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# Proposal of a new based feature-interaction eco-manufacturing methodology on CAD phase

Hadhami BEN SLAMA, Raoudha GAHA, and Abdelmajid BENAMARA

**Abstract** – Following the many environmental crises of recent decades, a turning point in the awareness of the fragility of ecosystems has been marked, that is to say an environmental awareness. This has contributed to the development of various environmental laws and regulations such as the «Waste Electrical and Electronic Equipment» (WEEE), “Restriction of Hazardous Substances” (RoHS) and «Energy Using Products” (EuP) Directives or the “Registration, Evaluation, Authorization and Restriction of Chemicals” (REACH) Regulation. Then, the productive model of industrial societies is questioned. A greater awareness of environmental issues is emerging. At the beginning and with the aim of minimizing the environmental impacts (EIs), the research work focused essentially on two axes: recycling and chemical substances. The process plan operations order has also an influence on the EIs of a product. In this paper, we propose a new based scenarios methodology by using the feature interactions technology (FIT) and a multi-criteria decision support method (MCDSM) that allows the non-environmental expert designer to have the optimal manufacturing process plan on CAD phase. First, we present our state of art. Then, we introduce our new methodology based on both FIT and MCDSM in order to choose the greenest manufacturing scenario. Finally, a case study of feature interaction will be presented for demonstration purposes.

**Keywords:** CAD/ Eco-design/ Eco-manufacturing/ Environmental Impact/multi-criteria decision support / Scenarios/ Feature interaction.

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Hadhami BEN SLAMA<sup>a</sup>, Raoudha GAHA (✉)<sup>b</sup>, Abdelmajid BENAMARA<sup>a</sup>.

a.Laboratoire Génie Mécanique, Ecole Nationale d'Ingénieurs de Monastir, Université de Monastir, Rue Ibn Aljazzar 5019 Monastir, Tunisie.

b. Laboratoire de Mécanique de Sousse, Ecole Nationale d'Ingénieurs de Sousse, Université de Sousse, BP 264 Sousse Erriadh, Tunisie.

[raoudha.gaha@gmail.com](mailto:raoudha.gaha@gmail.com)

raoudha.gaha@gmail.com.

## 1. Introduction

Following the many environmental crises of recent decades, a turning point in the awareness of the fragility of ecosystems has been marked, that is to say an environmental awareness. A wide range of environmental problems has emerged. Those problems include anthropogenic climate change (global warming), the acidification of surface water (acid rain), depletion of stratospheric ozone (ozone hole), etc. This has contributed to the development of various environmental laws and regulations such as the «Waste Electrical and Electronic Equipment» (WEEE) [1], “Restriction of Hazardous Substances” (RoHS) [2] and «Energy Using Products” (EuP) [3] Directives or the “Registration, Evaluation, Authorization and Restriction of Chemicals” (REACH) [4] Regulation. Thus, the productive model of industrial societies is questioned hence the birth of the concept of eco-design. Eco-design approaches, aimed at reducing the environmental impacts of products over their entire life cycle, neglect the manufacturing phase. Manufacturing is the transformation of a raw material into a finished product by a process that causes a waste and environmental emissions. Therefore, researchers in this field tend to reduce environmental impacts from the manufacturing phase, where the notion of eco-manufacturing comes from. In this paper, first we present a literature review of works treating the optimization of the manufacturing phase from an environmental point of view. Second, we present a state of the art presenting eco-manufacturing integrating Computer Aided Design (CAD) systems; also, we underline the role of multicriteria decision support methods and the micro/macro-planning in the designer's decision-making regarding the greenest manufacturing scenario. Third, we describe our approach in order to eco-assist designers early in the design process and we validate it on a case study. Finally, we conclude our points and we propose perspectives for this work.

## 2. Eco-manufacturing: Overview

## 2.1. Manufacturing Optimization from an environmental point of view

Manufacturing operations consume energy. Overall, they account for 19% of greenhouse gas emissions [5] and 37% of energy consumption [6]. With regard to energy consumption, a lot of methods for energy measurement; monitoring, modeling and optimization are applied to machining systems in order to improve their energy performance. For machining, the improvement of processes that surpass efficiency measures requires the measurement of the energy consumption of machining processes or systems [7], [8].

Energy modeling and optimization are considered as basic measures for energy efficient machining. Energy models can be divided into three categories:

- Linear type cutting energy consumption models which are based on material removal rate (MRR),
- Detailed parameter type cutting energy consumption correlation models
- The process-oriented machining energy consumption model.

In 2016, Feng et al formulated multicriteria optimization approaches for making the best use of energy delivered to the production processes [9]. In 2017, Hu et al introduced a single objective optimization problem minimizing the machine tools energy consumption (MTE) while machining a part [10]. In 2017, He et al represented a method to optimize machining parameters with respect to the both environmental and economic objectives [11]. In 2018, another study is represented by Hu et al [12] to clarify the relationship between the processing sequence of a part features (PSFP) and the energy consumption of tool change and tool path during the feature transitions. They introduce a model that minimizes the energy consumption of machine tools during the feature transitions which include all the tool path and tool change operations.

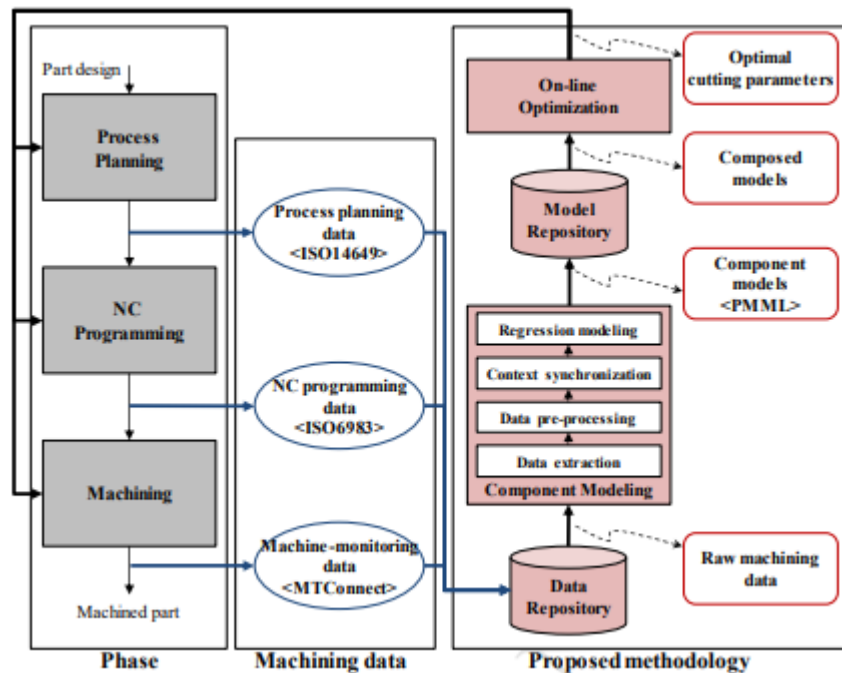
Carbon Dioxide CO<sub>2</sub> is the most dangerous greenhouse gas in the atmosphere. Since the industrial revolution, the concentration of CO<sub>2</sub> rises and reaches 410 ppm (parts per million, i.e.; number of moles CO<sub>2</sub> per million moles of air) in June 2018 [13]. The CO<sub>2</sub> emissions contribute to global warming caused by the rise in temperatures and climate change [14-15]. Then, with the growing concerns on ecosystems, several intergovernmental and binding agreements are introduced to reduce the impacts of global warming. For instance,

countries adopted the Paris Agreement at the COP21 in Paris, which went into force in November of 2016 [16]. Manufacturing has an essential role that radically influences our ecosystems; thus, many researches are focused on industrial activities aiming to reduce the carbon intensity. In 2016, Liu et al also presented a numerical approach to calculate optimal cutting parameters in the aim to reduce carbon emissions and machining costs [17]. Zhang et al in 2017 proposed an optimization model for the process parameters of multi-pass dry machining to trade off process time, energy consumption and carbon emissions and then relieve the impact the environment [18]. Liu et al propose an integrated optimization model based on cutting parameters and it affect scheduling in order to reduce the completion time and the carbon emissions in machining processes [19]. In 2018, Sihag and Sangwan presented a systematic methodology to calculate the carbon emissions of CNC machine tool [20].

The optimization of the manufacturing phase can be also seen in the minimization of cutting parameters regarding different environmental impacts. In 2017, Li et al presented an integrated approach of process planning and cutting parameter optimization to minimize the total energy consumption of CNC machining based on a multi-objective simulated annealing algorithm [21]. Rajesh et al also, study cutting parameters optimization in order to reduce cutting temperature in turning based on a Genetic Algorithm at dry and MQL condition [22]. Shin et al present a new methodology in order to implement an online energy optimization environment. This methodology is used to select optimal cutting parameters [23]. Figure 1 illustrates an overall flow of the proposed methodology. In 2018, Zhou et al presented a cutting parameter optimization method for machining operations to balance carbon emissions, cutting time and cutting cost, in the part machining process [24]. One the unsustainable process is lubrication-based machining process due to the bad impact of cutting fluid on the environment. Hence, Alok and Das in 2019 present a multi-objective optimization of cutting parameters during sustainable dry hard turning [25]. Chen et al. also proposes an integrated approach of cutting tool and cutting parameter optimization to minimize the energy footprint and production time of the face milling process using a multi-objective Cuckoo Search algorithm [26].

The use of cutting fluids in machining has a very hazardous effect. It leads to health and environmental problems. Therefore, the disposal of cutting fluids must be optimized in order to respect the environment protection laws. Vegetable-based ecofriendly cutting fluids are in demand. Several researches considered vegetable-based cutting fluids as an environmentally friendly fluids and it has a better lubricating ability comparing to other fluids [27-28]. Moreover, alternative ecofriendly machining techniques such as minimum quantity

lubrication (MQL), cryogenic machining, etc. are required in order to reduce detrimental environmental effects of cutting fluids. Therefore, researchers are interested in dry machine technique. This technique uses coated tools [29] textured cutting tools [30-31], and other sustainable techniques [32]. Near-dry machining or MQL or minimum quantity cutting fluid (MQCF) represent a solution so as to hazardous environmental effects [33-37].



**Fig 1. An overall flow of the proposed methodology by [23]**

In this section, we observed from the above literature that multiple studies consider energy consumption, carbon emission and cutting fluids as an important process response. However, it is clear that in order to determine the optimal decision making, requires the knowledge of the different techniques that the designer is not an expert. Therefore, the eco-manufacturing integrating CAD is highlighted in the next section.

## 2.2. Eco-manufacturing integrating CAD

To increase productivity, companies are asking for improved CAD tools combining different functions such as manufacturing, cost estimation, environmental assessment, etc. Therefore, the trend in CAD systems is to integrate non-geometrical information at different levels into the purely geometrical model, such as taking into account engineering constraints and features. Bianconi et al distinguish two main areas of data exchange: horizontal (the same level of product development)

and vertical (exchanging data between systems of different levels of product development) exchange [38].

The need to analyze products in environmental terms during its design phase has led to the development of environmental impact analysis tools integrating CAD systems. Several studies, according to the literature, attempt to link these two types of software to help the designer make decisions. The history of integrating CAD systems with eco-design tools began in 1995. Among these works are methodologies [39-47], prototype tools [48-56] or commercial tools [57-60] in order to assist the non-environmental expert designer to eco-design his products.

Introduire la section suivante

## 3. Multi-criteria decision support methods: Overview

Multi-criteria analysis methods are decision support tools developed since the 1960s. Numerous methods are proposed to enable decision-makers to make a good «choice». Multi-criteria decision-support methods (MCDSM) are techniques that allow the integration of any type of criteria, these procedures seem to be more likely to lead to a judicious compromise rather than an often outdated optimum [61]. MCDSM are categorized into 3 categories; single synthesis approach methods, summary overridden methods and interactive methods.

- **Methods of the single criterion synthesis approach:** These approaches are used in the event that the decision-maker is able to judge any pair of actions {a, b} according to one of the following cases: either a is preferred to b, or b is preferred to a, either the decision-maker is indifferent between a and b. There is therefore no incomparability between two actions. Several methods have been developed in this decision support class, which can be mentioned: Technique for Order by Similarity to Ideal Solution (TOPSIS) [62]; Simple Multi-Attribute Rating Technique (SMART); Multiple Attribute Value Theory (MAVT) [63]; Multi Attribute Utility Theory (MAUT) [64]; Analytic Hierarchy Process (AHP) [65-67].
- **Methods of overridden synthesis:** These approaches allow for incomparability between actions. Some are characterized by structures of preference strong, weak, indifference, incomparability. Several methods have been developed in this decision support class, which can be mentioned: Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) [68], Elimination Et Choix Traduisant la REalité (ELECTRE) [69]; Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH) [70].
- **The interactive methods:** These approaches are characterized by continuous interaction between the study man and the decision-maker throughout the decision-making process.

reference

#### 4. Overview of Micro/Macro-planning

The environmental impact assessment of the manufacturing process is the subject of numerous

researches. This involves reducing or avoiding processes that have an impact on ecosystems, human health, etc. In 1995, Sheng et al. and Munoz et al. analyzed the environmental impact of different waste streams [71-72]. They applied a scoring system that assesses some indicators (toxicity, carcinogenetic, irritation, flammability, and reactivity) to reduce the complexity of treatment solutions through a feature-based approach. A hierarchical parts planning strategy for environmentally friendly machining is developed in [73], where it is shown that a feature can be machined with different scenarios. The aim is to choose the most impactful machining scenario. In the work of Sheng et al in 1995, the environmental impact can be calculated at the level of each feature independently of the others (micro-planning) [74]. But, obtaining microplans does not necessarily result in a globally feasible process plan for a given part. Hence, Srinivasan et al propose another approach that considers the level of a set of features that interact (macro planning) [75]. The structure of the microplanning decision model is shown in figure 2. Sormaz and Khochonovis classify the interactions between features into the three types: Shared volume by several features, tolerance/datum dependencies or coincidental/grouping relationships [76]. In 2001, D'Souza et al., presented the microplanning, as the decomposition of machining features generated by the macroplanner into sub-features [77]. They described the implementation of a microplanner that is capable to accomplish optimally the abovementioned tasks, either minimize time or cost for 2.5-D Pocket Machining. In 2000, Tseng and Jiang proposed a methodology which analyzes the different manufacturing costs for the different feature-based machining methods, then, the one with the lowest manufacturing cost is considered as the "best" from the manufacturing point of view [78]. In 2015, Gaha et al., adopted the methodology proposed by Tseng and Jiang to evaluate the environmental impact (EI) as well as cost of a part's manufacturing process till the detail design phase [79].



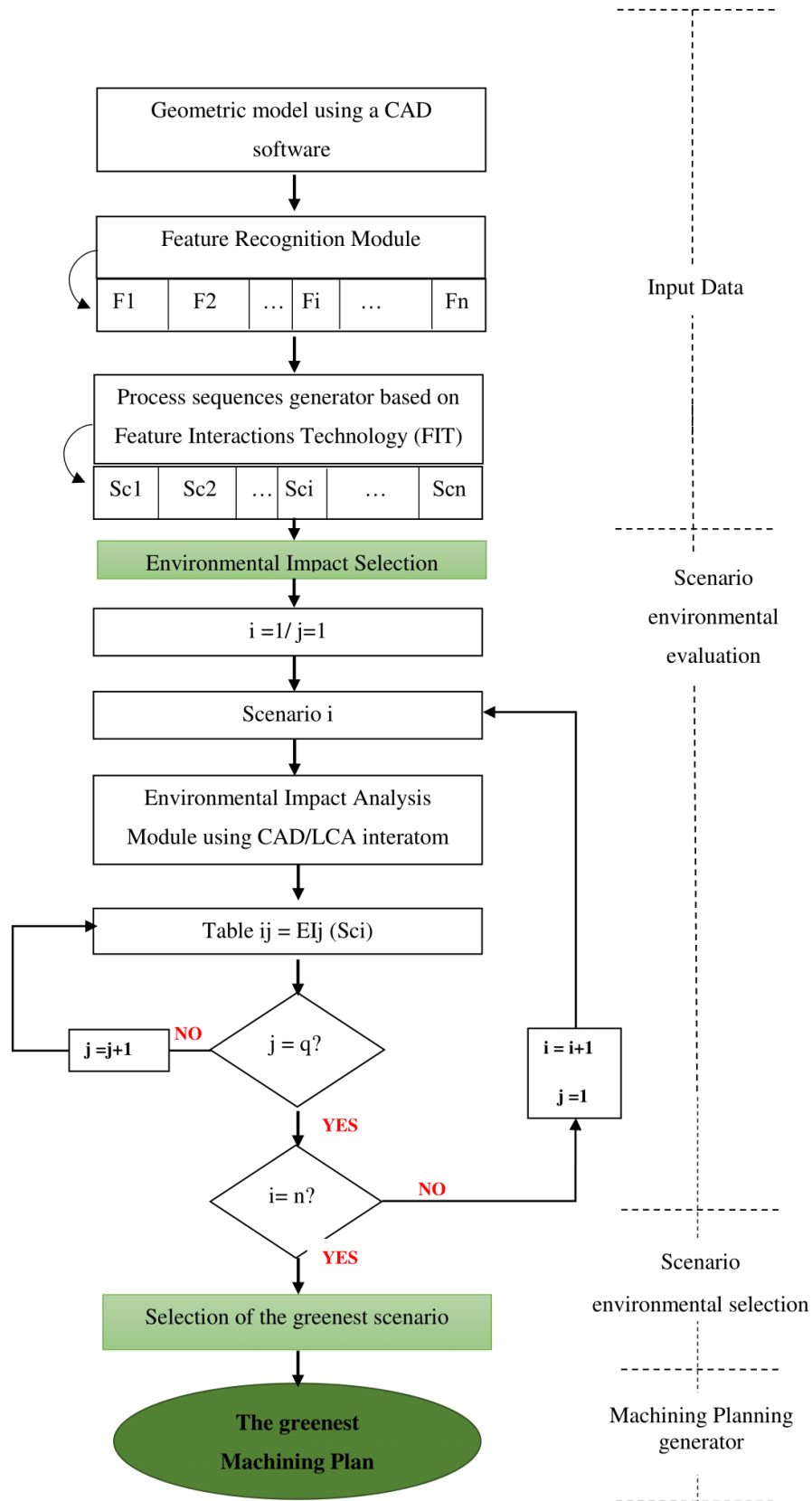


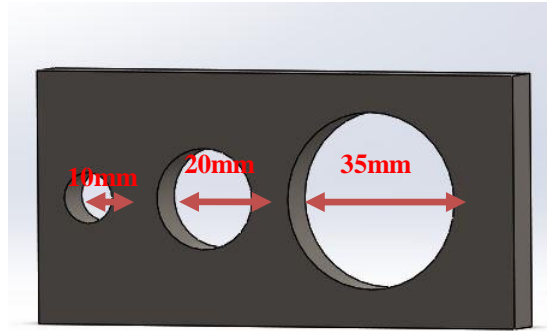
Fig 4. A new based feature-interaction eco-manufacturing methodology on CAD phase

## 6. Case study

To validate our methodology, we consider a sample part 100mm\*60mm\*10mm with three holes with increasing diameters to be drilled (Figure 5). The work piece material is assumed to be AISI 4043 alloy steel with a density equivalent to 7850 kg/m<sup>3</sup>.

Three feasible sequences with feature interaction can be considered for drilling:

- (A) 3 drills of the corresponding hole sizes are used.
- (B) The 10 mm drill is used to create a pilot hole on holes 2 and 3, then two final drills of 20 mm and 35 mm.
- (C) The 10 mm drill is used to make a pilot holes on holes 2 and 3, the 20 mm is used to make a pilot hole on hole 3 and finally a 35 mm is done.



**Fig 5. Case study for feature interaction**

For ease of calculation, the LCA is practices with the software “Bilan Produit”, developed by ADEME [81].The database used is developed in collaboration with EcoInvent Center and the Swiss Center for life cycle inventories [82].By using CML method [83], 8 environmental impacts are considered [EI1= Energy consumption (MJ eq) , EI2=Resource consumption (kg Sb eq), EI3=Greenhouse effect GWP 100 mod (kg CO2

eq), EI4=Acidification (kg SO2 eq), EI5= Eutrophication (air water soil) ( kg PO4 --- eq), EI6=Photochemical pollution (kg C2H4), EI7 = Aquatic ecotoxicity (kg 1,4-DB eq), EI8 = Human toxicity (kg 1.4-DB eq)]. At the scenario environmental evaluation level, a CAD/LCA integration system is used to calculate the EIs for each possible machining scenario and the process outputs are shown in figure 6.

	EI1	EI2	EI3	EI4	EI5	EI6	EI7	EI8
Sc1	5,53	2,67E-03	3,84E-01	1,33E-03	8,22E-04	1,21E-04	3,89E-01	8,64E-01
Sc2	3,29	1,59E-03	2,28E-01	7,87E-04	4,88E-04	7,18E-05	2,31E-01	5,14E-01
Sc3	2,33	1,12E-03	1,62E-01	5,59E-04	3,47E-04	5,10E-05	1,64E-01	3,64E-01

**Fig.6 Case study results matrix**

From figure 7 the sequence with the lowest environmental impact is C and is chosen as the best

sequence. The next stage is generating the machining plan related to this sequence.

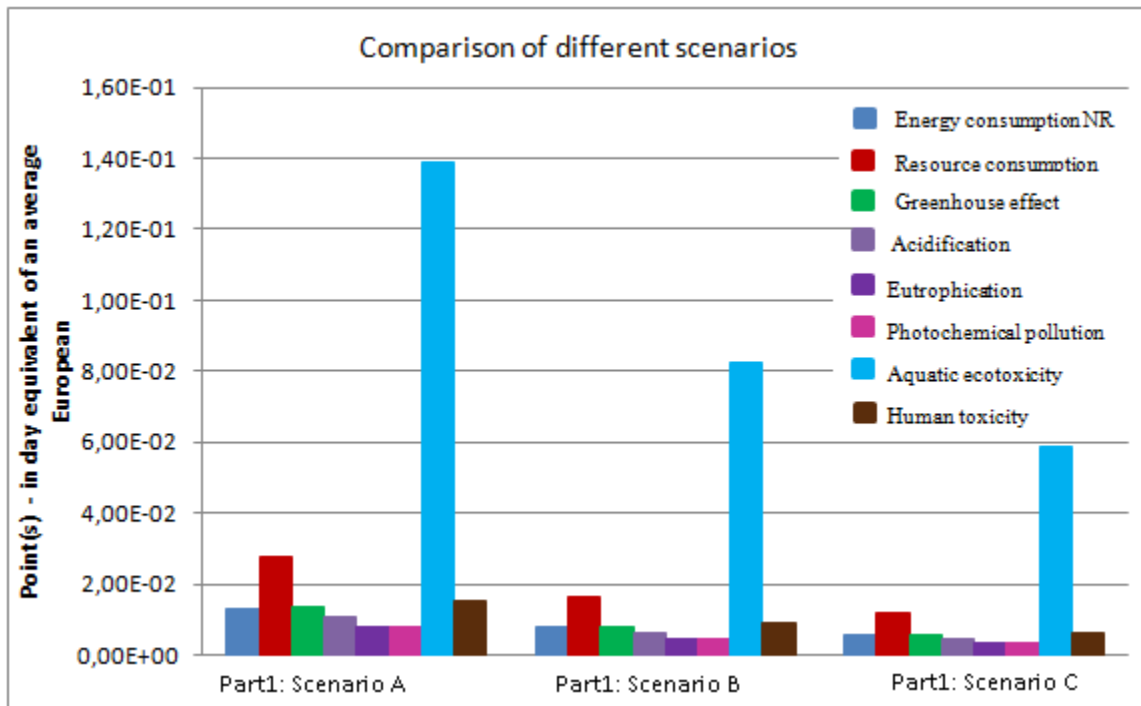


Fig 7. Comparison of different results

## 7. Conclusion

This paper is developed base on the work of Vukelic (2019). It presents and discusses the need for integrating environmental performances into manufacturing process based on feature interactions technology and MCDSM in order to optimize the manufacturing part process in terms of environmental impact (such as energy consumption, CO2 emission, cutting fluids, etc.) till detail design phase. A methodology for analyzing different manufacturing environmental impacts was proposed using an activity-based FIT/MCDSM model. Future works should focus on detailing the FIT-based process sequences generator and since cost constraint is a priority for manufacturers, the establishment of a methodology based on a good environment/cost compromise could attract their attentions.

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