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# Public Perception of Bioenergy Chain: an Integrated Evaluation Based on Semantic Differential Approach and Multi-Criteria Analysis

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Stakeholders perception of biomass chain – in terms of socio-economic and environmental sustainability – is an important topic in territorial planning. On this subject rational and emotional aspects of perception have to be taken into account in participative approaches.
The innovation of the present research was the application of semantic differential approach for the evaluation of bioenergy chain perception. The methodology was applied for the investigation of three types of bioenergy chain (biogas, vegetable oil and woodchips). Results were aggregate and evaluated by means of multi-criteria analysis (MCA). The case study area was located in Tuscany region (central Italy). The main outputs of the work highlighted how sustainability perception is linked to the characteristics of interviewed (e.g. age and localization of residence) as well as to specific context. Moreover the research emphasized the differences among renewable energy typology for each sustainability pillars.

## 1. Introduction

The potential presence of NIMBY-mentality (Not In My BackYard) in a population proves to be as one of the major limiting factors in bioenergy chain implementation (Van Rijnsoever et al., 2015). The literature on this subject demonstrated how the most applied technique able to get over or to limit that phenomena is the information of local population about detailed characteristics of intervention (van der Horst, 2007). However, this participative approach should be developed taking into account the holistic framework of the system and the affective feature of public perception. Therefore the personal experience as well as emotional aspect of single interviewed seem to be important insights for the evaluation of sustainability perception of bioenergy chain. In this context two main problems arise: i) the evaluation of affective variables in a survey related to analysis of bioenergy perception and ii) the clear definition and assessment of sustainability.
A few studies were developed to overcome the first limits. Among recent works Dragojlovic and Einsiedel (2015), by a survey experiment, find that if people are exposed to an argument about the impact of biofuels production the potential support policies for bioenergy chain worse. Kortsch et al. (2015) demonstrated through a standardized questionnaire that the approval of biomass plants does not seem to be a permanent construct, but has to be seen in context of the experiences over time. More in general NIMBY effect has been treated in different contexts. A Benefit/Cost assessment was indicated in Maggi et al. (2013) as method to diminish risk below acceptance limit in case of energy plants modifications. A study of German and Austrian inhabitants by Wüste and Schmuck (2013) confirms as prior to bioenergy plants being built, mainly the economic aspects of bioenergy plants are considered; in addition the authors stress how local population's lack of information deal to resistance about bioenergy projects.
In order to clearly explain emotional aspect regarding bioenergy chain implementation and planning, the semantic differential (SD) approach seems to be a promising method (Osgood, 1952; see section 2.1 for more methodological details). SD was applied to evaluate public acceptance of Japanese population about $CO_2$ geological storage as well as other global warming mitigation strategies (Tokushige et al., 2007). Read et al. (2013) used SD in Australian context to assess the utility of the theory of planned behaviour in exploring intentions to oppose wind farm developments.

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About the second aspect (sustainability classification) numerous authors have attempted to define biomass chain sustainability taking into account perception of local stakeholders and decision makers (see e.g. Plate et al., 2010); however, the implementation of a holistic analysis of impacts in local and global perspectives is a difficult task (Hayashi et al., 2014). In this sense Sacchelli (2014) implemented a non-linear optimisation model to maximise acceptance of bioenergy plant in communication strategies. Additional insights about integrated analysis of bioenergy systems could be depicted in the application of multi-method approaches. Kühmaier et al. (2014) merged Geographic Information System (GIS), fuzzy logic and MCA to depict the best localization of biomass-logistic and trade centers in Austria. The optimal site for a biogas plant implementation was also depicted by Silva et al. (2014) through MCA (ELECTRE TRI method) and GIS. Perpiña et al. (2012) identified location suitable for biomass plants using spatial analysis and Analytic Hierarchy Process (AHP) in a case study in Spain. Dwivedi and Alavalapati (2009) combined SWOT analysis and AHP to study the perception of stakeholder groups regarding forest biomass-based bioenergy development in United States.
With these premises the objective of this work was to define the perception of sustainability expressed by people about three different bioenergy chains: biogas produced by processing residual waste from livestock, vegetable oil from dedicated crops, woodchip from forest residues and pruning of agricultural permanent crops. Perception was analysed taking into account the emotional aspect of respondent statement. To reach this goal a multi-method approach was applied, by means of combination of SD technique and MCA.

## 2. Methodology

### 2.1 Elicitation of perception by means of the semantic differential approach

A face-to-face questionnaire was designed for this research. The first section of the questionnaire defined the general characteristics of interviewed such as class of age (0-20, 21-40, 41-60 and >60), gender, class of yearly income (<30,000€, 30,000-60,000€ and >60,000€) as well as residence (urban center with more than 5,000 inhabitants – class 1, urban center with less than 5,000 inhabitants – class 2, urban sprawl or scattered house – class 3). In the second part of the survey the perception of the three kind of bioenergy chain was depicted by the application of semantic differential approach (Osgood, 1952).
The main advantage of this tool in respect of other stated preferences based-methods is related to the analysis of combined perception that involved both rational and emotional aspect of interviewed. The employed technique allows to measure the meaning given to a stimulus through a standardized measurement procedure. It is used to detect the structure of the attitudes that play an important role in the explanation of people mental representation. In this procedure, people are asked for their perception of the topic using pairs of antithetical attributes. In particular the semantic differential approach applied rating-scale up to a maximum of 50 antithetical couples of elements. The rating-scale is constituted by two anchor categories and an intermediate continuum (Corbetta, 2003).
The value attributed by each respondent for every scale represents the position of the perception in the "semantic space" expressed as quality (positive or negative direction) as well as power (distance from anchor point) (Maggino, 2005). The complexity of semantic space can be reduced by means of rating-scale coding. In this procedure different scales with similar meaning can be classified into an unique category. In our case study a focus on 15 rating-scales was applied. Each scale was composed by 7 positions. Then, a categorization of the above scales into three sustainability pillars was defined. Due to the lack of similar researches in literature, the antithetical attributes and the relative classification in sustainability pillars were defined through focus groups involving experts in bioenergy sector (researchers and local stakeholders). The parameters presented to respondents were reported as follows:
- Economic: cheap/expensive; improves local economy/makes local economy worse; increases real estate values/decreases real estate values; non competitive with agriculture/competitive with agriculture; low maintenance cost/high maintenance cost.
- Social: compatible with modern life/non compatible with modern life; pleasant/unpleasant; low impact on landscape/high impact on landscape; creates new jobs opportunity/does not create new jobs opportunity; socially favorable/socially unfavorable.
- Environmental: reduces pollution/increases pollution; improves environmental quality at global scale/reduces environmental quality at global scale; improves environmental quality at local scale/reduces environmental quality at local scale; low impact due to transport/high impact due to transport; renewable/not renewable.
In this context we referred to the three pillars of sustainability including political, cultural as well as technological parameters (Hacking and Guthrie, 2008).
The questionnaire were presented to citizen of Tuscany region choose as case study area. Interviewed were defined according to a stratified sample based on the above general characteristics. A total of 318 valid face-to-face interviews were collected.

**2.2 Aggregation of perception: the multi-criteria analysis**

As suggested in literature one of the most applied method to analyse complex systems with multifaceted variables is MCA. MCA was defined as "a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals and groups explore decisions that matter'' (Belton and Stewart, 2002). MCA family is in general subdivided into two categories (Buchholz et al., 2009): i) Multi Objective Decision Making (MODM) and ii) Multi Attribute Decision Making (MADM). Methods belonging to the first group aim to find the optimal solution within an indefinite set of scenarios, usually by means of optimization techniques such as linear or nonlinear programming. MADM-based tools are applied to establish the best alternative or scenario among a set of discrete possibilities. Among MADM methods the Compromise Programming (CP) (Zeleny, 1982) was applied in the present work. The CP calculates a score function for each alternative based on a "distance from an ideal point" (DIP). The strategies are then ranked according to these distances (Behzadian and Kapelan, 2015). The alternatives that are closer to the ideal solution – in other terms alternatives with values closer to zero – are the best one. Separation from ideal point *D* for each *b-th* bioenergy chain typology was calculated in terms of a distance metric (Eq. 1):

$$D_b = \frac{\left\{ \sum_{j=1}^{n} \cdot \left[ \frac{(v_{i,j} - v_{x,j})}{(v_{i,j} - v_{a,j})} \right]^m \right\}^{1/m}}{q} \tag{1}$$

where *n* is the number of *j* criteria (in our case *economic*, *environmental* and *social* sustainability pillars), $v_{i,j}$ is the ideal value for the *j-th* criterion (1 in the seven-point scale; see anchor antithetical attributes), $v_{b,j}$ is the value of the *b-th* alternative for the *j-th* criterion, $v_{a,j}$ is the non-ideal value for the *j-th* criterion (7 in the seven-point scale), *m* is the metric used in the analysis and *q* is the number of questionnaire. The magnitude of *m*, ranges between 1 and infinity. It indicates the compensatory level among different criteria (from "1" – total compensatory approach – to "∞" – total non-compensatory approach; Fattahi and Fayyaz, 2010). In this research the Euclidean distance *m=2* – that permits a partial compensatory evaluation – was applied. That choice depend on previous application in similar works based on natural resources assessment and management (Diaz-Balteiro and Romero, 2008).
The quantification of $v_{b,j}$ index was carried out as in Eq. 2.

$$v_{b,j} = \frac{\sum_{p=1}^{z} p_j}{z_j} \quad \forall p \in z \wedge \forall z \in j \tag{2}$$

where *p* is the value of the antithetical attribute and *z* is the total number of couples of antithetical attributes belonging to *j-th* criterion.

## 3. Results and discussion

The main results of elaboration are reported as follows. Figure 1 outlines the DIP for each type of bioenergy chain related to different parameters of interviewed.
Good perception of these renewable energies increase with class of age (Fig. 1a), in particular for biogas. A stabilisation or a little worsening is only stressed for the ">60 years" category. From gender point of view (Fig. 1b), females seems to perceive the three kind of bioenergy as more sustainable in comparison to males. Biogas and woodchips stress a different level of sustainability directly related to yearly income of respondents (Fig. 1c). Only vegetable oil denotes a variable trend for this parameter. An interesting aspect is the different sustainability perception of bioenergy chains linked to localisation of interviewed residence (Fig. 1d). A more positive perception of these renewable energies is highlighted for people living in rural context such as scattered houses. A focus on woodchip perception for this last category stresses how wood-based energy chain is recognised more sustainable in respect to biogas and vegetable oil for 24% and 28%, respectively.

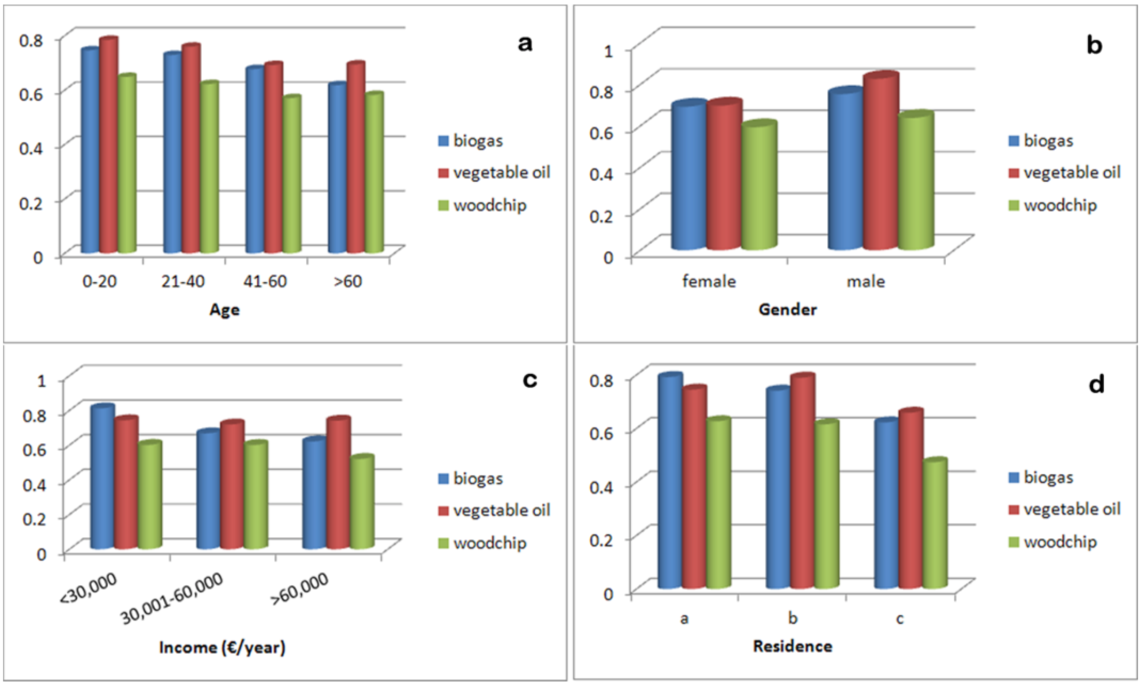


*Figure 1: Distance from Ideal Point based on bioenergy chain typology and interviewed characteristics*

Figure 2 reports the results for the whole sample of respondents. It confirms how woodchip bioenergy seems to be more appreciate in respect to biogas and vegetable oil for all sustainability pillars (Fig. 2a). Small differences are presented for appreciation of environmental impact among biogas, vegetable oil and woodchip. However an evident gap is outlined from woodchip bioenergy and biogas-vegetable oil for other parameters. Woodchip economic sustainability is recognised greater of 17 and 20% in respect to biogas and vegetable oil. In addition, woodchip social sustainability stresses an higher value of 18% and 20%, respectively. Eventually, also the aggregation of results according to Eq. 1 (Fig. 2b) demonstrates how wood-based chain is supposed the more sustainable among other bioenergy chains, in particular compared to vegetable oil.

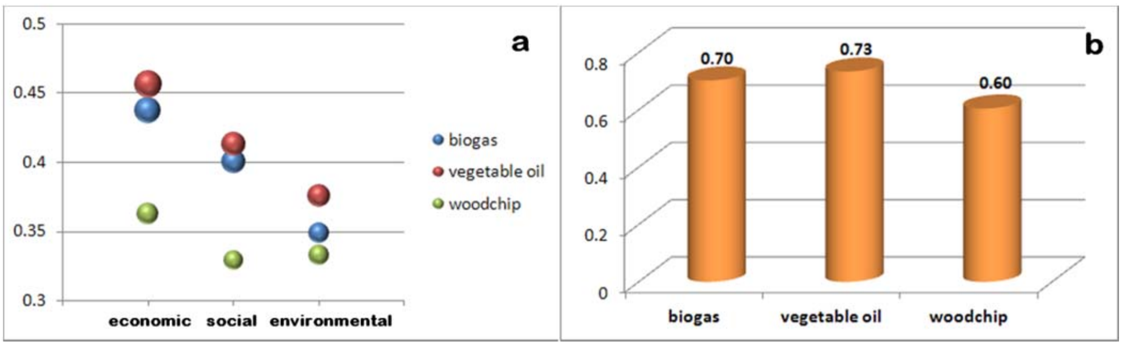


*Figure 2: Distance from Ideal Point based on bioenergy chain typology and sustainability pillar*

The above results suggest how the awareness of bioenergy chain seems to be strictly dependent to people characteristics and perception. In general, the consciousness of different typology of renewable energy (and, specifically, the recognition of their sustainability), increases with age and yearly income. This aspect stresses how the concept of "active citizenship" is revealed as a dynamic parameters that increase throughout people life, in line with Kortsch et al. (2015) statements. Familiarity with bioenergy is an additional important variable for perception analysis. As matter of fact interviewed with residence close to rural area (e.g. in scattered houses or in centres with less than 5,000 inhabitants) demonstrate an higher positive viewing of energy produced through biomass in respect to people living in major cities. Proximity to already installed power plants seems to be a further factor for a positive bioenergy chain perception. To prove this assertion the classification of Tuscany bioenergy plants has been reported in Table 1 (source: http://www.repowermap.org).

*Table 1: Classification of bioenergy plants in Tuscany*

| Plant typology | Number of plants | Percentage on total (%) |
|---|---|---|
| Biogas | 9 | 19 |
| Vegetable oil | 8 | 17 |
| Woodchip | 31 | 65 |
| *Total* | *48* | *100* |

Table 1 shows that the DIP trend and percentage partitioning of bioenergy plants follow an indirect proportion. Effectively, as it clearly emerges from particular local contexts (north Italy, Central Europe, etc.), a consolidated presence of biomass plants facilitate the knowledge transfer to stakeholders of other geographically close areas. A good level of expertise is denoted among respondents by the analysis of sustainability perception for each pillar. Environmental benefits are perceived quite similar for the three kind of bioenergy. The differences depicted for economic and social parameters seem to highlight the high unitary cost needed for biogas in case of plants realization and maintenance as well as the potential competition with local agricultural practices. In particular for vegetable oil chain a trade-off between crops for food Vs crops for energy can arise for regional context, characterized by a relevant number of high quality products.

## 4. Conclusions

Applied method seems to be an useful support for planning bioenergy chain at local scale. It appears appropriate to define guidelines for communication to stakeholders as well as information strategies for policy-makers. Semantic differential application favorites the understanding of biomass chain peculiarities to interviewed due to user-friendly language and score attribution. In this way not only objective responses of people but also emotional parameters as well as mental representation of a problem, can be assessed and quantified. Participative approaches implemented for explanation of bioenergy characteristics can be suitably preceded by proposed technique. Therefore perception of specific categories of local population can be highlighted and “ad hoc” communication strategies depicted. A correct understanding of the technical-logistical as well as economic variables can indeed promote the involvement of public and private citizens in the decision-making process, facilitating the procedure of realization of biomass plants and bioenergy chain.

Nevertheless in order to make the method a practical decision support system (DSS), additional analysis should be developed. In the MCA model the present research considered a distance metric equal to 2. A sensitivity analysis based on different level of metric could be implemented. Future lines of work should focus on comparison between SD-MCA model and other techniques in the same case study. Eventually, spatially based and geostatistic analysis could be implemented to depict important variables for bioenergy chain perception from geographic point of view.

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