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# A coupled evaluation and optimization approach to drive product variety towards sustainability

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**Abstract**

Increasing customer demands for highly personalized and environmentally friendly products urge companies to find new ways for managing their production systems. The aim is to cope with diversity of items while delivering profitable products with lower environmental impact. This paper proposes a coupled evaluation and optimization approach to steer product variety towards environmental and economic sustainability. A predefined set of indicators enriched with weights given by the user ensures the evaluation, while optimization uses linear programming. The paper highlights the impact of variety steering on environmental and economic sustainability indicators. Additionally, the paper underlines the need to translate regulations into concrete company goals through integrating carbon markets into the proposed model.

**Keywords:** sustainability, evaluation, variety, linear programming, analytic hierarchy process

## 1. Introduction

Increasing customer requirements and emergence of market niches resulted in the proliferation of product variety. ElMaraghy *et al.* (2013) define variety as a number or collection of different things of a particular class of the same general kind. They define variant as an instance of a class that usually exhibits slight differences from the common type or norm. Producers strive to provide a wider spectrum of choice to gain market share and accommodate as many product variants as possible. However, each product variant induces a certain cost and environmental impact and generates a given profit. Thereby, the challenge is to handle enough variety to meet customer requirements while steering such variety towards sustainability. While variety management is concerned with definition of product architecture, variety steering aims to determine the variation of such predefined product architecture (Blecker *et al*. 2006; Jiao *et al.* 2007).

This paper focuses on steering variety towards environmental and economic sustainability. This topic is scarcely addressed in literature and no explicit frameworks have been proposed so far, to the best of our knowledge. In current research we approach such a problem using green supply chain management and optimisation tools. Indeed, is argued that green supply chain management can benefit from optimization tools in various ways (Sbihi & Eglese 2007). More specifically, this paper proposes a coupled evaluation and optimization approach. The aim is to support the decision making process on the distribution of production volumes among variants while considering the economic and environmental optimization criteria. A predefined set of indicators enriched with weights reflecting each indicator's relative importance ensures the evaluation. The optimization model uses linear programming to find trade-offs between all indicators while taking carbon market into account.

As shown in Figure 1, section 2 provides a brief review of green supply chain performance evaluation and optimization. Section 3 presents the proposed approach comprised of indicators' weighting and optimization. Section 4 illustrates the proposition with a numerical example inspired from a real case company; it ends with a discussion of some added value and limits of the proposed approach. Conclusions and future research directions are summarized in section 5.

 

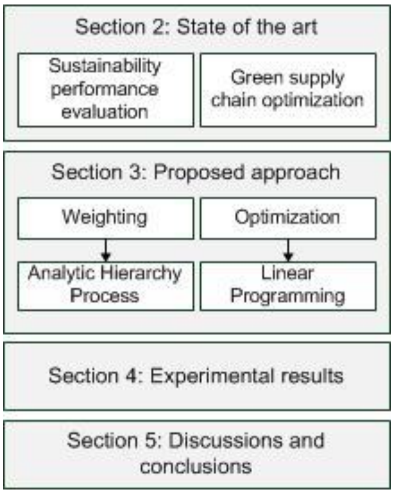


Figure 1. Graphical Abstract

## 2. State of the art

### *2.1 Sustainability performance evaluation*

Literature is rich in sustainability evaluation frameworks and indicators' systems. Many of them focus on the external reporting of company performance (Global Reporting Initiative 2002; Labuschagne *et al.* 2004; UNEP 2009). Beyond benchmarking purposes, more methodological guidance is required to support decision makers in taking the "right" decisions on product, production process, and supply chain design alternatives. In this vein, life cycle thinking gained a lot of interest as it expanded the focus from production sites to the whole product life cycle (UNEP & SETAC 2009). Life Cycle Assessment (LCA) is a method for assessing the environmental impact of product throughout its life cycle phases (ISO 14040 2006; ISO 14044 2006). Dekker *et al.* (2012) enumerated several metric systems applied to supply chains, which, however, focused only on greenhouse gases emissions. Recently, a comprehensive assessment model was proposed to assess sustainability performance of mass customized solutions, the S-MC-S model (Sustainable Mass Customization – Mass Customization for Sustainability) (Bettoni *et al.* 2013). The S-MC-S assessment model relies on a mixed life cycle and multi-level perspective. The life cycle aspect considers product life cycle phases (i.e. extraction, material processing, manufacturing, logistics, etc.). The multi-level aspect considers the product, production processes and supply chain levels. Indicator formulas are implemented in an assessment engine connected to the Ecoinvent data base which gives more reliability to the indicator values (Pedrazzoli *et al.* 2012). However, a challenge is the high number of indicators which may compromise the decision making process. One way to address this is by prioritizing indicators so as to focus on the most relevant ones, according to company priorities. The Analytic Hierarchy Process (AHP) (Saaty 2008) is a common method that can be applied in this context. In fact, AHP and decision making approaches at large, help defining trade-offs between environmental and economic criteria and company concerns (Dey & Cheffi 2012; Bhattacharya *et al.* 2013).

### *2.2 Green supply chains optimization*

Environmental considerations have emerged in operations management. Evidence of this is the body of literature coupling green principles with supply chain management. One relevant question that operations management research attempts to answer is how to balance environmental and business concerns (Neto *et al.* 2009; Dekker *et al.* 2012). Most studies that integrate environmental considerations into supply chain optimization focus on transportation, warehousing and inventory management (Min *et al.* 2006; Bauer *et al.* 2010; Goel 2010; Bloemhof *et al.* 2011; Wang *et al.* 2011; Digiesi *et al.* 2012; Jaegler & Burlat 2012; Hiremath *et al.* 2013). Moreover, intensive studies involve reverse logistics and closed loop supply chains (CLSC) (Krikke *et al.* 2003; Kongar & Gupta 2006; Kannan 2010; Arcelus *et al.* 2011; Abdallah *et al.* 2012; Olugu & Wong 2012; Jindal & Sangwan 2013). However, CLSC is considered only as a green practice and its environmental impact is not analysed explicitly (Dekker *et al.* 2012). Mirzapour Al-e-hashem *et al.* (2013) proposed an optimization model for aggregate production planning while integrating manufacturing operations. However, many simplified assumptions surround the environmental criteria modelling such as waste ratio calculations and the maximum allowed amount of greenhouse gases emissions. Dekker *et al.* (2012) reviewed applications of operations research to green logistics. Their survey pointed out the lack of life cycle perspective in green operations optimization.

Wang *et al.* (2011) used mixed-linear programming to design supply chain network while considering initial investments for environmental protection and carbon emissions during supply chain operations. They underlined the role of managing the capacity to reduce the environmental impact of transportation and inventory level. Laws, regulations and government action at large, are often addressed only through empirical studies that analyse their importance (Adcroft & Willis 2005; Tan & Rae 2009) and relevance to company strategies. One important achievement in this respect is the EU Emissions Trading System (EU ETS) resulting from the Kyoto Protocol. According to this system, companies receive a certain carbon emission allowance (i.e. threshold). They have to buy or sell a given amount of carbon emissions according to their effective emissions during a given period of time (EP & CEU 2009). EU ETS motivates companies to engage in sustainable development, since it compels them to jointly optimize both economic and environmental performances. Little research has been carried out on this subject; see for example Chaabane *et al.* (2011).

## 3. Proposed approach

The proposed approach is comprised of two steps: weighting and optimization (Figure 2). First step relies on interviews to capture manager priorities. Its input is performance indicators the company is using or another indicators set such as Global Reporting Imitative (2002). The aim of these interviews is to allow manager perform pair wise comparisons of the performance indicators, resulting in a judgments matrix. The outputs of this step are indicators weights obtained by applying AHP to these judgements. Second step is based on linear programming, its inputs are indicators values calculated for each product variant $i$. Indicators weights are used in the second step. During this step, constraints are total production capacity of the company and customer demands per variant; expected upper and lower bounds of the demand. The output of the model is the distribution of production volumes among variants. This distribution is assumed to be a trade-off between variety and sustainability.

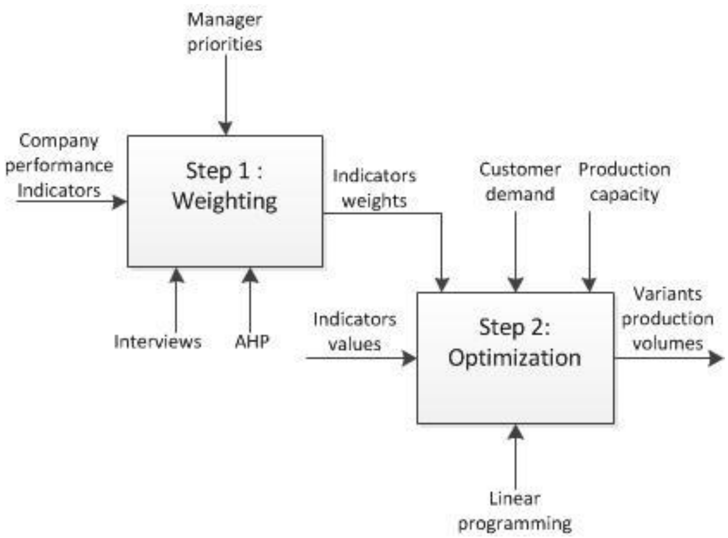


Figure 2. Proposed approach

### *3.1 Weighting*

During interviews, company managers weight indicators according to their priorities. Afterwards interviews output is processed using the Analytical Hierarchy Process (AHP). We assume that a predefined set of $m$ indicators $I^j$, $j \in \{1..m\}$ is already available at the company. This can be either the company's own indicators or common frameworks such as the Global Reporting Initiative (2002). Manager performs a pair wise comparison of the indicators. The result is the matrix $P$ (Equation (1)), where $\delta_{ij}$ is the relative importance of indicator $i$ over indicator $j$. The average value of normalized $\delta_{ij}$ (Equation (2)) results in the weight of indicator $j$ (Equation (3)).

$$P = \begin{pmatrix} \delta_{11} & \cdots & \delta_{1m} \\ \vdots & \ddots\ \delta_{ij}\ \ddots & \vdots \\ \delta_{m1} & \cdots & \delta_{mm} \end{pmatrix},\ \delta_{ij} \in ]0,9] \tag{1}$$

$$\delta_{ij}^{n} = \frac{\delta_{ij}}{\sum_{l=1}^{m} \delta_{lj}}\ , i, j \in \{1..m, 1..m\} \tag{2}$$

$$\alpha_j = \frac{\sum_{k=1}^{m} \delta_{jk}^{n}}{m}\ ,\ j\ \in \{1..m\} \tag{3}$$

In order to check the consistency of the judgements a consistency ratio ($CR$) is calculated according to Equation (4). If $CR$ is lower than $0.2$ judgements are said to be consistent (Saaty 2008).

$$CR = \frac{sum\ product_{k\in\{1..m\}}\ [\alpha_k, \sum_{i=1}^{m} \delta_{ik}] - m}{RI.(m-1)} \tag{4}$$

*3.2 Optimization*

Optimization aims to reduce costs and the environmental impact (and thus increase profit) by varying production volumes of product variants, these are represented by $x_i$. The backbone of the objective functions is indicator values $I_j^i$ such that $i$ refers to product variant and $j$ refers to the indicator, $i \in \{1..n\}$ and $n$ is the number of variants. We define $\gamma_j$, such that $\gamma_j = 1$ if an increase of the value of indicator $j$ is desired, $-1$ otherwise. For each indicator $I_j^i$, an objective function $f_j$ is calculated as shown in Equation (5).

$$f_j = \sum_{i=1}^{n} \gamma_j . I_j^i . x_i\ ,\ j \in \{1..m\} \tag{5}$$

We consider the cost/profit that can be induced by Eco taxes as follows: if the amount of greenhouse gases passes a given threshold $T$, then company has to pay carbon tax $f_T$ (calculated as shown in Equation (6)). $\beta_j$ is a Boolean variable such that $\beta_j = 1$ if indicator $j$ contributes to greenhouse gas emissions, $0$ otherwise (Equation (7)). $CC$ is the emissions' unitary cost in the company's carbon market. When a company's emissions respect the allowed amount of emissions, it is paid by other companies where emissions exceed such a threshold.

$$f_T = \mathrm{CC}\ (\sum_{j=1}^{m} \sum_{i=1}^{n} \beta_j . I_j^i . x^i - T) \tag{6}$$

For optimization, we use the weighted sum scalarization technique (Ehrgott 2013). Accordingly, the function that needs to be optimized is the weighted sum of the objective convex functions $f_j$. Here, we propose to use the weights $\alpha_j, j \in \{1..m\}$ , given by the manager to each of the indicators $I_j^i$.

The objective function can be written as in Equation (7), where $\alpha_c$ is the weight of the cost indicator:

$$\max Z = \sum_{j=1}^{m} \alpha_j . f_j - \alpha_c . f_T \tag{7}$$

Equation (7) can then be written as follows:

$$\max Z = \sum_{j=1}^{m} \sum_{i=1}^{n} (\gamma_j . \alpha_j . I_j^i - \beta_j . \alpha_c . CC . I_j^i) . x^i + \alpha_c . CC . T \tag{8}$$

 

Let $P^i_{min}$ and $P^i_{max}$ be the minimum and maximum values of possible production volumes of variant $i$, respectively (Equation (9)). Additionally let $P_t$ be the total production volume (Equation (10)). $P^i_{min}$, $P^i_{max}$ and $P_t$ can be determined based on expected sales and production capacity.

$$0 \leq P^i_{min} \leq x^i \leq P^i_{max} \quad (9)$$

$$\sum_{i=1}^{n} x^i \leq P_t \quad (10)$$

The subsequent optimization model is as follows:

$$\max Z = \sum_{j=1}^{m} \sum_{i=1}^{n} (\gamma_j . \alpha_j . I^i_j - \beta_j . \alpha_c . CC . I^i_j) . x^i + \alpha_c . CC . T$$

s.t.

$$0 \leq P^i_{min} \leq x^i \leq P^i_{max}$$

$$\sum_{i=1}^{n} x^i \leq P_t$$

## 4. Experimental results

We applied our proposed approach in the furniture sector, more specifically a furniture manufacturer providing several variants of customized kitchens to the luxury market. The company has three product lines. Our study involves one product line comprising 6 variants. It aims to balance the production between these variants so as to minimise the environmental impact and costs. The first step is to weight the indicators using pair wise comparisons and AHP. The second step is to solve the linear programming model to come up with a given distribution of the production volumes among variants. In current research we consider only weights that are calculated by AHP. This might be a burden for the optimization because we only consider a single point of the Pareto curve (depicting Pareto optimal solutions). However we base our model on the assumption that the chosen weights are most suitable to the company. Hence, a manager is not interested in more optimal solutions if they correspond to weights other than what he decided. On a practical level, one can vary weights around the values given by the manager so as to find more optimal solutions.

### *4.1 Indicators weighting*

The predefined list of indicators used in the case study is taken from the S-MC-S assessment model. It is presented in Table 1. Table 2 summarizes pairwise comparisons of the indicators.

Table 1. Indicators definitions (Bettoni *et al.* 2013)

| *Indicator* | *Definition* | *Unit of measure* |
|---|---|---|
| GWP – Global Warming Potential | The GWP indicator measures the contribution to global warming caused by the emission of greenhouse gases into the atmosphere. | kg eq. $CO_2$ |
| HTP – Human Toxicity Potential | The HTP indicator measures the relative impact of the emitted substances on human eco toxicity potential. | kg eq. 1,4-DCB |
| ED – Energy Depletion | The ED indicator measures the energy consumed during the whole life cycle of the product. | MJ |
| NRD - Natural Resources Depletion | The NRD indicator measures the depletion of non-renewable abiotic natural resources. | Kg antimony eq. |
| WD – Water Depletion | The WD indicator measures the water of any quality (drinkable, industrial...) consumed during the whole life cycle of the product. Water used in closed loop processes is not taken into account. | $m^3$ |
| WP - Waste Production | The WP indicator calculates the quantity of waste produced during the whole life cycle of the product. | kg |
| UVPC - Unitary Production Cost | The UVPC indicator measures the direct costs (deducting overheads and taxes) related to the manufacturing of one product unit, calculated as the average one weighted on the expected product mix. | € |

Table 2. Indicators pair-wise comparisons

| | *GWP* | *HTP* | *ED* | *NRD* | *WD* | *WP* | *UVPC* |
|---|---|---|---|---|---|---|---|
| *GWP* | 1.00 | 1.00 | 1.00 | 3.00 | 0.33 | 5.00 | 0.20 |
| *HTP* | 1.00 | 1.00 | 5.00 | 3.00 | 1.00 | 7.00 | 3.00 |
| *ED* | 1.00 | 0.20 | 1.00 | 3.00 | 0.33 | 3.00 | 0.33 |
| *NRD* | 0.33 | 0.33 | 0.33 | 1.00 | 0.33 | 0.33 | 0.20 |
| *WD* | 3.00 | 1.00 | 3.00 | 3.00 | 1.00 | 3.00 | 0.33 |
| *WP* | 0.20 | 0.14 | 0.33 | 3.00 | 0.33 | 1.00 | 0.33 |
| *UVPC* | 5.00 | 0.33 | 3.00 | 5.00 | 3.00 | 3.00 | 1.00 |
| ***Weigh*** | **0.12** | **0.27** | **0.09** | **0.04** | **0.18** | **0.05** | **0.25** |

After applying AHP, subsequent weights are represented in the last row of Table 2. Consistency Ratio (CR) value calculated according to Equation (4) is $0.1542$. This value is lower than $0.2$, and judgements are then said to be acceptable.

The indicators values are calculated by an assessment engine connected to an environmental data base (Avai *et al.* 2010). Data concerning the 6 variants is entered through a set of product, process and supply chain editors. Each of these variants is characterized with given material type, dimensions, shape, etc. The description of variants, however, is beyond the scope of this paper.

*4.2 Optimization*

The function that needs to be minimized is represented by Equations (11) to (13), where $i$ is the variant, with $i \in \{1, 2, 3, 4, 5, 6\}$. Equations (14) to (21) represent total indicators values among all variants $i$s. We propose the use of another indicator, $Cost$, that includes $UVPC$ and cost incurred by the case company in the carbon market. We introduce an income indicator which takes negative value when $Cost \geq 0$, and positive value when $Cost < 0$ (Equation (15)). This latter case occurs when a company decreases its emissions so that it can be reimbursed for the amount of carbon emissions it could emit but did not.

Let:

- $1500$ be the amount of greenhouse gases ($T$) the case company can emit in a given carbon market (GWP is the only indicator that represents greenhouse gases emissions).
- $30$ be the emissions unitary cost ($CC$).
- $150$ be the total production volume ($P_t$).

$$\max Z = \sum_{i=1}^{6}(\alpha_{HTP}.HTP^i + \alpha_{ED}.ED^i + \alpha_{NRD}.NRD^i + \alpha_{WD}.WD^i + \alpha_{HTP}.WP^i + \alpha_{UVPC}.UVPC^i - \alpha_{GWP}.30.GWP^i).x^i + \alpha_{UVPC}.30.1500 \quad (11)$$

s.t.

$$6 \leq x^i \leq 10 \qquad \text{if } i \in \{1, 2, 3, 4\} \quad (12)$$

$$60 \leq x^i \leq 64 \qquad \text{if } i \in \{5, 6\} \quad (13)$$

$$\sum_{i=1}^{6} x^i \leq 158 \quad (14)$$

Indicators values and production volumes are represented in Table 3. Minimum ($P_{min}^i$) and maximum ($P_{max}^i$) production volumes are defined. Their values shown in Table 3 are chosen based on average data. In general they can be defined based on concise demand and production data.

Table 3. Variants data

| Variants | Indicators values | | | | | | | Production volume | |
|---|---|---|---|---|---|---|---|---|---|
| | GWP | HTP | ED | NRD | WD | WP | UVPC | $P_{min}^i$ | $P_{max}^i$ |
| 1 | 20.95 | 11.71 | 1368.3 | 0.19 | 0.17 | 2.00 | 11.21 | 6 | 10 |
| 2 | 23.56 | 16.87 | 1485.2 | 0.22 | 0.19 | 2.27 | 13.41 | 6 | 10 |
| 3 | 22.84 | 16.69 | 1444.4 | 0.21 | 0.18 | 2.27 | 14.35 | 6 | 10 |
| 4 | 22.36 | 12.53 | 1471.4 | 0.21 | 0.18 | 2.14 | 13.80 | 6 | 10 |
| 5 | 23.07 | 12.84 | 1518.2 | 0.22 | 0.19 | 2.18 | 16.10 | 60 | 64 |
| 6 | 22.10 | 12.57 | 1466.4 | 0.21 | 0.18 | 2.15 | 14.86 | 60 | 64 |

 

The linear programming problem is solved using Simplex method. We varied $\Delta_i$ in order to check the impact of production volume variance on the indicators. Table 4 shows the results obtained for different values of $\Delta_i$ such that $\Delta_i = P^i_{max} - P^i_{min}$. Columns 3 to 10 represent the sum of indicators among all variants.

The first row of the table relates to the standard (Std) situation within the case study, that is: $P^i_{min} = P^i_{max} = 8, i \in \{1, 2, 3, 4\}$ and $P^i_{min} = P^i_{max} = 63, i \in \{5, 6\}$. Data relating to this situation are described in detail in Table 3.

Table 4. Production volumes variance impact on indicators ($\sum_{i=1}^{6} x^i \leq 158$ , $T = 1500$)

| $\Delta_V$ | $P^1_{min}$, $P^2_{min}$, $P^3_{min}$, $P^4_{min}$, | $P^5_{min}$, $P^6_{min}$ | Indicators values | | | | | | | Decision variables | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | GWP | HTP | ED | NRD | WD | WP | Cost | $x^1$ | $x^2$ | $x^3$ | $x^4$ | $x^5$ | $x^6$ |
| Std | 8 | 63 | 3563 | 2063 | 23418 | 33.73 | 29.07 | 342 | 64274 | 8 | 8 | 8 | 8 | 63 | 63 |
| 4 | 6 | 60 | 3248 | 1871 | 21369 | 30.78 | 26.52 | 312 | 54628 | 6 | 6 | 6 | 6 | 60 | 60 |
| 8 | 4 | 58 | 2979 | 1705 | 19618 | 28.26 | 24.34 | 286 | 46368 | 4 | 4 | 4 | 4 | 58 | 58 |
| 12 | 2 | 56 | 2709 | 1539 | 17867 | 25.74 | 22.16 | 260 | 38108 | 2 | 2 | 2 | 2 | 56 | 56 |

As shown, in Table 4, all indicators values decrease with the increase of the gap between minimum and maximum production volumes of each variant $i$. Such a decrease is expected, since the model has as many options as the interval of decision variables (production volumes of the variant) increases. It is then more likely to find more optimal solutions. The manager, for instance, can select one of the proposed solutions according to the production system capacity that determines which $\Delta_i$ the company can afford.

The trend that can be noticed in the solutions offered by the model (i.e. decision variables) values is the minimization of total production volumes of the variants. The lower variant minimal production volume, the lower is total production volume.

Let us consider the case where the total production volume is fixed, however it can be distributed among variants according to their lower, $P^i_{min}$ and upper, $P^i_{max}$ limits. This is illustrated in Table 5. Such a case arises when demand volumes are higher than company's production capacity.

Table 5. Production volumes variance impact on indicators ($\sum_{i=1}^{6} x^i = 158$ , $T = 1500$)

| $\Delta_V$ | $P^1_{min}$, $P^2_{min}$, $P^3_{min}$, $P^4_{min}$, | $P^5_{min}$, $P^6_{min}$ | Indicators values | | | | | | | Decision variables | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | GWP | HTP | ED | NRD | WD | WP | Cost | $x^1$ | $x^2$ | $x^3$ | $x^4$ | $x^5$ | $x^6$ |
| Std | 8 | 63 | 3563 | 2063 | 234184 | 33.73 | 29.07 | 342 | 64274 | 8 | 8 | 8 | 8 | 63 | 63 |
| 4 | 6 | 60 | 3556 | 2052 | 233805 | 33.64 | 29.00 | 341 | 64036 | 10 | 6 | 8 | 10 | 60 | 64 |
| 8 | 4 | 58 | 3548 | 2033 | 233522 | 33.56 | 28.94 | 340 | 63784 | 12 | 4 | 6 | 12 | 58 | 66 |
| 12 | 2 | 56 | 3540 | 2014 | 233238 | 33.48 | 28.88 | 339 | 63533 | 14 | 2 | 4 | 14 | 56 | 68 |

It can be seen from Table 5 that indicators values decrease more slowly than in Table 4 (i.e. variable total production volume). This is evident from the fact that environmental and cost indicators depend greatly on the quantities produced. In the current case, the key inductor of environmental and economic performances is the distribution of production volume among variants. Thus, the model balances production volumes according to variant impacts, in terms of 1) environmental and economic sustainability, 2) and priority ($\alpha_i$). According to the results shown in Table 5, variants can be ordered as follows, according to their contribution to the improvement of overall performance: 1 and 6 then, 4 then 2 and 5.
Figure 3 shows the variation of the income for different carbon market threshold values, with:

$$Income = -\sum_{i=1}^{6} UVPC^i - CC.(\sum_{i=1}^{6} GWP^i - T) \quad (15)$$

A company's greenhouse gases emissions amount to approximately $3500\ kg$. Thus, it incurs a carbon cost until the threshold exceeds this value, then revenue is generated by the reimbursement to the company for the non-emitted but allowed amount of greenhouse gases. This highlights the importance of considering the carbon market in the optimization of the economic and environmental performance of the company.

 

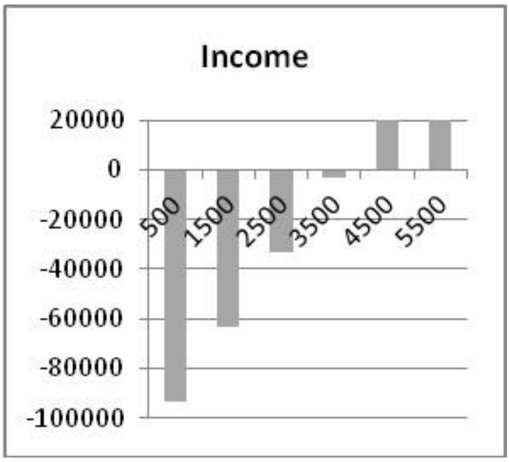


Figure 3. Carbon threshold impact on income

The above results highlight the relevance of our approach which uses reliable evaluation tools and known optimization techniques. The evaluation relies on sustainability performance indicators connected to an external environmental data base. The use of deeply developed tools for the evaluation proves to have a leverage effect for using the model among SMEs. Further on, proposed approach combines company concerns, through indicators' weightings, with variety steering towards sustainability. This presents a major added value of the paper; putting together evaluation and optimization with company concerns. It however, may burden the optimization, since we focus on a single Pareto optimal solution. One could think of optimization while considering a complete Pareto front and then proposing the results to the manager who can pick the best solution or set of solutions based on 1) total indicators values 2) and priorities he assigns to each indicator (hence objective functions). This scenario should be applied to a case study in order to check its feasibility. Notwithstanding, current model still holds since it allows for a better variety steering process while considering sustainability criteria. It takes advantage of the availability of evaluation tools providing reliable environmental and economic data based on integrated modelling of the product, process and supply chain. Furthermore, the proposition puts together linear programming, AHP, scalarization to enable sustainability performance improvement.

## 5. Discussions and conclusions

In this paper we propose a combined evaluation and optimization approach to mitigate variety impact on sustainability. Indicators are weighted according to company priorities, thus providing more decision support to managers. Optimization aims to minimize emissions and cost through balancing production volumes between variants and integrating the carbon market. Production capacity and demand are considered at this point. Our proposed approach helps in bridging the gap between sustainability performance measurement and optimization through a holistic approach putting together indicators weighting, calculation and optimization. Decision makers are involved in the calculation of the indicators weights, thus final results reflects in some way their requirements.

The paper underlines the impact of variety steering on sustainability indicators. When the variants' production volumes are flexible, the cost and environmental impact are lower. Furthermore, this paper points out the relevance of the carbon market to company environmental and economic performances. From this, it follows that environmental considerations should be considered from a win-win perspective rather than an external constraint. In this sense optimizing company sustainability performance generates economic value (e.g. reimbursement from the carbon market) instead of making companies incur additional costs. In many cases, the main reason of managers being reluctant to improve their environmental performance is due to the costs induced by such initiatives. This phenomenon is less frequent in SMEs where personal convictions of managers (often owners of the company) encourage them to adopt environmentally friendly production strategies. While in global corporates economic value remains the first concern of the company. Government efforts should, therefore, be reinforced in order to broaden the scope of regulations so as to compel firms to reduce their environmental footprint in different impact categories (e.g. resource utilization, waste production, etc.). Despite the relevant body of literature addressing the relationship of regulations to company performance, more research is needed to put together: 1) government regulations 2) in-company constraints and 3) evaluation criteria (i.e. indicators). Such frameworks would help managers cope with regulations and laws while accommodating customer requirements in their offers of products and services.

Further on, the paper shows that, beyond scheduling, reverse logistics and routing problems, green supply chain management exhibits high potential for using optimization. More specifically, several issues can be approached using optimization techniques, such as incorporating carbon markets in cost minimization, coupling cost and environmental footprint minimization, drive the environmental footprint down based on heterogeneous indicators (e.g. energy consumption, greenhouse gases emissions, etc.), to name a few. One way to promote this area is to integrate the development of sustainability evaluation tools and optimization models. This provides the optimization models with access to additional indicators drivers, hence broadens the scope of the optimization in sustainability areas.

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