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Review

A holistic review of applied methodologies for assessing and selecting the optimal technological alternative from a sustainability perspective

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ABSTRACT

Assessing and selecting the optimal technological alternatives in industrial sector is a fundamental tool to improve and adapt the industrial processes to the European legislation, which encourages the incorporation of new technologies for minimising the environmental impacts of companies such as Best Available Techniques. The aim of this study is to perform a holistic analysis of this process from a sustainability perspective. That is to say, its purpose is to analyse the studies that have been published in the literature over the last decade concerning the way the different improvements incorporated into different industrial sectors (Best Available Techniques, green technologies, remediation technologies, emission abatement technologies, etc.) are assessed and selected from a range of perspectives (environmental, technical, economic, social, etc.). Thus, an extensive review of the literature was performed to determine which criteria are the most widely used, the methodologies applied to choose those criteria, the sources of information the data is obtained from, the methodologies for calculating the indicators that allow each criterion to be measured, the different normalising and weighting methods that are applied, the techniques that are most commonly used to compare and choose the best technological alternatives and, finally, the sensitivity analyses that are most often applied to such processes. As a result, the process for assessing and selecting technologies is characterised and the guidelines to direct the selection of the set of methodologies that are the most appropriate to make a decision related to technology selection in future applications are established.

1. Introduction

Technological development has historically been considered the main effective source of both competitive advantage among enterprises and the economic growth and social benefit of countries (Afuah, 2000; Liao and Cheung, 2002; Azzone and Manzini, 2008).

The growing need to comply with the progressively more restrictive environmental requirements imposed by the European Union through the introduction of legislation such as Directive 2010/75/EU (DIE Directive) has led to an increased use of new technologies capable of minimising the negative effects that industrial activity has on the environment (Canton, 2008; Musango and Brent, 2011). A number of different technologies can be applied to the same industrial sector, one example being the BREF documents (BAT Reference Documents), which contain the BATs (Best Available Techniques) proposed by the European Commission for different industrial sectors.

Assessing and selecting technological alternatives encloses a process made of different stages ranging from choosing and obtaining criteria on which the selection will be based to comparing the alternatives based on the weighting/valuation of those criteria. Furthermore, as this process strongly depends on different factors as the technology being assessed or the decision-makers (Smith, 1990), there are countless methods which have been created for the different stages of multi-criteria decision-making for technology selection. Thus, to know which ones are the most appropriate in each stage of the decision making process is one of the most important challenges to be considered.

Many attempts have been made to classify these methodologies in terms of their characteristics and/or applications according to the stage they belong. The following are some of the more remarkable examples:

- Tran and Daim (2008) reviewed Technology Assessment (TA) applications in public, business and non-governmental domains and classified the TA methodologies, based on the categories described by De Piante Henriksen (1997) which range from economic evaluation to impact assessment. The paper shows

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how TA approaches and dominant actors in the field have evolved over last decades.

- Lahdelma et al. (2000) and Huang et al. (2011) analysed the role of Multi-Criteria Decision Making (MCDM) methodologies in solving environmental issues and identified their advantages in public decision-making where the function of stakeholders were identified as an essential role.
- Herva and Roca (2012) focused on making decisions regarding corporate environmental evaluation for what were identified the Ecological Footprint (EF), Life Cycle Assessment (LCA) and Environmental Risk Assessment (ERA) as the main methodologies to obtain indicators. When large number of criteria was considered, what often resulting in double-counting of effects, MCA methods were identified as the most applied methods.
- Ahlroth et al. (2011) analysed the weighting and valuation processes in different environmental systems analysis tools and highlighted the lack of consistent weighting/valuation sets which makes incomparable the valuated impacts.
- Pohekar and Ramachandran (2004) reviewed the MCDM methodologies that are most commonly applied to the field of planning and managing sustainable energy technologies highlighting AHP and outranking methods.
- Wang et al. (2009) reviewed the methodologies employed in different stages of the decision-making for sustainable energy, analysing which are the most common criteria and the methods applied for choosing and weighting those criteria in the energy decision-making. MCDM methods have identified as the most applied in that field.
- Barry et al. (2008, 2011) focused on identifying the most important criteria for sustainable energy technology selection in Africa, of which the maintenance, management or economic development are highlighted.

As can be seen, on one hand some authors undertake a review of TA methods, which are focused on analysing the global impact resulting from the introduction of new technologies in different areas of society (Coates, 1976). TA is used in many studies as the basis of technology selection process as it can help decision-makers in identifying sustainable technology solutions (Musango and Brent, 2011). On the other hand, other authors classify and analyse the corresponding methods belonging individual stages such as selecting criteria (Barry et al., 2008, 2011), weighting/valuation of alternatives (Ahlroth et al., 2011) or final decision-making by MCDM applications (Lahdelma et al., 2000; Huang et al., 2011; Pohekar and Ramachandran, 2004; etc). That is to say, most reviews focus on the analysis of methods belonging to the same type, which are applicable to a single stage of the process. Only Wang et al. (2009) reviewed the methodologies in different stages of the decision-making, but this is centred in the sustainable energy field. Then, it can be stated that though some partial reviews have been developed, an integral analysis of the whole process therefore becomes indispensible.

The aim of this study, then, is to perform a holistic analysis of the process of technology assessment and selection in the field of improving industrial sustainability in order to give an integral idea of the current trends in methods that can be applied in the different stages of the process. To this end, an extensive review of the recent literature is carried out in order to identify the most widely used current criteria, the methodologies applied to choose those criteria, the sources of information the data are obtained from, the methodologies for calculating the indicators, the different methods of normalisation and weighting that are applied, the techniques that are most commonly used for comparing and choosing the best technological alternatives and, finally, the sensitivity analyses that are most often applied to such processes.

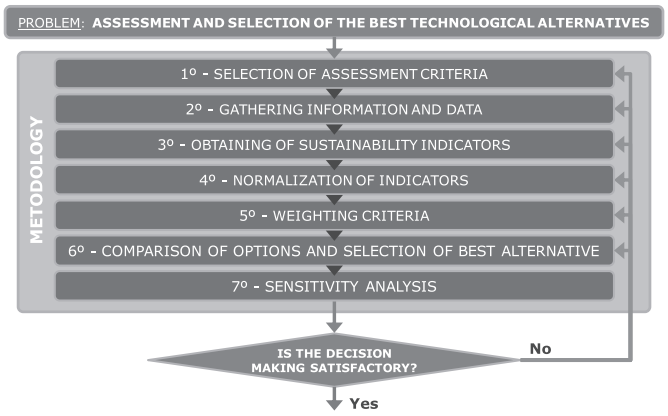

Fig. 1. Stages in the process of assessing and selecting optimal technological alternatives.

The methodology used in the reviewing process is detailed in the next section, followed by the literature review in Section 3. The discussion is included in Section 4 and the conclusions in Section 5.

2. Research methods

The first stage of the study consisted in analysing the methodologies that have been applied to the process of technology assessment and selection most frequently over the last decade.

This was achieved by conducting a literature review of recent papers published in leading international journals indexed in recognised databases (e.g. JCR) and which were related to the assessment and selection of technologies belonging to one of the following fields:

- Best Available Techniques (BATs),
- Technologies for the purification of soils, waters and/or polluted gas streams,
- Green technologies or sustainable technologies, and
- Generic, emerging or process technologies that are analysed in respective studies from the point of view of sustainability or environmental improvement.

The search strategy was to find studies related to improving industrial sustainability through the identification of the optimal technologies by means of scientific search engines. To do so, the keywords technologies, technology assessment, technology selection, green technologies, Best Available Techniques, remediation technologies, cleaner production, decision making, environmental assessment and sustainability were combined to search relevant papers.

The timeframe of the searched journal papers is between 2000 and 2013. The reason for choosing this period is that the Member States had to adopt the laws, regulations and administrative provisions necessary to comply with the Directive 96/61/EC (IPPC Directive) before 2000. From this moment, industries have been encouraged to incorporate different technologies for promoting the protection of the environment as a “whole”, such as BATs.

Taking into account the frameworks defined and used in decision-making processes for assessing and selecting technologies by most of the reviewed authors, such as Guo et al. (2006), Gaudreault et al. (2009) or Giner-Santonja et al. (2012), among others, it can be stated that the process for assessing and selecting technological alternatives involves alternatives, data, criteria, preferences/weightings and final decisions based on the comparison of the overall resulting data.

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