Production and use of biomass from short-rotation plantations in Andalusia, southern Spain: limitations and opportunities

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Abstract

Woody energy crops from short-rotation plantations (SRP) present a high potential for development in Spain. In this paper a PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) analysis combined with AHP (Analytic Hierarchy Process) was conducted based on expert knowledge to identify the main factors conditioning the production and use of SRP biomass in Andalusia, South of Spain. According to the findings, a strategic plan to further develop the SRP sector should focus on reducing the uncertainty associated with its economic viability, developing the market and designing institutional innovations in the form of specific public norms. It is also necessary to take advantage of the opportunities faced by the sector such as the increasing importance of renewable energies in energy plans, the potential market for biomass and the climate-change abatement attributes of biomass.

Keywords: *Energy crops, woody biomass, short-rotation plantations, PESTLE, AHP.*

Résumé

Les cultures énergétiques ligneuses provenant de plantations à courte rotation (PCR) présentent un fort potentiel de développement en Espagne. Dans cet article, l´analyse du contexte PESTEL (Politique, Économique, Sociologique, Technologique, Écologique et Légal), combinée avec le PAH (Processus Analytique de Hiérarchie), a été réalisée sur la base des connaissances d'expert afin d'identifier et d'évaluer les principaux facteurs qui déterminent la production et l'utilisation de la biomasse à partir de PCR en Andalousie, dans le Sud de l'Espagne. Les résultats indiquent qu'un plan stratégique pour développer davantage le secteur de la PCR devra être axé sur la réduction de l'incertitude de sa viabilité économique, le développement du marché et la conception des innovations institutionnelles des normes publiques spécifiques. Il est également nécessaire de profiter des forces et des opportunités identifiées dans le secteur, comme l'importance croissante des énergies renouvelables dans les plans énergétiques, le marché potentiel de la biomasse et les caractéristiques environnementales de la biomasse liées à la réduction du changement climatique.

Mots-clés: Cultures énergétiques, biomasse ligneuse, plantations à courte rotation, PESTEL, PAH.

1. Introduction

Since the Treaty of Lisbon, energy has been placed at the heart of EU activity. Security of supply, respect for the environment and economic competitiveness are the cornerstones of European energy policy. The European Directive 2009/28/EC on the promotion of the use of energy from renewable sources, which is part of the Climate and Energy Package, established a 20% target for the share of energy from renewable sources in gross final consumption of energy by 2020 for the EU in general and for Spain in particular. Thus, the Spanish Renewable Energy Action Plan (PANER) (2011-2020) includes objectives consistent with the European Directive. Furthermore, in Andalusia, the largest region of Spain, the Andalusian Sustainable Energy Plan PASENER 2007-2013 aims for the contribution of renewable energy to represent 27.7% of the final regional energy consumption. Energy policy in Spain and Andalusia has been developed with three goals: increasing security of supply; improving the competitiveness of the economy; and ensuring economic, social, and environmentally sustainable development. Renewable energy can contribute positively to the three goals. The sector in Spain has left behind the launch phase of renewable energy and is in a phase of consolidation and development. The country has a strong regulatory framework to support renewable energy, the result of whose growth in recent years has been remarkable. Thus, they have grown in terms of primary energy consumption from covering a share of 6.3% in 2004 to covering 11.3% in 2010 (IDAE, 2011). Renewable energies have, therefore, enormous potential for growth in Spain (Montoya et al., 2014), since these figures are still far from the national targets. Moreover, renewable energies have shown economic results in terms of the profits generated, given their capacity to create jobs, develop rural areas, and improve the environment (Eggers *et al.*, 2009; Dinica, 2009; Soliño, 2010; Scarlat *et al.*, 2013).

Biomass in particular makes a crucial contribution to national renewable-energy targets (Gómez et al., 2010). Biomass is, among renewable energies, the source which most contributes to the energy infrastructure of Andalusia, amounting to 6.3% of the total primary energy and 78.7% of the renewable energy consumed, with a great potential at the regional level (AAE, 2012). Most of Andalusian biomass is devoted to generating electricity (45%) and thermal energy (40%) (AAE, 2013). Biomass is obtained in Spain in general and Andalusia in particular from diverse sources, such as forest waste, olive stones, and nutshells, guaranteeing an abundant supply. Residual biomass is the main renewable source such as crop and pruning wastes (Rosúa and Pasadas, 2012), as a-

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griculture constitutes one of the main economic activities in the region, with 4.7 million agricultural hectares (57% of the territory), of which about 1.4 million devoted to olive groves. However, according to García *et al*. (2012), even 100% of wastes from pruning of vineyards, olive, and fruit trees were used; together with 30% of the poplar production of biofuel production would cover only 20.2% of the heating needs in Spain, and 51.2% in Andalusia. This requires the search for other energy crops to satisfy the potential demand in a secure, environmentally friendly and competitive manner and to fulfil the objectives in EU and Spanish energy programmes (ISAPER, 2011). Among the measures that are being analysed for the promotion of energy crops are those for the introduction of woody energy species in farmland with low-productive capacity or deforested and unproductive forest areas (IDAE, 2011). In this context, biomass generation from woody energy crops takes on special importance to face this challenge given the stability and feasibility associated with its supply and it may represent a new market niche in marginal rural areas (Favero and Pettenella, 2014).

Woody energy crops from short-rotation plantations (SRP) are a form of woody-energy crop consisting of fast-growing trees cultivated and repeatedly harvested on two- or three-year cycles. The freshly harvested product can be burnt in power stations and some types of large-scale wood-fuel heating plant or be used in smaller-scale boilers when processed into more refined forms of wood fuel. SRP is considered to be a low-carbon fuel, as CO_2 emissions released during combustion will be re-absorbed by new growth. SPR are not widespread in Spain in general, or in Andalusia in particular. The area devoted to SRP is restricted to experimental plots, which have demonstrated a high potential for biomass production (AAE, 2011; Durán Zuazo et al., 2013). The major fast-growing tree species suitable for SRP in Andalusia are poplar (*Populus* ssp.), eucalyptus (*Eucalyptus* ssp.) and paulownia (*Paulownia fortunei x Paulownia tomentosa*), these woody species being the most thoroughly studied in Spain, in contrast to willow (*Salix* sp.) and black locust (*Robinia* sp.) (AGAPA, 2012; Durán Zuazo *et al*., 2013; Jiménez *et al*., 2013). Eucalyptus has traditionally supplied pulp for the paper industry while poplar has been used mainly for producing wood, pulp, and veneer although for some years it has been used for biofuels (Ciria, 2011). Poplar has raised the greatest short-term expectations, not only because of the high suitability of the biomass produced in comparison with other herbaceous energy crops, but also due to the long-standing availability of the selected material. SRP woody energy crops have a great potential in Spain in general, and Andalusia in particular, where many agricultural zones are abandoned or under risk of abandonment or have low-productivity profiles. In these zones, fast-growing woody species and short plantation cycles may contribute to the increased production of renewable energy required in Spain, contributing to the rural development of many rural areas and also offering multiple positive environmental externalities.

In this context, the present paper investigates the factors conditioning the development of SRP woody biomass in Andalusia, both in the short as well as in the medium to long term. The objective is to identify the critical negative factors that hamper a broader production and use of SRP and the positive factors that need to be bolstered. The study is based on the PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) analysis, a strategic-planning framework, combined as a novelty with AHP (Analytic Hierarchy Process), a multi-criteria method for weighting the conditioning factors. This combination is an added value of the present work from a methodological perspective, allowing a quantitative approach in strategic planning.

2. Methodology: The PESTLE/AHP framework

PESTLE analysis is a methodological framework for strategic planning in which the factors influencing a given system are grouped into six categories: Political, Economic, Social, Technological, Legal, and Environmental. PESTLE analysis can be used for a number of purposes, such as business planning, marketing strategy, and new-product development (HIA, 2011). The aim of PESTLE is to identify the factors influencing a system, their impact, and their positive or negative effects on the system (Srdjevic *et al*., 2012). Although PESTLE has been developed and focused mainly on business and companies as the 'system' of interest, some studies have recently adopted a broader view and definition of the system analysed. Hence there are some precedents focusing on a sector as a whole and the key stakeholders involved: the rural tourism sector in Latvia (Zvaigzne, 2007), the higher-education sector in the United Kingdom (Zhang *et al*., 2011), the marine energy industry of the United Kingdom (Kolios and Read, 2013), and the renewable-energy sector of Malawi (Zalengera et al., 2014). A sector as a whole, in our case the complete chain from production to the use of biomass from SRP in Andalusia, and the key stakeholders of the SRP sector, in our case essentially farmers, industry, SMEs, and consumers, may face common problems and opportunities. The specific enterprises belonging to this sector would probably face a specific problem which would need further research. However, in this paper we are interested in the large picture concerning the development potential of SRP in Andalusia.

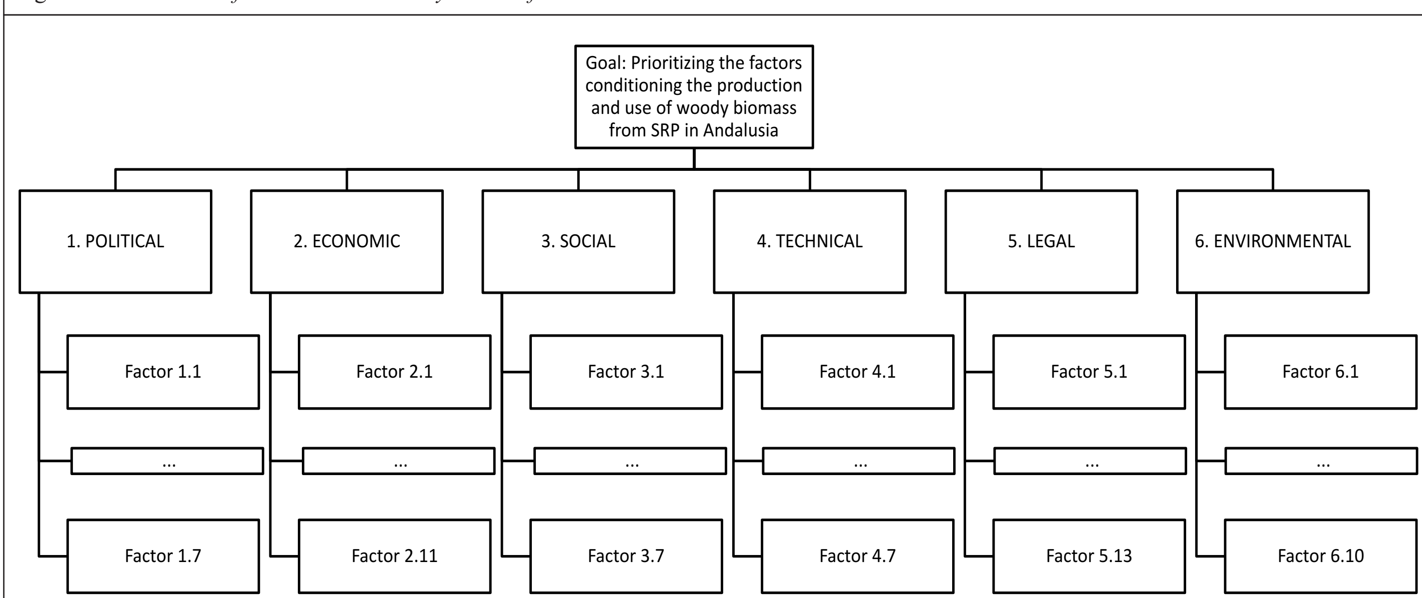
PESTLE analysis is a process that may be implemented in three steps (HIA, 2011; Srdjevic et al., 2012): 1) analysing the system and defining the influence factors; 2) evaluating the impact that each factor may already or in the future exert on the system; and 3) planning actions to minimize any threats and maximize any opportunities. In our case, the system was the production and use of woody biomass from SRP in Andalusia (S Spain), as stated above. Defining the factors influencing this system was based on an extensive literature review, including statistical, legal, normative, technical, and scientific documents. Subsequently, key actors and stakeholders actively involved in the biomass sector at regional and national level were identified and contacted to compile a long list of factors. Subsequently a focus group with 6 experts was convoked as a pre-test to refine the factors, by excluding repetitious and ambiguous statements while including relevant factors previously not considered. The experts in this pre-test had different profiles and expertise (biomass producers, professional organizations, entrepreneurs, biomass industries, SMEs, researchers, etc.) in different items related to the biomass sector, in particular woody biomass.

To structure and prioritize the factors, the PESTLE analysis, as a novelty, has been combined with AHP (Analytic Hierarchy Process) (Saaty, 1980). Although AHP has been previously combined with SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis (Kurttila *et al*., 2000), a similar framework to PESTLE, and with SWOT/PESTLE (Srdjevic *et al*., 2012), the direct combination of PESTLE and AHP is generally new, and specifically in the case of SRP biomass. Hence, the decisional structure underlying the PESTLE analysis of the SRP in Andalusia was defined as an AHP hierarchy model (Figure 1), in which the elements were: 1) Goal or overall objective: prioritizing the factors conditioning the production and use of woody biomass from SRP in Andalusia; 2) Categories of factors: Factors were grouped into the 6 PESTLE categories (political, economic, social, legal, technical and environmental); and 3) Factors: Specific issues influencing biomass from SRP (7 political, 11 economic, 7 social, 7 legal, 13 technical, and 10 environmental factors) were finally identified.

Subsequently, the priority (or impact) of each factor on the system today, i.e. in the short term, and in the future, i.e. in the medium to long term, was evaluated, as well as its likelihood of change over time. The impact evaluation is critical in PESTLE analysis, as it is usually based on qualitative approaches by using categorical scales, which presents the problem of the incommensurability of impacts and impossibility of being compared. The AHP approach was used here to make this evaluation quantitative, allowing the different types of impact to be prioritized on a ratio scale and making them commensurable and comparable. In this sense, AHP has been used to improve the assessment process in diverse techniques for strategic planning, such as Quality Function Deployment (Partovi, 2006; Ho *et al*., 2012), and in Environmental Impact Assessment (Kaya and Kahraman, 2011; Aryafar *et al*., 2013). Additionally, AHP allows the incorporation of qualitative, subjective and intangible information into the evaluation process, for instance in the form of expert knowledge, as well as quantitative and hard-data information when available (Parra-López *et al*., 2008a).

For each node of the AHP model, i.e. one element and the sub-elements depending on it, the local priorities of the sub-elements (w_L) can be evaluated based on hard data, if available, or soft data in the form of expert knowledge and/or stakeholder preferences. To evaluate our PESTLE/AHP model for SRP in Andalusia, expert knowledge was used due to the low availability of hard data for Andalusia and the complex nature of the issues investigated (technical, environmental, social, economic, etc.). In particular, 23 experts with diverse profiles and experience in the subject were interviewed (5 biomass producers, 3 professional organizations, 3 entrepreneurs, 3 biomass industries, 5 SMEs, and 4 researchers) following a structured questionnaire submitted on May 2013. Experts were asked to evaluate, according to their experience, the impacts of the categories and factors on the production and use of SRP in Andalusia for today as well as in the future, and the likelihood of change. Due to the high number of categories and factors in

Figure 1 - *AHP model for the PESTLE analysis used for SRP in Andalusia.*



some categories (higher than 7 ± 2, as recommended in AHP) the evaluation of the priorities by the experts was based on the 'direct rating' method (Forman and Selly, 2001). The rating scale ranged from 0, in the categories/factors with null priority, to 9, in those with very high priority, as defined by Parra-López *et al*. (2008b). These ratings were transformed into priorities through the 'ideal mode' method, i.e. assigning a priority of 1 to the higher rating ($w_{L(for\ max\ rating)} = 1$) and calculating the rest priorities proportionally. That is, if in a node the maximum rating of a factor equalled 8, this would have a priority of 1. If another factor had a rating of 4, this would have a priority of 0.5. Therefore, priority ranges from 0 to 1. The ideal mode is recommended in 'open models' to guarantee that the addition or removal of an 'irrelevant' element will not change the ranks of existing elements (Forman and Selly, 2001).

The local priorities for each expert (w_L) were synthesised to establish the global priorities (w_G) of each factor with respect to the goal according to each expert. This was done by weighted addition, i.e. by weighing the local priorities of the factors with the local priorities of the categories of factors (Saaty, 1980):

$$w_{G(F)} = w_{L(F,C)} * w_{L(C)}$$

where $w_{G(F)}$ is the global priority of factor F, $w_{L(F,C)}$ is the local priority of factor F with respect to the category C that it belongs to, and $w_{L(C)}$ is the local priority of category C.

Subsequently, the individual local and global priorities of all experts were aggregated through the Weighted Arithmetic Mean Method (Ramanathan and Ganesh, 1994), i.e. through the arithmetic mean of the priorities for each node:

$$w_{L(gr)} = \sum_{e=1}^{E} w_{L(e)} \text{ and } w_{G(gr)} = \sum_{e=1}^{E} w_{G(e)}$$

where $w_{L(gr)}$ and $w_{G(gr)}$ are the local and global priorities, respectively, of a given factor/category for the group; $w_{L(e)}$ and $w_{G(e)}$ are the local and global priorities of this factor/category for expert *e*, respectively; and E is the number of experts. This allowed the average priorities to be calculated according to all the experts. The average assessment of the whole group of experts is considered to be more reliable than individual assessment, thus minimizing any individual bias or lack of knowledge on any particular topic. The use of average values in group decision making is quite common in the scientific literature, as reported by Saaty (1989).

Additionally, the heterogeneity of responses between experts was analysed by *ad hoc* Agreement Index (AI) defined for each category/factor as the inverse of the variance of the priorities for the experts. For instance, for the case of the global priorities of a given factor is:

$$AI = 1 \Big/ \tfrac{1}{E} \sum_{e=1}^{E} [w_{G(e)} - w_{G(gr)}]^2$$

The greater the AI in a category or factor, the greater the consensus among experts on its priority. Priorities and agreement for local and global priorities were segmented for the categories and factors by terciles for today, future, and likelihood to change. This allowed the priorities and agreements to be clustered into three categories (low/medium/high priority/agreement), for the sake of discriminating critical categories and factors that influence the production and use of woody SRP biomass in Andalusia. Critical categories/factors are defined as those with high priority and high (strong) agreement.

3. Results and discussion

3.1. Critical categories of factors

Table 1 shows the categories of factors influencing the production and use of woody biomass from SRP in Andalusia, their local priorities and agreements referred to today (the short term), and the future (the medium to long term), as well to its likelihood of change over time. Critical categories, i.e. those with high priority and strong agreement, are marked in the corresponding columns. The economic and political categories are critical today –that is, they are of high local priority (LP = 1.0000, 0.9518, respectively) with strong agreement between experts (AI = 54.7195, 31.8823, respectively). Moreover, their high priority, i.e. their importance as conditioning the development of SRP, will continue in the future although, for economic issues, it is not so clear for all the experts (AI = 26.1132: medium agreement). The remaining categories (social, legal, environmental, and technical) are not so influential, although the opinions of the experts in general diverge, i.e. they reach medium to low agreement in these categories. In particular, the social and legal categories seem to be the least influential, in that they have low priority today and may remain so in the future. Despite its relatively low influence today (in the short term), and in the future (in the medium to long term), in the development of woody biomass from SRP in Andalusia, experts strongly agree (AI = 42.3560: high agreement) that the social category has the highest likelihood to change over time (LP = 1.0000: high priority). This may be due basically to the increasing social concern for agriculture and its impact on the environment and sustainable rural development, as stated in previous studies in the region (Salazar and Sayadi, 2011; Salazar *et al*., 2013).

3.2. Critical factors

Table 2 details for each category the factors conditioning the development of woody biomass from SRP in Andalusia, their global priorities and agreements. Critical factors are marked in the corresponding columns. Additionally, factors are classified as opportunities or threats for the development of the sector, as indicated in another column. To comment on the results and for the sake of simplicity, we will focus on the critical factors.

First of all, a set of factors are critical today and will continue to be critical in the future (Table 2). They are mainly economic and political threats related to uncertainty of a

Table 1 - *Categories of factors conditioning the production and use of woody biomass from SRP in Andalusia.*

	Today			Future			Likelihood to change		
	Local priority (LP)	Agreement Index (AI)	Critical category	Local priority (LP)	Agreement Index (AI)	Critical category	Local priority (LP)	Agreement Index (AI)	Critical category
1. POLITICAL	▲0.9518	▲ 31.8823	*	▲0.9860	▲ 31.3722	*	▼0.7299	▬ 19.6527	-
2. ECONOMIC	▲1.0000	▲ 54.7195	*	▲1.0000	▼ 26.1132	-	▼0.8291	▬ 20.7120	-
3. SOCIAL	▼0.7802	▬ 18.6682	-	▼0.8593	▲ 38.5066	-	▲1.0000	▲ 42.3560	*
4. TECHNICAL	▬0.8657	▬ 18.9706	-	▬0.9253	▬ 27.3366	-	▲0.9521	▼ 19.2349	-
5. LEGAL	▼0.8170	▼ 14.9000	-	▼0.9017	▼ 21.9711	-	▬0.8829	▲ 23.5705	-
6. ENVIRONMENTAL	▬0.8191	▼ 16.1108	-	▬0.9116	▬ 28.4055	-	▬0.9024	▼ 17.2534	-

Critical category (high priority and agreement): *, yes; -, no.
▼▬▲ = Terciles for each column: low, medium and high priority/agreement.
See text for explanation of the priority/agreement indexes.

Other factors are critical today, i.e. over the short term, but their relative relevance will decrease in the future (Table 2). The importance of the economic factors is patent again. Most of these are barriers related to low profitability, high uncertainty and costs, and vigorous competition with other crops. The lack of knowledge of the stakeholders concerning biomass policies is also hampering the diffusion and development of SRP today. The most critical factor, which could be considered a key opportunity, is to satisfy the potential of boiler installations in Spain. In fact, it is possible to install up to 40,000 biomass boilers per year, considering only the cold areas of Spain. Also it is important to highlight that 40% of homes along the Spanish Mediterranean coast are single-family dwellings and burn diesel, which could potentially change to boiler biomass (González, 2013). In descending order of global priorities, these critical factors, in detail, are:

- 2.11. Great potential boiler installation to increase national biomass consumption (GP = 0.9992 for today).
- 2.6. High requirements of SRPs of fertile and irrigated soils, spurring competition with other agricultural food crops that are more profitable over the short term (GP = 0.9676).
- 2.9. Low profitability with a high-risk investment for large electric companies (GP = 0.9388).
- 1.3. Poor knowledge of stakeholders involved in the sector of policies and plans for biomass in general, and SRP in particular (GP = 0.8996).
- 2.7. High costs of installation and assembly of pellet heating systems for the end user (GP = 0.8797).

new and limited market, and weak public support. On the other hand, the contribution of SRP to the abatement of climate change seems to be a great opportunity for the development of the sector. All these critical factors, in descending order of global priorities, in detail, are:

- 2.8. Lack of information on operating and selling costs and uncertainty of return on investment with long-term plantations (GP = 1.0000, 0.9277, for today and future respectively).
- 1.2. Lack of tools to support the production, processing, and use of biomass SRP. In particular, lack of subsidies since the beginning of the plantation to the cutting of the first rotation (2-5 years) (GP = 0.9648, 0.8606, respectively).
- 2.1. Limited supply of woody biomass from SRP and market availability in Andalusia (GP = 0.9069, 0.8922, respectively).
- 6.2. Contribution to reduced CO_2 emissions and greenhouse gases (GHG) (GP = 0.8666, 0.9156, respectively).

Table 2 - *Factors conditioning the production and use of woody biomass from SRP.*

	Today				Future				Likelihood to change		
	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Critical factor
1.1. Absence of a regulatory framework for the production, processing and use of biomass SRP.	▲0.9049	▬ 13.6425	T	-	▲0.9766	▲ 27.3704	T	*	▼0.6463	▲ 21.6387	-
1.2. Lack of tools to support the production, processing and use of biomass SRP. In particular, lack of subsidies since the beginning of the plantation to the cutting of the first rotation (2-5 years).	▲0.9648	▲ 14.5014	T	*	▲0.8606	▲ 18.0633	T	*	▼0.5712	▲ 17.2891	-
1.3. Poor knowledge of stakeholders involved in the sector of policies and plans for biomass, in general, and SRP in particular.	▲0.8996	▲ 18.8162	T	*	▲0.8522	▼ 13.0052	T	-	▼0.6698	▲ 24.6815	-
1.4. Poor promotion of the use of biomass SRP, little diffusion in information campaigns and lack of good actions at the institutional level and in the public sector.	▲0.8632	▬ 12.7289	T	-	▲0.8832	▬ 15.5721	T	-	▼0.6255	▲ 20.3840	-
1.5. Shortage of pilot and demonstration projects in abandoned and marginal agricultural land to produce biomass SRP and spread the use of best management practices and utilization in the land.	▼0.7032	▼ 7.8938	T	-	▼0.6366	▼ 9.0412	T	-	▼0.5560	▲ 18.6331	-
1.6. Lack of public investment in renewable energy compared to conventional. As the International Monetary Found recently recommended at minimum should equate this situation.	▲0.9224	▼ 10.9165	T	-	▲0.9126	▼ 12.6883	T	-	▼0.5337	▲ 15.9233	-
1.7. Importance of renewable energy in energy policy. The spread of SRP can help to achieve the regional energy planning objectives and renewable energy production.	▲0.9881	▬ 12.9229	O	-	▲1.0000	▲ 18.0134	O	*	▬0.7305	▬ 13.4930	-

2) Economic factors

	Today				Future				Likelihood to change		
	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Critical factor
2.1. Limited supply of woody biomass from SRP and market availability in Andalusia.	▲ 0.9069	▲ 16.4274	T	*	▲ 0.8922	▲ 18.5387	T	*	▼ 0.6539	▲ 16.2728	-
2.2. Low demand and low SRP biomass market development in Andalusia.	▲ 0.9089	▬ 12.2794	T	-	▲ 0.8995	▼ 13.0540	T	-	▼ 0.6576	▬ 15.1754	-
2.3. The pellets supply chain is still in development.	▬ 0.8220	▼ 9.4819	T	-	▲ 0.8559	▼ 8.0761	O	-	▬ 0.7129	▲ 15.6530	-
2.4. SRP biomass can not compete in production costs and prices with other waste biomass from woody agricultural crops abundant in Andalusia, especially olive and other tree species.	▲ 0.8512	▬ 11.8131	T	-	▬ 0.7895	▼ 9.8836	T	-	▼ 0.6145	▲ 20.0562	-
2.5. SRP biomass can not compete with other energy arable profitable cultivation during the first year of establishment in the field.	▬ 0.7707	▼ 10.0062	T	-	▼ 0.6995	▼ 8.3525	T	-	▼ 0.5968	▬ 13.9641	-
2.6. High requirements of SRPs of fertile and irrigated soils, competing with other agricultural food crops more profitable in the short term.	▲ 0.9676	▲ 17.6730	T	*	▬ 0.8518	▼ 11.2380	T	-	▼ 0.5679	▲ 17.0782	-
2.7. High costs of installation and assembly of pellet heating systems for the end user.	▲ 0.8797	▲ 20.7716	T	*	▼ 0.7363	▼ 13.3128	T	-	▬ 0.7355	▬ 13.0903	-
2.8. Lack of information on operating and selling costs and uncertainty of return on investment with long-term plantations.	▲ 1.0000	▲ 29.3805	T	*	▲ 0.9277	▲ 17.9227	T	*	▬ 0.7108	▲ 21.2296	-
2.9. Low profitability with a high-risk investment for large electric companies.	▲ 0.9388	▲ 14.4685	T	*	▬ 0.8364	▬ 13.8370	T	-	▼ 0.5881	▬ 15.0578	-
2.10. Growing importance of international markets for the export of biomass SRPs to countries with more developed legal framework and market niches.	▲ 0.8403	▼ 10.0289	O	-	▬ 0.8101	▼ 12.4912	O	-	▼ 0.6845	▲ 23.2151	-
2.11. Great potential boiler installation to increase national biomass consumption.	▲ 0.9992	▲ 15.5243	O	*	▲ 0.9374	▬ 14.4059	O	-	▲ 0.8539	▬ 14.7219	-

3) Social factors

	Today				Future				Likelihood to change		
	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Critical factor
3.1. Poor collaboration between the different actors involved in the sector: farmers, entrepreneurs, users, institutions, etc.	▬ 0.7614	▬ 13.4535	T	-	▬ 0.7772	▬ 16.9307	T	-	▲ 0.8026	▲ 17.5881	*
3.2. Low level of training, information and advice to producers and users of biomass, compared to other energy resources, in terms of management, technology and demand and market potential.	▼ 0.7409	▲ 15.5070	T	-	▬ 0.7902	▲ 24.9658	T	-	▲ 0.9081	▲ 19.8530	*
3.3. Low social awareness towards environmental and economic benefits of the use of energy from biomass, in general, and SRP obtained in particular.	▼ 0.7559	▬ 13.1506	T	-	▬ 0.7611	▲ 19.2624	T	-	▲ 1.0000	▲ 16.9296	*
3.4. Social groups opposing views on the use of biomass and its impacts: deforestation, tree fell, etc.	▼ 0.7109	▲ 14.4835	T	-	▼ 0.7164	▲ 19.6342	T	-	▲ 0.8427	▼ 8.7363	-
3.5. Major requirements and biomass user dedication: the need for storage, handling and care of the facilities, etc.	▼ 0.6857	▲ 24.0253	T	-	▼ 0.7380	▲ 20.0883	T	-	▲ 0.9052	▼ 10.4458	-
3.6. Producer resistance to change and little entrepreneurship because, among others, the high level of uncertainty in the sector.	▬ 0.8232	▲ 15.0736	T	-	▬ 0.8346	▲ 20.4271	T	-	▲ 0.8453	▲ 17.1057	*
3.7. Little concern of professionals (architects, engineers, technicians) for biomass energy compared to other European Union countries.	▼ 0.7076	▬ 13.1776	T	-	▼ 0.7223	▬ 17.0219	T	-	▲ 0.8989	▬ 13.4103	-

- 4.7. Limited development of a strategic plan to position the receiving plant biomass near production areas, in order to reduce costs in the supply chain, and ensure delivery of the product on favourable terms (GP = 0.8419).

On the other hand, experts emphasize some factors that are not critical today but which will become crucial over the future, i.e. over the medium to long term (Table 2). Mainly political and legal factors contribute to the medium to long term stimulation of the renewable-energy sector. For instance, as previously stated, the European, Spanish, and Andalusian Energy Plans aim the total contribution of renewable energy to be increased in final energy consumption. These results also emphasize the negative effects over

4) Technical factors

	Today				Future				Likelihood to change		
	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Critical factor
4.1. Lack of experience at both the farmer and businesspersons, creating uncertainty at all levels of the chain.	▬ 0.8262	▬ 12.6272	T	-	▬ 0.7802	▬ 14.8245	T	-	▲ 0.8273	▼ 11.5718	-
4.2. Lack of genetic selection programs for SRP species used, optimization of phytosanitary control, mineral nutrition, planting and watering to allow greater production of biomass per hectare and reduce unit costs.	▬ 0.7822	▬ 12.4234	T	-	▼ 0.7335	▼ 13.1064	T	-	▬ 0.7878	▼ 10.2168	-
4.3. Low introduction of new fast-growing woody species for biomass production systems in short rotation.	▼ 0.6903	▲ 19.8910	T	-	▼ 0.6485	▲ 30.9185	T	-	▲ 0.9203	▼ 10.2541	-
4.4. Scarcity of new industries and new uses for SRP biomass: Marriage with other biomass for more quality, etc.	▬ 0.8231	▲ 16.8216	T	-	▲ 0.8599	▲ 19.8790	T	*	▲ 0.9043	▲ 15.6555	*
4.5. Low spread of farming in marginal areas and on abandoned land to contribute to its economic, social and environmental sustainability.	▬ 0.7974	▲ 18.1306	T	-	▬ 0.8318	▲ 19.0593	T	-	▲ 0.8840	▬ 13.9324	-
4.6. Inadequate logistics (machinery and pre-treatment in the field, planting, methods of collection, transport and storage) and its associated processes in plant biomass supply.	▬ 0.8327	▼ 11.6997	T	-	▬ 0.8071	▬ 14.4770	T	-	▲ 0.8421	▼ 11.2899	-
4.7. Limited development of a strategic plan to position the receiving plant biomass near production areas, in order to reduce costs in the supply chain, and ensure delivery of the product on favourable terms.	▲ 0.8419	▲ 14.9752	T	*	▲ 0.8597	▬ 15.8505	T	-	▬ 0.7760	▲ 16.2209	-
4.8. Little investigation of the use of twigs of crops to shorten the return period.	▼ 0.6780	▼ 10.9306	T	-	▼ 0.6810	▼ 12.2508	T	-	▬ 0.7047	▼ 11.1339	-
4.9. Little research to adapt plantation for the automation of collection processes and treatment.	▬ 0.8332	▼ 11.7308	T	-	▬ 0.7818	▬ 14.2793	T	-	▲ 0.8788	▬ 13.5686	-
4.10. Poor adaptation of local boiler to biomass produced locally.	▬ 0.8185	▬ 14.0292	T	-	▲ 0.8618	▬ 14.3802	T	-	▬ 0.7911	▼ 12.3009	-
4.11. Poor dissemination of micro-generation.	▼ 0.6398	▼ 11.7462	T	-	▼ 0.6381	▼ 11.9242	T	-	▼ 0.6632	▬ 13.3352	-
4.12. Few studies about possibilities for biofuels from 2nd, 3rd, and 4th generation.	▼ 0.6216	▼ 10.9472	T	-	▼ 0.6012	▬ 13.6024	T	-	▬ 0.7037	▼ 9.7079	-
4.13. Few studies about gasification and possibility of injecting gas to natural gas network.	▼ 0.6286	▼ 10.4035	T	-	▼ 0.6170	▼ 11.7193	T	-	▼ 0.6464	▼ 10.7210	-

5) Legal factors

	Today				Future				Likelihood to change		
	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Opport. / Threat	Critical factor	Global priority (GP)	Agreement Index (AI)	Critical factor
5.1. Lack of territorial contracts and long-term SRP exploitation.	▬ 0.7584	▼ 10.6874	T	-	▼ 0.7611	▬ 13.9379	T	-	▬ 0.7289	▲ 15.2490	-
5.2. Scarcity of R&D and studies in the context Andalusia on the profitability of crops, current demands and offers and potential markets.	▼ 0.7526	▼ 10.6827	T	-	▼ 0.7370	▬ 14.0494	T	-	▬ 0.7285	▬ 13.1933	-
5.3. Lack of technological and institutional innovations in the sector: certifications systems, new and best practices, new products, new uses, logistics centres of biomass treatment and distribution , etc.	▬ 0.8052	▼ 11.7436	T	-	▬ 0.8203	▲ 17.7061	T	-	▲ 0.8688	▬ 15.2406	-
5.4. Lack of biomass related companies having special emphasis on R&D with institutional support and difficulty involving them in R&D.	▬ 0.8247	▬ 13.8402	T	-	▬ 0.8085	▲ 20.1423	T	-	▬ 0.7984	▬ 13.3439	-
5.5. Lack of a competitive stable framework for electricity generation as in other countries.	▲ 0.8661	▬ 12.5561	T	-	▲ 0.8861	▬ 17.3035	T	-	▬ 0.7697	▼ 10.9366	-
5.6. Lack of a plan for changing from carbon power stations to biomass power stations as in other countries.	▬ 0.8349	▬ 11.8967	T	-	▲ 0.8797	▲ 17.4500	T	*	▬ 0.7895	▬ 12.8518	-
5.7. Lack of extension and training programs at all levels of the chain: qualified installers, specialization courses, etc.	▲ 0.8627	▼ 10.2394	T	-	▲ 0.8661	▼ 12.7732	T	-	▲ 0.8659	▬ 14.5570	-

the long term if specific actions are not undertaken to promulgate the legal framework for developing biomass and specifically SRP production and processing. In descending order of global priorities, all the critical factors, in detail, are:

- 1.7. Importance of renewable energy in energy policy. The spread of SRP can help achieve the regional energy-planning objectives and renewable-energy production (GP = 1.0000 for the future).
- 1.1. Absence of a regulatory framework for the production, processing and use of biomass SRP (GP = 0.9766).
- 5.6. Lack of a plan for changing from carbon power stations to biomass power stations as in other countries (GP = 0.8797).
- 4.4. Scarcity of new industries and new uses for SRP biomass: combination with other biomass for more quality, etc. (GP = 0.8599).

Finally, certain factors have a high likelihood of changing over time (Table 2). These critical factors represent threats that need to be overcome especially over the medium to long term. These are related mainly to social issues, such as social awareness of environmental sustainability of SRP, the training and knowledge and resistance to change of farmers, and the collaboration among stakeholders involved in the SRP sector. All these critical factors, in descending order of global priorities, in detail, are:

- 3.3. Low social awareness towards environmental and economic benefits of the use of biomass energy, in general, particularly SRP (GP = 1.0000 for likelihood to change).
- 3.2. Low level of training, information, and advice to producers and users of biomass, compared with other energy resources, in terms of management, technology, and demand and market potential (GP = 0.9081).
- 4.4. Scarcity of new industries and new uses for SRP biomass: combination with other biomass for more quality, etc. (GP = 0.9043).
- 3.6. Producer resistance to change and little entrepreneurship because of, among other factors, the high level of uncertainty in the sector (GP = 0.8453).
- 3.1. Poor collaboration between the different actors involved in the sector: farmers, entrepreneurs, users, institutions, etc. (GP = 0.8062).

Conclusions

The development of renewable energy is a priority commitment of the EU, Spanish, and Andalusian energy policy. Renewable energy has many positive effects on the society in general: for example, the sustainability of their sources, reduced emissions, technological change, the possibility of moving towards more distributed forms of energy, reducing dependence energy and the trade-balance deficit, increasing the level of employment and rural development. The use of biomass from short-rotation plantations (SRP) constitutes a renewable source of energy more environmentally sustainable than fossil fuels and constitutes an opportunity to develop a sector of enormous potential in many rural areas of Andalusia (southern Spain). The development of the production of this type of biomass as renewable source of energy may help achieve the objectives of the EU, Spanish, and Andalusian energy plans and programmes. The potential development of the boiler may represent a catalyst for the development of the demand over the short term. Also, the explicit recognition of the environmental benefits of biomass from SRP, related to climate-change abatement, is a major issue by which to justify public support for this cultivation and use. The public support to energy crops is patent in Andalusia where diverse political measures aim to develop a program to promote energy crops, with the participation of public and private sector, encouraging the development of agro-energy in the region. However, a specific plan or specific norms within energy crops, for woody biomass from SRP is missing and would be desirable.

SRPs is still a relatively new sector in the region, and additionally to new opportunities for the future, its development is conditioned by many limitations and barriers. The critical factors hampering the development of woody-biomass production under short-rotation management and its use in Andalusia are mainly economic and political threats that are expected not to change markedly over the medium to long term. The main efforts to develop and promote SRP should focus on reducing the uncertainty associated to its economic viability, developing the market and designing institutional innovations in the form of specific public norms for biomass in general and short-rotation woody crops in particular. These institutional innovations need to accommodate the new challenges associated with the technical innovations faced by all stakeholders in the SRP sector. Therefore, it is necessary to define how to foment the developments of the sector, in general, and the new industries, define quality standards, and specify contractual forms among the agents of the sector. In addition, there is a need to test and demonstrate the good economic performance of SRP for farmers and investors. Topics of special interest to be investigated are profitability, costs, subsidies, and potential markets. Additionally, demonstrating the technical viability of SRP in marginal lands, not in competition with food cultivations, is of the highest priority.

In fact, although there are several research and development advances in the field of energy crops, in general, and woody biomass from SRP, in particular, at the Spanish and Andalusian level, these experiments require a period of years to render conclusive results about the economic and technical impact of the development of SRP. In general, there are still underdeveloped points in the learning process on the implementation of energy crops (genetics, crop itineraries, machinery, and methods of use) and management of forest and agricultural remains (equipment and methods). In Spain, in particular, there is little experience in co-combustion processes, highly developed in other European countries. At economic level, a sharp increase is forecasted in the renewable energy sector in Spain, especially wind power, hydraulic power, and PV solar energy, whereas in the case of biomass a slow increase is expected. The specific economic and technical impact of biomass SRP is therefore uncertain and requires further research.

From a methodological perspective the use of AHP allowed a transparent and quantitative approach to the PESTLE analysis. It provides a mathematical rationale for the quantitative evaluation, comparison and aggregation of the priorities of the different elements of the PESTLE analysis. In any case, some questions require further investigation, such as the consideration of the interrelations between the conditioning factors. For further improvement of our knowledge, future research could be undertaken using other methods (e.g. ANP, Analytic Network Process) for this specific case study or for similar decision-making situations in the bioenergy sector.

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