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Multicriteria Analysis and LCA Techniques

With Applications to Agro-Engineering Problems

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(Authors' Note)

Contents

Acronyms

ANPA	Italian National Agency for Environment Protection
ARSIA	Tuscany Regional Agency for Development and Innovation in the Agricultural sector
AU	Average Utilization
CER	Cumulated Energy Requirement
CPO	Crude Palm Oil
CTI	Italian Heat Technology Committee
EC	European Commission
EEA	European Environmental Agency
EFB	Empty Fruit Bunches
EIA	Environmental Impact Assessment
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
EU	European Union
FFB	Fresh Fruit Bunches
FTS	Full Tree System
GHG	Greenhouse Gases
GWP	Global Warning Potential
ISTAT	Italian National Institute of Statistics
ITABIA	Italian Biomass Association
kW_{th}	Thermal Kilowatt
LCA	Life Cycle Assessment
LHV	Lower Heating Value
MCA	Multi-Criteria Analysis
NDP	Nominal Device Power
PKO	Palm Kernel Oil
POME	Palm Oil Mill Effluent
PTO	Power Take Off
RED	Renewable Energy Directive

SFP	Specific Fuel Consumption
t_{db}	Tons Dry Basis
t_{wb}	Tons Wet Basis
UT	Usage Time
VOC	Volatile Organic Compounds

Chapter 1
Introduction

1.1 General Introduction: Purposes and Organization

In recent years, the development of both numerical algorithms and computer power has made it possible to extend the use of numerical methodologies to analyze and elaborate data in sectors different from traditional ones (mathematics, physics and industrial engineering). This is the case of agro-engineering processes, concerning both field and industrial operations.

In agriculture, the empirical approach is still widely used to solve problems and to optimize the different phases of the production chain. This traditional approach keeps preserving its effectiveness and popularity due to the extreme variability of scenarios available, as well as to the lack of consistent and homogeneous data for each phase of the chain. However, the use of numerical analysis is quickly gaining ground, progressively supporting and ousting traditional methods, so that, nowadays, a certain level of abuse in the exploitation of numerical methodologies is observed. The robustness and efficiency of numerical tools are often considered as a sufficient reasons for performing extensive computations to investigate different scenarios without any preventive selection based on a critical analysis of the problem. As an example, the problem of identifying a function by means of patterned data sampling can be mentioned. The general approach was to acquire an amount of data as large as possible. After the discovery of the Shannon theorem, the collection of a limited number of data was found to be sufficient to reconstruct all kinds of functions, whether periodical or otherwise. For this reason, a reflection on the correct application of numerical methodologies seems to be necessary, with the aim of investigating the essential key-points of problems, without losing oneself in considering minor and irrelevant details. As a consequence, research in the agro-engineering sector has lately concentrated its efforts on developing methodologies capable of performing analysis of specific aspects of agricultural processes, obtaining definite answers and, at the same time, allowing one to save time and resources by avoiding useless computations.

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Nowadays, one of the most critical problems to be considered in all production processes is represented by the environmental impact of each phase of the working chain, in terms of both consumption of non-renewable resources and raw materials (such as fossil fuels), and emission of greenhouse gases, by-product reuse and waste disposal. This is also the case in the agro-food industry. Over the last decade, the role of agriculture and, consequently, farms has slowly changed. Originally, farms were only considered as technical-economic units exploiting the land resources to implement agricultural, forestry and/or zootechnical productions. At present, farms have acquired important tasks such as landscape conservation, land coverage and environmental protection against various types of pollution. These new tasks have been associated with farms not only by national and European policies but also by market needs. A typical example is provided by agriculture in Tuscany, Italy, whose high-quality products are associated with the culture of the specific territory in which they are produced, too. Thus, it is not unlikely, in the near future, to think of some kind of environmental certification characterizing these products as an added value to their quality.

In this framework, the authors of this book have spent significant efforts during last years to establish adequate methodologies aimed at evaluating the environmental sustainability of agro-engineering processes, in terms of both their energetic costs and environmental impacts. This is not an easy task to accomplish, since such processes are extremely heterogeneous, due to the variety of environments in which crops grow, to the different typologies of cultivars of each crop, to the various levels of mechanizations in fields, and so on. Such an approach is based on the logic of a total-quality philosophy applied to the production chain, where quality means optimization of resources required for performing process operations, providing at the same time useful information for strategic planning.

Life cycle assessment (LCA) methodology has proved to be one of the most effective tools for carrying out this kind of analysis, and, for this reason, it has become very popular. However, as discussed before, the wide variability and complexity of possible scenarios often determine a huge amount of configurations to be investigated, which require considerable computational time and resources, making it difficult to use LCA in practical applications. As a consequence, some sort of pre-filtering is required which should be capable of selecting the most relevant cases to be investigated by means of LCA.

Recently, some of the present authors have been involved in a study concerning optimal plant configuration for the management of riparian vegetation in Tuscany, in the area of Chianti in Florence Province, and its possible reuse as biofuel, evaluating the benefits and drawbacks from the economical, environmental and managerial points of view [1]. The lack of funds available for performing this study pushed the authors to develop and tune an innovative approach based on the joint use of multicriteria analysis (MCA) and LCA. This approach is the subject of this book.

In the previously cited study, the application of MCA for the analysis of possible chain scenarios allowed one to select the main targets in terms of energetic requirements, dramatically reducing the global number of chain configurations to be investigated by means of LCA. Following this approach, it was also possible to increase the number and typology of scenarios under investigation, extending the sphere of the analysis and completing it with additional results which would have been impossible to achieve otherwise. Results show how the proposed methodology, coupling MCA with LCA, is robust and, at the same time, easy to implement, and provides one with a clear view of the most suitable solutions. Moreover, it allows the operator to establish a precise, reliable and repeatable procedure for evaluating different scenarios in a single way. In the authors' opinion, this represents the most valuable merit of the proposed methodology.

As its main purpose, this book would like to represent a useful reference for all engineers, researchers and high-level students who might be interested in applying LCA as an effective tool for their professional and/or academic activities in the agro-engineering field. In particular, an appropriate and systematic use of LCA methodology could be of interest for those farmers who are determined to follow a different approach in the working chain of their products, pursuing a target of "total quality". Actually, this requirement has become more and more essential for being competitive on global markets, which more and more often require a certification of quality taking into account energy consumptions and environmental impacts associated with each product. On the agro-industrial side, too, LCA could be useful to managers for establishing and controlling process optimization. Keeping in mind these basic concepts, which represent one of the most important research activities of the group, especially for Tuscany farms, the authors have produced this book, which provides a wide-ranging view on the application of both MCA and LCA to different contexts in agriculture.

The book contents are organized as follows. In Chap. 2, the general theory of both MCA and LCA techniques is explained and discussed. In the following chapters, some applications of the proposed methodology are presented, in order to provide the reader with some practical examples: energetic use of biomass and biofuels (Chap. 3); agricultural and forestry mechanization (Chap. 4); olive oil production chain (Chap. 5); oil palm production chain (Chap. 6). Such applications are discussed in detail with the aim of improving and deepening the reader's knowledge on the subject, guiding her/him in implementing and applying the methodology to her/his field of interest.

Reference

1. Recchia L, Cini E, Corsi S (2010) Multicriteria analysis to evaluate the energetic reuse of riparian vegetation. Appl Energy 87:310–319

Chapter 2
General Theory of Multicriteria Analysis and Life Cycle Assessment

2.1 Objectives of the Proposed Methodology and Its Application

As reported in the Chap. 1, one of the most critical problems to be considered in all production processes of the agro-industrial sector is represented by the environmental impact of each phase of the working chain, in terms of both consumption of non-renewable resources, emissions of greenhouse gases, by-product reuse and waste disposal. Moreover, these environmental aspects must be evaluated assuring the technical feasibility and the economical sustainability of the proposed solutions.

This is not an easy task to accomplish, since such processes are extremely heterogeneous, due to the variety of environments in which crops grow, to the different typologies of cultivars of each crop, to the various levels of mechanisations in fields, and so on. The life cycle assessment (LCA) methodology has proven to be one of the most effective tools for carrying out the environmental analysis, even if the large variability and complexity of possible scenarios often determine a huge amount of configurations to be investigated, which require considerable computational time and resources. Therefore, some sort of pre-filtering is required which should be capable of selecting the most relevant cases to be investigated by means of LCA.

As a consequence of the previous considerations, the innovative approach proposed in this book is based on the implementation of the multicriteria analysis (MCA) and the LCA: particularly, the application of the MCA to the alternative solutions allowed to select the most suitable ones in terms of economical and environmental sustainability, dramatically reducing the global number of chain configurations to be investigated by means of LCA.

In the following paragraphs the fundamentals of the two methodologies are briefly illustrated, reporting also some indication about the main common choices adopted in the development of the proposed applications.

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2.2 Generals About the MCA

The development of the MCA is very recent and has been carried out during the last three decades with the aim to consider several consequences of proposed solutions of various typologies of problems. Particularly, the MCA has been introduced after having relieved that intuitive solutions are often not the most suitable and even if they are profitable for a specific aspect they could not be for another one. In fact, the MCA has been introduced because of the necessity to develop multiple evaluations at the same time, taking into account different points of view highlighted by different typologies of stakeholders. Therefore, this methodology can be classified as a supporting tool for decision makers because it is not able to identify the right solution whilst it is useful to organise all the available information, to supply a possible interpretation and to check the pros and cons associated with all the alternatives.

The decision process constitutes several steps: at first the different options must be identified; then a group of parameters to be used to compare the alternatives must be set; finally, all the scenarios must be judged regarding the fixed criteria with the aim to identify the most suitable options.

It is obvious that this approach may be applied in several sectors and whenever it is necessary to carry out a choice in a decision process. However, the methodology can be developed with a different type of detail according to the stage and complexity of the decision process. In fact, if the decision process is carried out at a planning stage, data available for each hypothesised scenario present lower quality and quantity than those which can be collected at successive design stages (i.e. feasibility study). Moreover, the specific sector where the decision process is developed implies a different level of complexity and a different set of criteria which can be applied more or less easily.

The MCA is not uniquely defined and a lot of techniques have been developed with the aim to better adapt the methodology to the specific problem to be solved, including all the preferences promoted by different stakeholders.

Anyway, the main structure of the MCA provides to set all the possible alternatives and to define the criteria to be used for the evaluation.

Particularly, the MCA has a precise structure that includes several steps (see Fig. 2.1):

1. Problem identification and objectives definition;
2. Problem structuring, defining both the options and the criteria to be used;
3. Preference modelling, where scoring and weighting are carried out;
4. Aggregation and analysis of the results;
5. Discussion and negotiation about the obtained results.

The first step is the identification of the problem under discussion, defining also the goals and scopes of the analysis. In this phase it is important to consider all the laws, local constraints and policies that usually highlight the most critical aspects and cause the most important differences between the hypothesised alternatives.

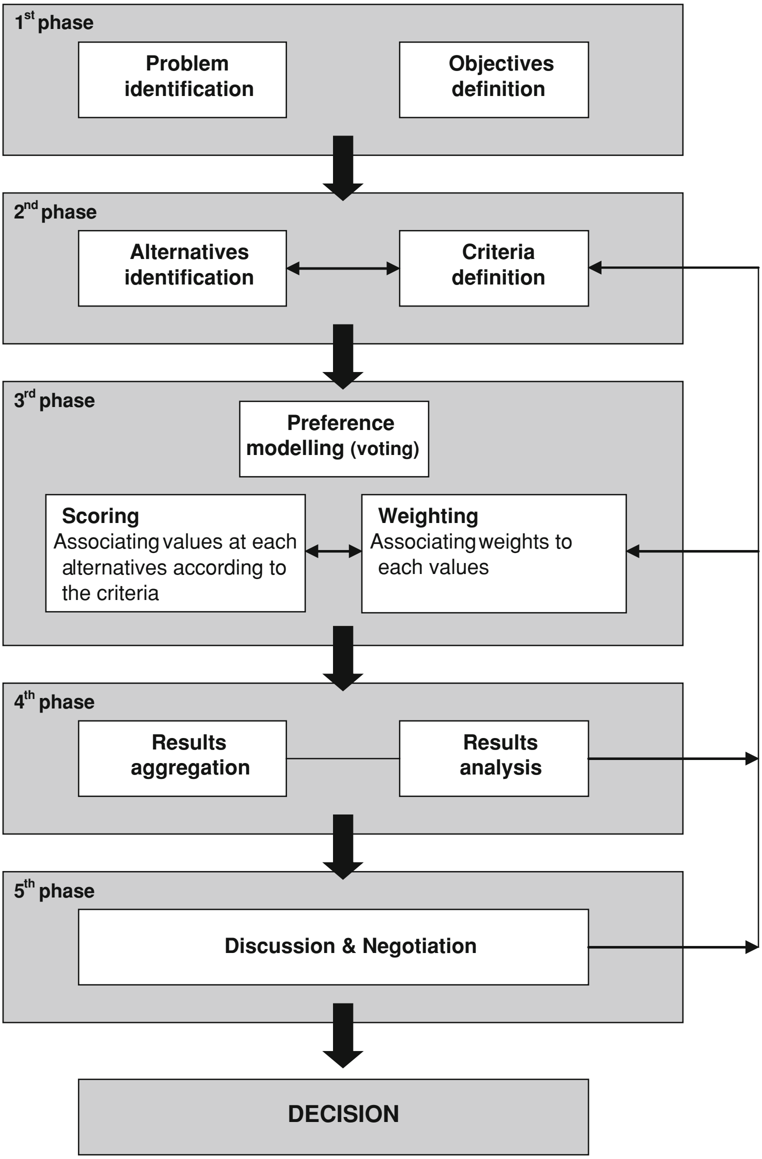

Fig. 2.1 Typical structure of the MCA

In fact, right decisions can be made only if the objectives to be achieved are clearly defined. Therefore, the goals must be specific and measurable, although they could be time-dependent, i.e. reachable in the brief, medium or long period.

Afterwards, the problem is structured fixing both the possible alternatives and the criteria to be used to evaluate and compare them.

Concerning the alternatives, two different cases are possible: in the first case they are decided a priori and the decision makers must compare them in order to indicate the most suitable ones; in the second case the possible solutions are identified by the decision makers as a result of a systematic discussion in order to assure the pursuit of the proposed goals. Often, if the solutions are not previously defined, a rational methodology may be implemented dividing the analysed process into sub-processes which may be combined together in order to obtain all the possible alternatives and which may be independently evaluated according to the fixed criteria. This approach assures to cover and to assess all the possible solutions for a specific chain.

In any case, this step must be carried out according to the experts team which must have sufficient knowledge of the problem to be solved and of the site characteristics, in order to define alternatives which can be implemented in specific situations and to fix criteria able to select the most suitable ones according to the technical level, political issues, local needs, etc. Therefore, it is profitable to assure a working group where are present both local and foreign experts, able to highlight the site peculiarities and to supply an external perspective of the situation. Reference [2] also indicates the benefits originated by teams where gender diversity, mixed nationality and different perspectives (e.g. politicians, technicians, academics, etc.) are assured.

Concerning the criteria, it must be considered that they explain the point of view of both experts and stakeholders and must be able to carry out a comparison between the alternatives, therefore they must be fixed taking into account the proposed solutions in order to highlight the differences. For instance, it is not profitable to choose the means of transport as an indicator for assessing the transport facilities and their efficacy on logistic alternatives, if in all solutions the same mean or very similar typologies are adopted.

Usually, criteria can be organised in two different ways. In a hieratical structure known as value tree, the fundamental objectives are fixed and cause the definition of the specific criteria. Alternatively, it is possible to list all the criteria and in a successive phase divide them into groups characterised by the same aim to be pursued. Anyway, it must be guaranteed that the criteria possess the following properties:

- Certain value relevance according to the objectives fixed by stakeholders;
- Understandability in order to assure the immediate comprehension of the criteria by all the decision makers who, consequently, are able to use them in the evaluation and comparison of processes regarding each proposed solution;
- Measurability, meaning that at least one indicator measurable in a qualitative or quantitative way corresponds to each criterion, otherwise the criterion must be considered non usable;
- Completeness because the criteria all together must be able to cover all the proposed aims and must be able to evidence all the possible differences. This scope could not be reached at the first stage and some lack was evident in the indicators′ definition only at the final stage when the different solutions are confronted.

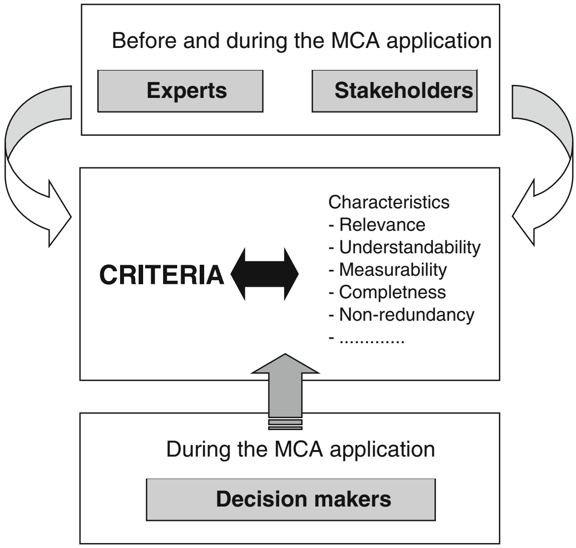

Fig. 2.2 List of criteria characteristics and indication of subjects involved in their definition

Particularly, the comparison allows verifying if the results agree with the expected outputs; if some incoherent result occurs a specific analysis must be done and eventually it may be interesting to introduce other indicators, which may better respond to the objectives. For this reason also the decision makers may contribute to modify or integrate the criteria, but only in a second phase basing on the assumptions of experts and stakeholders (see Fig. 2.2);

- Non-redundancy avoiding that two different criteria using indirectly the same indicator overestimating a specific aspect. Moreover, it is also important to check if there are some unnecessary criteria, in order to improve the economical sustainability and to reduce the time needed to develop the MCA. However, it is possible that the double counting is done because the same indicator implies several effects from different points of view: for instance, the transport distance expressed in kilometres may be a useful indicator both for environmental and economical aspects; therefore, in this case considering twice the benefits due by reduced transport distance could be considered correct and may clearly highlight the profitability associated with solutions that adopt this logistic approach.

In addition, it must be suggested to use a limited number of criteria. Firstly, problems associated with the correct understandability of certain criteria may be avoided by the stakeholders excluding those criteria, that may result as too much technical and may require a very high level of knowledge of the environmental and/or economical issues. On the other hand, a reduced size of criteria may help to limit the risks of redundancy and double counting, contributing to permit a more easy comprehension of the expected effects of certain decisions. Finally, in this way it is possible to guarantee a better communication of the obtained outputs of the MCA.