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Towards an integration of environmental criteria in the OEM/subcontractors relationship

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Abstract— Faced with the rise of the sustainable development challenge, industry has integrated this dimension in the product design through the concept of eco-design. Many eco-design tools and methods have been developed during the last decade, leading to a fragmentation of eco-design approaches in the industry. One of the main identified weaknesses is the methodological discontinuity between different members of industrial value chain. OEMs (Original Equipment Manufacturers), which externalized a non-negligible part of their production, settle mainly quantitative and costly approaches. Because of a lack of expertise and financial resources, subcontractors focus on qualitative and simplified approaches. This research work aims at the development of a method to foster interaction between the eco-design approaches of the different levels of the industrial value chain.

Index Term— OEM, subcontractor, Eco-design, LCA, value chain, SME.

I. ECO-DESIGN, A CURRENT ISSUE

A. Needs for integrating environment in product design

From the mid 80's, the awareness concerning the impact of human activity on environment has particularly grown. The Millennium Ecosystem Assessment notes that “*Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history [...]*”[1].

In 1986, the Brundtland commission defines the concept of sustainable development which tries to conciliate economic development with social and environmental issues [2]. One of the main identified issues is the anthropic consequence of greenhouse gas emissions on global warming [3], the Kyoto protocol signed by 191 countries in 1997 provides a fall of 5,2% of collective GHG emission for the period 2008-2012 compared to 1990 level. France is committed to reduce by four its GHG emissions between 1990 and 2050 [4]. This involves a huge reduce of fossil energy consumption.

In parallel, the world raw materials and fossil energy demand rises and leads to increase cost. Economic consequences are important, e.g. in France energy bills expanded of 14,4 billion euros compared to 2011 while volumes imported have slightly increased [5]. The International Energy Agency explains thereby for the case of conventional oil that the maximum of production (peak oil) has been reached in 2006 and will never grow more [6].

The former issues have progressively been integrated in the French law and then in the EU community law.

Until 2000's, regulations concerned two main aspects:

- Limitation of pollutant emissions on manufacturing plant. Such regulations grew in parallel with the environmental awareness. From exclusive curative approach (end of pipe) until 60's, environmental law evolves to become more and more preventive and proactive since the 80's. It could be mention thereby the French law governing industrial risky activities in 1976 (ICPE) [7].
- Limitation of fossil energy consumption since oil shocks in 70's. We can mention thermal regulation on building since 1974 [8] or settlement of strong tax on fuel in order to decrease the fossil energy dependence.

Environmental regulations have evolved: while it was mainly focused on impacts limitation during the production phase (with regulations concerning manufacturing plants), the regulation enlarges the scope and focuses on many aspects of the product (end of life, energy consumption) and by extension on its entire life cycle. The manufacturing plant approach is now completed by a global product/process approach [9]. It can be mention for example directives concerning:

- the amount of recycling material in a vehicle (ELV) [10],
- the end of life of electronic and electric components (WEEE) [11],
- the restriction of hazardous substances (ROHS) [12],

- the registration/evaluation/authorization of chemical products used (REACH) [13].

Many strategies were developed to minimize the impact of human activity on environment. Industrial ecology for instance focuses on reduction of industrial impacts and functional economy focuses on the service given by a product instead of the product itself.

However, in France 52% of Greenhouse gas emissions are due to products life cycle (especially transport and manufacturing phases) [14]. A design method has been developed in order to decrease product impacts on environment: eco-design.

Eco-design could be viewed as the materialization of these new issues in the industry. It could thus allow:

- integrating sustainable development principles in the product development process,
- limiting energy and raw materials uses,
- dealing with the regulation progress which may include at the same time many aspects of the product life cycle (materials uses, energy consumption during the use phase, end of life management).

B. *Fragmented eco-design approaches*

1) *Definition*

According to the international standard XP ISO TR 14062, eco-design is defined as the integration of environment constraints during the product development [15].

As a global approach, it means that the entire life cycle of the product is considered, from the extraction of raw materials to the end of life of the product through manufacturing, transport and use phases. It is also a multicriteria approach, the product influence on environment is measured throughout many impacts categories in order to avoid eventual impact transfers during the eco-design process. Le Pochat underlines the complexity of environmental impact categories. But he remarks that usually are considered together categories linked with energy consumption, raw materials consumption, pollutants emissions and also waste production [9].

Beyond these two aspects, eco-design could be also viewed as the implementation of the sustainable development concept for the product development. It allows reaching both ecological and economical requirements in this context [16]. In this way, a company which implements this kind of strategy will design a more environmental friendly product while maintaining competitiveness objectives, quality, respect of regulations and time-to-market [17].

2) *Many methods and tools*

One of the main issues concerning the integration of eco-design in industry is the numerous methods and tools. Baumann et al. have counted more than 150 eco-design tools in

2002 [18]; from a study based on literature, Reyes counted in 2007 124 tools or methods [17].

Some categorizations have been made, according to the eco-design level integration [19] or the product innovation degree [16]. Bellini & Janin categorize eco-design approaches according to two main tools categories [20]:

- Tools used to build the product environmental profile in order to increase its performance: the assessment tools.
- Tools used to help the designer to find environmental improvement axis: the recommendation tools.

Another type of distinction is also the number of life cycle phases taken into account, the number of environmental criteria or also the type of data collected to make the evaluation part.

An analysis is done of this last categorization where the nature of data is discriminant: quantitative and qualitative approaches.

3) *Quantitative approaches*

This kind of approach is based on the quantitative assessment of input and output on system borders. There is an important need of accurate and metric data, e.g. the amount of energy consumption, of pollutants emissions during the life cycle.

The most well-known quantitative approach is the Life Cycle Assessment (LCA) which is a complete (on the whole product life cycle) and multicriteria method [21]. There are also simplified LCA where some aspects are simplified (e.g. the French Bilan Produit tool) or focused on one environmental aspect (e.g. Carbon Footprint) [20].

4) *Qualitative approaches*

The environmental product profile is determined usually with a questionnaire fulfilled by the manufacturer. Questions are often closed, orders of magnitude could be used, and this approach focuses more on nature of input and output on system borders than quantities (metrics).

We can mention among others:

- Matrix approach which consists on completing pre-established tables as MET matrix [22]. ESQCV (Simplify and qualitative life cycle evaluation) is also close to this kind of tool.
- Check-list: the product is assessed by questions on each life cycle step and these ones will then guide the designer (e.g. : Eco-design Strategy Wheel) [23].
- Standards and guidelines which can help designer in specific sectors (e.g. NF EN 62430 for electronic-electric sector) [24] or for specific environmental issue (e.g. NF ISO 22628 to improve de recyclability of vehicles) [25].

5) Eco-design and extended enterprise

Regarding the different eco-design approaches mentioned above, it could be noticed that they are large and fragmented. The settlement of these different approaches will depend on the maturity of the company concerning environmental issues, objectives targeted, step where environment is taking in account during the design process, product complexity or also financial and human resources mobilized [26]. This variability can be an obstacle for eco-design dissemination along the value chain, where the different actors use independently and without consultation their own tools.

However a significant part of the industrial production is externalized. It is no more possible to take into account eco-design as a single action established on a unique company, the issue is now to integrate eco-design in a context where companies acting in the product life cycle interact with each other.

In 2007, subcontracting gathered 4000 companies of twenty employees or more and employed for a turnover of 49 billion euros [27]. This study mentions that aeronautic and automotive sectors usually practice subcontracting. Contractors of these sectors have made a pyramidal organization with different level of subcontracting: from a first level with direct suppliers with which they share the product design to a third level with subcontractors which respond to the request of a higher level supplier.

According to AFNOR, industrial subcontracting consists for an OEM to delegate to a subcontractor one or more process of design, development, manufacturing, implementation and maintenance of the product. The subcontractor is expected to exactly comply with the guidelines or specifications adopted by the contractor. The latter often exerts strong pressure on prices while expecting a quality steadily increasing. Subcontractors have to invest massively without benefit of a long-term visibility on their order book [28]. In this way, the French SME's association (CGPME) identifies imbalance concerning the relations between contractors and subcontractors.

Regarding this issues, the second part of the paper focuses on how OEM and subcontractor collaborate to integrate the environmental dimension in the product design. Based on this work, global issues will be highlight and some solutions will be proposed in the third part.

II. ECO-DESIGN APPROACHES IN A CONTRACTORS/SUBCONTRACTOR CONTEXT

A. Eco-design, a matter of resources and expertise

1) OEM and eco-design practice

OEM generally have a higher maturity concerning environmental issues (compared with the rest of the industry), they mainly use quantitative methods based on life cycle approach as simplified or complete LCA (Life Cycle Assessment). Millet & al argue "Life Cycle Assessment (LCA) is the most successful tool to assess environmental considerations in the product design process" [29]. Bellini & Janin [20] explain in France this interest partly because of the environmental information obligation forecasted by the "loi de Grenelle II" and based on ISO 14040/ISO 14044 methodology: the BP X30-323-0 [30].

LCA is particularly adapted for the assessment of the environmental performance of a product on its entire life cycle. Following this assessment, a comparison between two products or technologies can be made, communication or building of an eco-design approach can also be considered; LCA is also used to inform consumers and to guide policy decisions on environmental dimensions [31].

Regarding the ISO 14040, an LCA study is applied in four steps (figure 1).

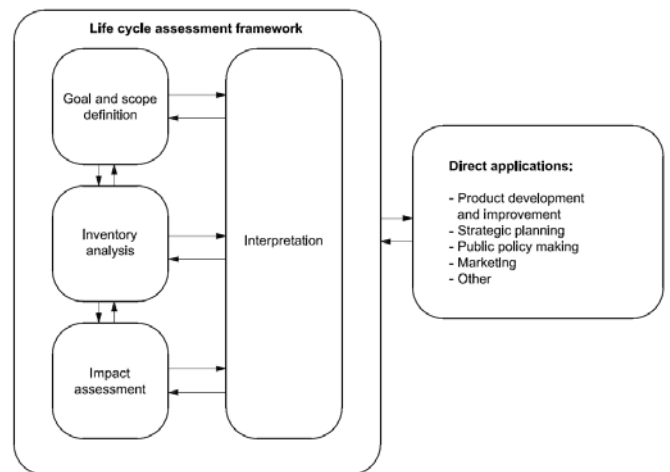


Figure 1: Stages of an LCA as defined by ISO 14040 [21]

This methodology is complex and conducted by environmental experts. An LCA study requires a large amount of design data, therefore its complete implementation cannot be achieved until last phase of the product development process [32]. An LCA study requires a detailed Bill Of Materials (BOM) and also the knowledge of the manufacturing process, data from suppliers and more generally data from the entire life cycle product (resources extraction, transportation, use, end of life) from internal and external sources.

Beyond the complexity of the data collection, an LCA method often requires the use of by default generic environmental data, specific calculation methods and a dedicated software that allow translating collected data into potential impacts on environment.

An LCA study is long (from many weeks to many months, depending on case of study), heavy, and results have to be post-processed to be understandable for non-experts (TABLE I).

TABLE I. MAIN ADVANTAGES AND DISADVANTAGES OF LCA PARTLY BASED ON TINGSTRÖM & KARLSSON SUMMARY [33] (ELEMENTS IN QUOTES)

<i>Advantages</i>	<i>Disadvantages</i>
Data exhaustiveness : “Reveals materials- and energy-flows upstream and downstream that could have been unseen by other methods”	An LCA on a new product/process is costly, difficult and time-consuming
“The result is based on a transparent system analysis and objective measures” : detection of impact transfers, quantified and multicriteria results	Data quality is variable : “data are often missing or have low quality and therefore much of LCA activities must be based on short series of measures, theoretical calculations and estimations”
LCA can be used as a basis to determine different environmental aspects	Expert method, difficult to handle : “To make a complete LCA, there is a large need for data and specialist knowledge”, difficulties to define the product system boundaries
Well adapted for communication outside the company	No impact assessment weighting method is generally accepted
“Possibility to compare the environmental performance for different forms of solutions”, to evaluate the product before and after design	Low integration in the design process : “The time aspect makes it difficult to use LCA in a product development process”

2) Subcontractor and eco-design

Subcontractors are mainly SMEs for which subcontracting represents two-third of total sales [34].

a) SME specificities

Because of the heterogeneity of SMEs due to the variability of companies and industrial sectors, it is usually hard to set a complete and exhaustive definition of the concept of SME [35].

Decree n° 2008-1354 defines a SME on a quantitative way. A SME is a company which has less than 250 employees and a maximal turnover of 50 million euros or a total asset less than 43 million euros [36].

On a more operational point of view, a SME is generally defined by its limited resources (financial and human), a lack of technical expertise, or also strong time constraints [37]. On an organizational point of view, the role of the management board is fundamental; interpersonal relations are favored by the small number of employees but the company strategy often focus on short term vision [38].

b) SMEs and eco-design

A French study shows that companies which have adopted a systematic eco-design approach are mainly big companies (more than 250 employees) whereas a large amount of PME are just aware of this kind of approach [39]. Moreover, this study pinpoints a strong heterogeneity of eco-design within SMEs depending on the sectors. The difficulties encountered are the complexity of tools or methods, the lack

of experience, references, practice and technical help, the high cost of investment.

Eco-design methodologies have been developed in the last decade to implement environmental criteria toward SME by taking into account their specificities. The Eco-design Integration Method for SMEs (EDIMS) [40], ECOFAIRE developed by EVEA or also Eco-design Pilot developed by TU Wien [41] can be mentioned.

All these methods or tools have the same goal: to improve the integration of environmental criteria in the product development process for companies which do not have any competences and experiences on that domain; do not have the financial capacity to implement LCA studies [17] or use expert tools [42].

c) An eco-design method for SMEs

In 2010, the NF E 01-005 based on the MAEICO methodology was released. This standard has the features of an eco-design guide “*particularly adapted for SME*”, especially in the mechanical industrial sector [43].

This standard seems to be well-adapted to redesign existing products by taking into account environmental aspects. It also considers the entire life cycle of the product through a questionnaire fulfilled by a multidisciplinary team. The goal is to sensitize and involve a maximum of actors within the SME, from the designers to the marketing or the purchase department. One of the positive aspects of this qualitative approach is the good integration within the conception process from the conceptual and detail design, the prototyping and testing to the production engineering and planning.

The NF E 01-005 tries to simplify one of the major steps of an environmental study: the data collection. This phase is usually time-consuming and tedious: mainly quantitative data may be collected from internal and also external sources. To bypass this difficulty, the standard proposes a questionnaire on the main environmental aspects of the product to redesign. The data collected are thereby qualitative or semi-quantitative and come from internal sources. Both quality and the exhaustiveness of the collected data are limited, but this methodology provides trends concerning the environmental profile of the product studied.

Thanks to this questionnaire, the standard provides a simplified environmental profile which shows the impact of each environmental aspect.

Depending on the nature of the profile, the standard guides the multidisciplinary team to guidelines of improvement. Indicators are set up to follow the evolution of these ways in time. Furthermore, the environmental aspect is not the only criterion taken in account, each way of improving is balanced by techno-economical and strategic criteria. This phase is suitable for debates and information exchanges between the various actors of the company. The solutions identified and selected are thereby much more industrially acceptable.

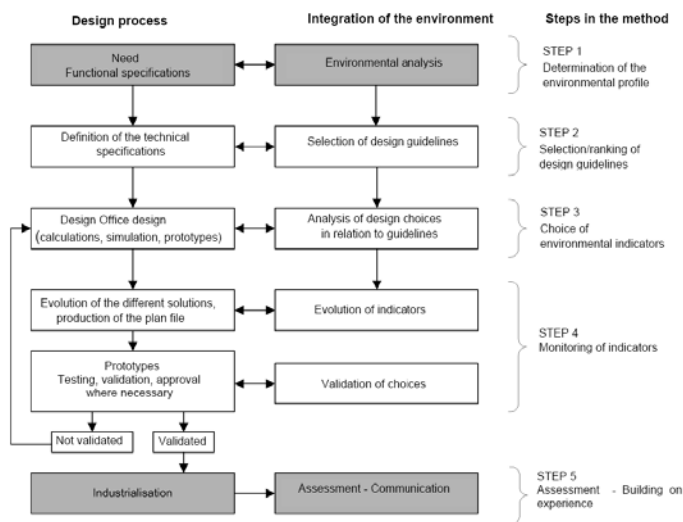


Figure 2: Stages of the standard NF E 01-005 and integration in the product design development [43].

The easiness of understanding is a positive point, but results are represented in a relative manner. It may be difficult to observe eventual transfers of impacts once improvement ways are set up.

The table II summarizes the advantages and the disadvantages of two neighbor qualitative methods: the standard NF E 01-005 we previously described and the Environmental Effect Analysis (EEA). The latter was used by Volvo since 1997 and shares the same architecture as the French standard: the study is led by a multidisciplinary team which decides, from a previous qualitative impact analysis, which ways of improvement will be conducted. Tingström & Karlsson have also made a critical analysis of this method in 2006 [33].

TABLE II. MAIN ADVANTAGES AND DISADVANTAGES OF NF E 01-005/EEA PARTLY BASED ON TINGSTRÖM AND KARLSSON SUMMARY [33] (ELEMENTS IN QUOTES)

Advantages	Disadvantages
Help to set up directly improvement strategies	Not recognized as an environmental assessment method
Easy to understand for an “interdepartmental team building”	Basic improvement ways, “the ambition tends to be limited to the data that are available”
Well integrated in the design process : “It is a qualitative method that can be used in early phases of the product development process”	“The results are not suitable for communication outside the company”
Easy data collection : “Based on environmental requirements which makes it relatively easy to find data”	“Does not give quantitative answers”
“Less time consuming” and less expensive than complete LCAs	Difficulty to compare systems

B. Comparison of an approach along the value chain

The study of the two methods brings up some differences but also some common ones.

First the objectives and context are not the same: the NF E 01-005 allows integrating environmental criteria from the preliminary design phase whereas the LCA approach is implemented later in the design phase because of the information needed for its carrying out. LCA is rather an environmental assessment method from which improving axes derive, or used for communication or also to compare environmental performance of two products.

The targeted audience is different: the NF E 01-005 is clearly defined for SMEs which do not have any financial resources to set up costly studies. The standard is bound to be set up by a multidisciplinary team that has only a slight environmental culture. The LCA is an expert methodology; its realization is long, costly and complex.

The data collection is usually the phase which limits the carrying out of an environmental impact evaluation [9]. As far as LCA is concerned, lots of quantitative information is needed, numerous internal and external agents are approached, data bases are often used... Regarding the audience, the NF E 01-005 simplifies this step. Collected data are mainly qualitative, less exhaustive and clear but also faster to collect. Interestingly the standard also integrates the compliance with environmental regulations.

Concerning the assessment phase, the LCA is a multicriteria method which calculates potential impact on environment whereas the standard is qualitative and describes the environmental weight of each product component.

Furthermore, the main difference between the two concepts is the treatment of the improvement phase: the NF E 01-005 is a guide which balances technical, economical, strategic and environmental requirements. The LCA method is only focused on the environmental aspects. The extraction of improvement ways from the results obtained should be specified by an expert. But in many cases, results are directly used to elaborate an eco-profile based on the standard ISO 14025.

TABLE III. COMPARISON BETWEEN NF E 01-005/EEA QUALITATIVE METHODS AND LCA QUANTITATIVE METHOD

Criteria	LCA	NF E 01-005/EEA
Integration in the design process	Low integration in the design process	Well integrated in the design process
Targeted Users	“Specialist knowledge”	“Interdepartmental team”
Data collection	Long, “materials- and energy-flows upstream and downstream” collection, data quality variable	Quick qualitative questionnaire, “limited data”
Results	Quantified, “transparent” and multicriteria results	Qualitative
Communication outside the company	“Suitable”	“Not Suitable”
Link with the improvement step	“A basis to determine different environmental aspects”, necessity to translate the results by an expert	Improvement ways are proposed directly from the obtained profile
Resources mobilized	“Costly”, time-consumed, expert competence	Not expensive, “less time consuming”, minimum of maturity

Finally beyond differences, a complementarity of these two approaches could be observed: LCA method is the most relevant for the assessment and communication phases while the standard is the most relevant for the way of improvement choice and its well integration in the product development.

C. *A gap to fulfill*

This eco-design approach comparison brought out a methodological gap between the different members of the value chain: OEMs use mainly quantitative approaches like LCA methodology while subcontractor as SMEs use qualitative and simplified approach which is still based on the life cycle thinking.

In the same time, LCA method becomes more and more essential as evidenced by the multiplication of good practices guide based on ISO 14040-14044 as BP X30-323 in France or the recent development of the European referential: the Product Environmental Footprint (PEF) [44]. These guides provide rules to harmonize practices and to facilitate environmental results diffusion.

This highlights major consequences:

- The trend for the future is the globalization of quantitative and costly approaches as LCA, and the risk subtended is that SMEs might be left to the margin.
- Eco-design is a systemic approach so its effectiveness depends on its implementation through the different entities which are involved along the life cycle. The fragmentation and multiplication of approaches and tools could lead to the decrease of eco-design effectiveness.
- Alone, LCA method is not a complete eco-design method and is not an adequate tool for the designer [29]. Its generalization must go with a progress of linked environmental improvement strategies.
- SMEs have to cope with quality, time and cost requests from contractors. Generalization of LCA could also lead to an additional pressure (and cost) for SMEs which already suffer of an imbalanced relationship with their contractors.

III. FROM FRAGMENTED ECO-DESIGN TO UNIFIED ECO-DESIGN

To fulfill this gap, it is proposed two main targets for the future work:

- Increase interoperability between qualitative and quantitative approaches,
- Balance relations between OEMs and subcontractors.

A. *Interoperability between eco-design tools in the value chain*

The multiplication of eco-design tools and methods is no more possible in an extended enterprise context where companies are interdependent with each other. These approaches have been developed to adapt environmental criteria to companies, sectors or countries specificities.

The idea is to increase the dialogue between the different approaches and especially to fill the gap identified between SME's and large companies. As previously seen these two approaches are also complementary. Their combination could increase the eco-design efficiency along the value chain in a collaborative product development.

The current trend is to develop simplified LCA approaches to make the method operational for a certain kind of companies, products complexity or specified sectors. If this simplification allows bypassing technical difficulties, it does not allow increasing the integration of the LCA in the product development and in the value chain.

Instead of adapting OEM's quantitative methodology, it is proposed to specify a bottom up methodology. In a first stage, it will be studied how an existing qualitative tool could be adapted to allow dialogue with LCA tools. On a second stage, it is suggested a global method to implement this kind of tool in the product development and the value chain.

It is suggested to take a tool that has proven itself on the operational plan : ATEP (Typological Environmental Product Analysis) which was developed by the French Technical Center for Mechanical Industry (CETIM) in 2005 [40]. ATEP is an operational tool to implement the standard NF E 01-005, especially for mechanical SMEs which want to conduct an eco-design action. The third version is available in free access via a web portal. The ATEP tool keeps the basic elements of the standard in an ergonomic interface, introduces some LCA's concept and also corrects some standard's weaknesses as:

- The introduction of the notion of the Functional Unit and a visual representation of the product life cycle.
- The highlight of the product context relative to regulations and sector specificities,
- The implementation of a strategic analysis to balance environmental choices with strategic, economical and technical constraints,
- The taking into account of impact transfers,
- Providing a graphical visualization of product environmental improvement.

Regarding the issues, a future development of ATEP would have to:

- Dialogue with the other tools in the supply chain to improve the eco-design efficiency in a subcontracting context,
- Keep the simplicity of use for SMEs
- Allow the implementation of ATEP results into OEM's LCA tool.

B. Balance relationship between contractors and subcontractors

The integration of environmental criteria is for SMEs a new constraint added to the previous ones. OEMs have thus more and more environmental requests and need data from subcontractors to feed quantitative method for the activities they externalize. How to increase the environmental integration on the value chain without adding a new pressure for SMEs?

Furthermore, OEMs and subcontractors are not equally concerned by the benefits from environmental actions. Contractors will easily communicate on their actions because they take place in a business to consumers (B to C) context and their visibility is higher. For SME, as a subcontractor, the potential benefits of its environmental action are low comparatively to the resources mobilized. There is also an imbalance concerning the economic benefits. So how to balance benefits of environmental actions on the entire value chain and not only for a limited number of actors?

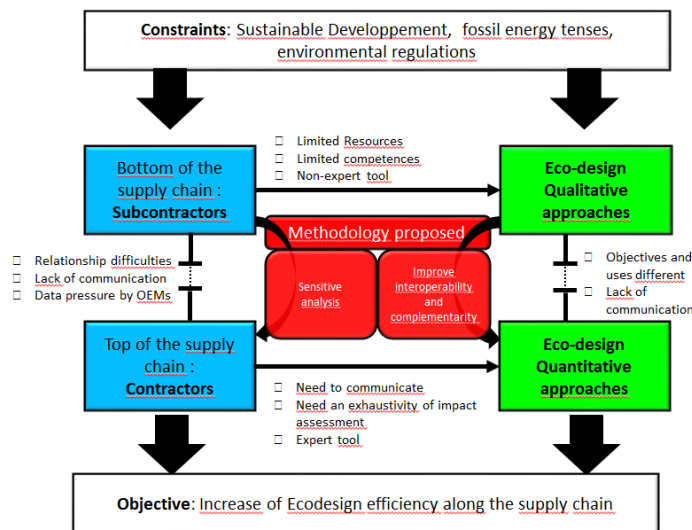


Figure 3: A proposition to increase the eco-design efficiency along the value chain.

It will be proposed a methodology for modeling the requirement level for certain types of target products to define. This assumption is that it is not necessary to collect all data to get a sufficiently accurate environmental profile. A sensibility analysis by type of product can determine which requirement level is sufficient to have a fairly image of the environmental impact of the product life cycle. The goal is to identify for each type of product which kind of data is required and also relieve data collection for SMEs. The objective is also to implement these results to feed the ATEP tool.

IV. CONCLUSION

By a context analysis of eco-design practices in the industry, we have highlighted an eco-design methodology gap between the different levels of the supply chain. Regarding the necessary development of collaborative design and the rise of

environmental issues, this gap is clearly a weakness for the integration of environmental criteria in the product development.

To respond to this problematic, we orientate our research to a methodology which could be able to increase interoperability between qualitative and quantitative approaches through the development of the ATEP tool. Additionally, we will also focus our research to balance relationship between OEMs and subcontractors. In this way, we will study potential contributions of Ecosocial design and also of Life Cycle Costing.

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