutants (exhaust gases produced from motor combustion) into less or non-toxic gases. There are mainly composed by three components: the canning in stainless steel, the substrate in cordierite, and the coating containing precious metals groups such as platinum, essential element to realize the catalytic conversion and reduction. As emissions regulations are becoming increasingly strict not only in Europe and North America, but even in emerging countries, the quantity of precious metals in catalytic converters will rise to meet future standards. On this basis, a project manager, who has recently heard about the circular economy concept, wants to know how the catalytic converters they design and develop could be more circular to retain the value of precious metals in their business and thus benefit from both economic and environmental spinoffs related to platinum exploitation.

4.2 Operating principle and first practical use of the framework

The first experienced version of the framework is composed of 20 attributes (5 for each building blocks) - as shown in Figures 1 and 3 - that are acknowledged, through literature, to foster products' circularity performance. In inputs, each of the 20 attributes is assessed through one or several multi-choice questions and the rating is made according to Likert scales detailed in Section 3. For example, one of the questions assessing the attribute "take-back process" of the product, included in the building block "reverse cycle", is related to the organisation and maturity of the current tack-back process and proposes four possible answers, scored according to Table 4: (i) "non-existant", scored with a "0"; (ii) "marginal", scored with a "1.67"; (iii) "in development", scored with a "3.33"; (iv) "well-established", scored with a "5". For the first operational version of this framework, assumption is made that each building block and associated attributes have the same importance regarding product circularity performance. In fact, to make calculations as easy as possible, if the overall circularity indicator is scored out of 100, each building block is scored out of 25 and attributes out of 5. In outputs, the overall circularity score, representing the product performance potential in a context of circular economy, is not only available but scores for each of the four building blocks (BB#) and associated attributes (ATT#) are also provided, as shown in Figure 3.

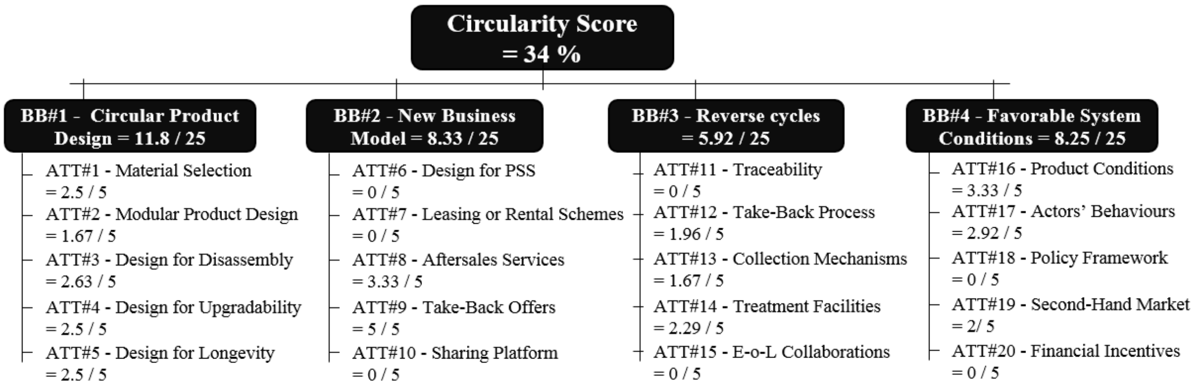

Figure 3. Application of the framework on the case study. Overview of the results.

4.3 Insights from the case study: findings and discussion

Contrary to existing tools reviewed in Section 2 and experienced in Saidani et al. (2017), such as the MCI or the CEIP, which provide a single score, the developed framework has the advantage to deliver a multi-dimensional and transparent scoring system. Indeed, results reducing the overall product circularity performance into one single indicator should be interpreted with caution. Additionally, it could be considered as counterintuitive to use a single indicator for a concept like circularity which is clearly multi-faceted (Griffiths and Cayzer, 2016). That is the reason why we provide not only a single and overall circularity score but also complementary scores associated to the four building blocks of the circular economy. Thus, it has the advantage to confront the user to the circular economy complexity gradually: a non-specialist in circular economy may have first a simple overview and trend of product's circularity, then one can look more precisely at the details, that is to say, at the four building blocks (BB) and their associated attributes (ATT). For instance, through this case study, some attributes that directly depend of company's and suppliers' responsibilities are rapidly identified (e.g. ATT#2 or ATT#6) as relevant actions levers for enhancing circularity performance. The results also show the importance of systemic considerations to reach a high and effective circularity. Here, even if take-back offers for catalytic converts are appealing (ATT#9 has a score of 5 out 5) due to the high value of platinum, reverse cycles are for the moment poorly developed (BB#3 has a score of 5.92 out of 25) regarding the catalytic converters installed in non-road mobile machinery.

5 CONCLUSION & WAY FORWARD

Measuring products and materials effective circularity could be performed by counting the proportions of products and materials that enter, or not, in a loop of the circular economy model (Graedel et al., 2011). However, at this stage - during product usage - it is often too late and difficult for designers to improve circularity, since the product is already on the market or at the end-of-life. This is the reason why it becomes helpful for industrial practitioners to have the means to estimate potential circularity performance during early phases of new or re-design product development. Even if existing tools provide a first and a rapid overview of products' circularity performance, they neither consider the whole complexity of circular economy paradigm, nor provide operational guidance for engineers, designers or managers willing to improve their products in the light of circular economy. The proposed framework experienced in this paper addresses this need by contributing to fill some of these gaps. The first version developed is promising since it has the advantages to be more holistic and more integrated. Indeed, thanks to the hybridization of a top-down - objective-driven - approach and a bottom-up - data-driven - approach, it simultaneously covers a wider spectrum of the circular economy than existing tools, and considers industrial practices and available data. Nevertheless, this research project is still at an embryonic stage and, as the framework has the convenience to be modular, flexible and therefore easily extendable, several worthwhile areas are left for future improvement:

- Refine the overall circularity score: as there are different ways to close the loop in a circular economy, the overall circularity score should go further than a single and overall score that considers all different possible closed-loops at the same level with no differentiation any;

- Improve and validate the scoring system: further investigations and tests with industrial practitioners should be performed in order to enhance scoring system, define appropriate aggregation method (e.g weighting or fuzzy logic) and therefore ensure more robustness;
- Consider uncertainties in the circularity score and assessment methodology due to the time scale issue of long life products (e.g. available technologies and actors involved might change between product development phases and actual end-of-life);
- Provide explicit design guidelines: based on building blocks and attributes scores, outputs should orientate industrial practitioners towards best available methods and tools to enhance product circularity performance, such as a state-of-the-art eco-innovation manual (O'Hare et al., 2014);
- Highlight involved stakeholders for each attribute, and beneficiaries of the product circularity, including manufacturers, politics, users, recyclers, retailers, society, environment;
- Ensure not only the completeness of indicators but also the consistency between an improvement in circularity score and benefits from sustainable development viewpoint.

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