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Full Research Article

Analysing the economy-wide impact of the supply chains activated by a new biomass power plant. The case of cardoon in Sardinia

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Abstract. This study investigates the impact on the economy of Sardinia (Italy) generated by a new biomass power plant fed by locally cultivated cardoon. The cardoon also serves the production of biopolymers. The impact is assessed at an economy-wide level using two multiregional closed Input-Output models, which allow us to take into account the entire supply chain activated and the supra-local effects generated by trade across local industries. The effects are computed under alternative scenarios simulating different levels of substitution of existing agricultural activities with the new activity (cardoon). Results show positive and locally significant impacts in terms of value added and employment. However, these impacts are substantially influenced by the degree of substitution. Results also suggest that there are specific territorial areas that are more sensitive to negative effects induced by substitution.

Keywords. Multiregional I-O model, biomass energy, supply chains, cardoon, Sardinia.

JEL Codes. R11, R15, Q42

1. Introduction

This study concerns a project for the construction of a biomass power plant at Porto Torres in Sardinia, an Italian region. The plant, having a power of 135 MWt, is expected to use about 250 thousand ton/year of biomass (straw) deriving from the local cultivation of cardoon (*Cynara cardunculus*) for the production of electricity and thermal energy. Moreover, the project contemplates the extraction of vegetable oil from the cardoon for the production of biopolymers as an alternative to petroleum-based plastics. The objective of the project is thus twofold: reducing the use of fossil fuels and stimulating local economy by cultivating cardoon.

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The present paper is aimed at assessing the local and supra-local economy-wide impacts deriving from the implementation of the power plant and, in particular, from the consequent activation of the cardoon supply chain within the specific agricultural and economic conditions of Sardinia. The methodology adopted consists of multiregional Input-Output (I-O) models that compute impacts in terms of value added and employment at both local and supra-local levels. Therefore, only socio-economic impacts are of interest here, while environmental implications, which can be particularly relevant in such a case, are not considered. Impacts derive from all the backward linkages that the biomass power plant will activate to guarantee its functioning, including the provision of biomass, and from the production and sale of oilseeds. They also come from possible substitution of existing agricultural activities that the introduction of the cardoon might cause in local economies.

Impacts are computed under alternative hypotheses about the land use associated with the new cardoon production. A scenario assumes that the cardoon will be established on uncultivated and suitable land (currently unutilized or that will be abandoned within few years). A further scenario hypothesises that all the land required by the cultivation of cardoon replaces pre-existing agricultural production. Another and more realistic scenario considers a mixed case where only a part of the land to be allocated to cardoon is unutilized while the remaining part substitutes existing activities.

The analysis of biomass power plants is a relatively recent topic. However, there is already a quite wide and well-established literature on the assessment of their overall impacts. Most of the relevant studies concentrate on what seems to be the most important concern underlying renewable energy, i.e. overall environmental implications (UCSUSA, 2011). Though such implications are beyond the scope of this paper, there are two major aspects faced by those studies that are also relevant to the present study. A first aspect regards the need for assessing all processing stages, from production of raw materials to distribution of energy. In environmental studies, this assessment is carried out by adopting a Life Cycle Assessment (LCA) framework (Heller *et al.*, 2004). A second aspect is concerned with the need for a spatially explicit analysis, based on the consideration that both magnitude and direction of impacts are not only localised but also differentiated across space (Höltinger *et al.*, 2014). Moreover, in these studies, there is an increasing awareness that all impacts have to be carefully taken into account for a proper evaluation. They are environmental as well as social and economic impacts with a focus on the entire production process, on the one hand, and on the local/spatial implications, on the other hand (Madlener and Vögtli, 2006). With reference to this kind of integrated socio-economic and environmental assessment (Ministry of Agriculture and Land – British Columbia, 2007), an increasing number of studies, evaluating economic impacts of biomass power plants, have been recently carried out. Following the abovementioned directions, these studies take the whole "from-biomass-to-energy" supply chain into account and explicitly consider local specificities and the consequent differential impacts (Kaffka *et al.*, 2011).

To perform such economic assessment, regional multisectoral models have been consistently adopted. Some studies use Computable General Equilibrium (CGE) models (Deloitte Access Economics, 2014), while others employ multiregional Input-Output (I-O) models. Among the latter, we can mention, in particular, the IMpact Analysis for PLANning (IMPLAN) I-O models (Timmons *et al.*, 2007). Both CGE and I-O models provide rich details in terms of local/regional interdependences and, therefore, of differential impacts. One of the main differences is that I-O models disregard possible impacts on prices. However, in the case of local medium-size plants, one may reasonably suppose that these impacts are not significant and can be therefore neglected. Since no major price impacts are expected in the case under study, we decided to adopt a multiregional I-O approach. This is a well-established and standardised methodological framework. Nevertheless, it was applied in a non-traditional way by assessing impacts associated with scenarios related to different degrees of crop substitution. This approach can be assimilated to sensitivity analyses performed by previous studies to assess the robustness of results (Abdoulmoumine *et al.*, 2012). However, the novelty here is that the use of I-O methodology goes beyond the mere sensitivity analysis as it looks at policy implications of a biomass power plant in Sardinia induced by different levels of crop substitution.

The rest of this article is organised as follows. The next section shortly describes the area under investigation. Section 3 illustrates the methodology adopted, the data used and how alternative scenarios have been modelled. Section 4 provides results under different scenarios whereas the last section offers some concluding remarks and suggestions for further research.

2. The area under study

The area under investigation is the Northwest portion of Sardinia, Italy. In particular, the project for the construction of a biomass power plant involves the municipality of Porto Torres, where the production of bioenergy and biopolymers will be carried out, and eight main local districts that have been identified as possible areas of cultivation of cardoon (Figure 1). These districts are: Anglona, Gallura, Goceano, Marghine-Barbagia, Mejlogu, Montacuto, Nurra-Sassarese-Romangia (where Porto Torres is located) e Planargia-Montiferru. These areas comprise about one hundred municipalities, which were regrouped on the basis of common historical, geographical and productive characteristics. The localisation of these areas is motivated by the need to rationalise the costs of transferring cardoon to the biomass power plant (and thus to reduce environmental impact related to road transportation), take advantage of strong socio-economic relationships between the northern part of Sardinia with the industrial site of Porto Torres and contrast negative dynamics of the agro-food sector in these areas.

Some general indicators about socio-economic characteristics of the various local districts provide interesting evidence on the substantial diversity across the areas under consideration (Table 1). Some territories, especially the coastal ones, reveal a significant degree of urbanization (Nurra Sassarese Romangia) and a presence of manufacturing industries (Marghine Barbagia and Gallura). Most territories, however, are characterized by low population density, depopulation, aging and high incidence of agricultural activity, though residual and incapable of ensuring the same productivity and profitability of other sectors. A common aspect is that agriculture in these areas has undergone a profound transformation in recent decades characterized by extensification and progressive abandonment.

The different territorial characteristics affected the identification of the areas potentially available for the cardoon. A study based on Land Suitability Classification (FAO, 1976) distinguishes the available land in five different classes of suitability characterized by different levels of productivity and profitability. It concludes that the area that can be allo-

Figure 1. The area under study, Sardinia, Italy (municipal administrative level)

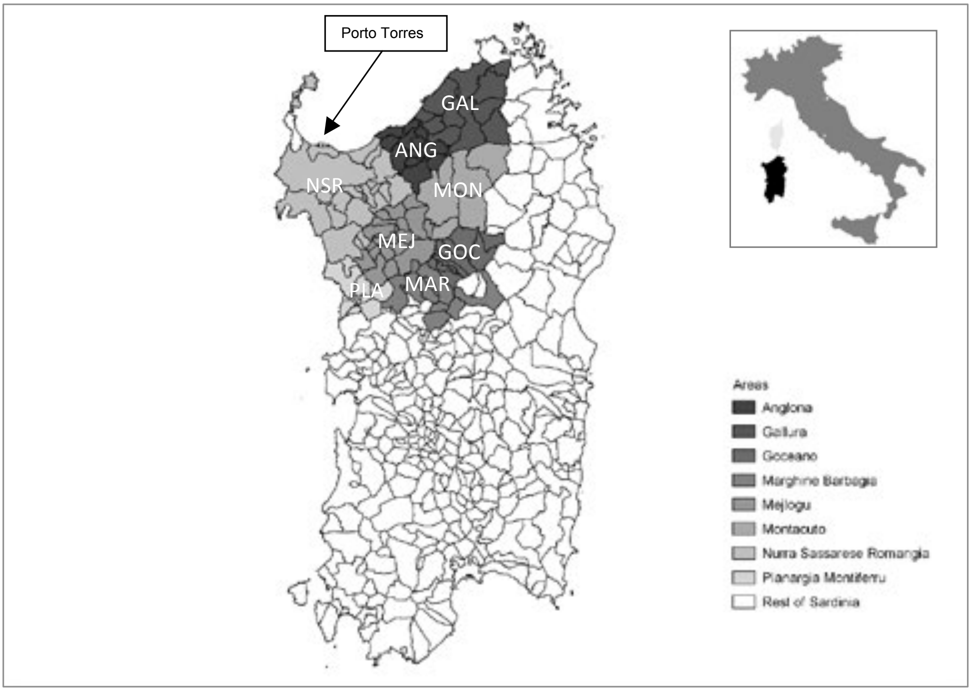

Table 1. Main socio-economic indicators of the local districts involved in the project, Sardinia, Italy.

District	Pop. (2011)		Employees (2008)			Var. % farms 2000-10	UAA per farm (2010)	Var. % UAA 2000-10
	per Km^2	Var. % 2001-11	% of Pop.	% in agr.	% in manif.			
Anglona	46.1	-0.2	28.1	8.0	7.2	-50.6	29.9	5.5
Gallura	29.5	-1.0	41.0	4.7	16.3	-50.5	26.5	-6.9
Goceano	24.5	-9.6	30.0	16.9	9.8	-47.6	30.3	-12.5
Marghine Barbagia	40.1	-7.2	38.4	7.5	26.5	-44.5	33.5	15.0
Mejlogu	24.9	-9.1	31.6	17.2	13.6	-52.1	39.3	5.4
Montacuto	23.7	-6.2	32.1	9.7	9.0	-31.2	41.5	21.3
Nurra Sassarese Romangia	138.8	4.0	33.5	4.3	8.2	-47.7	13.4	-1.5
Planargia Montiferru	39.8	-3.2	31.3	15.3	6.8	-49.0	27.5	11.2

Source: authors' own elaboration on Istat (2001a,b; 2012a,b,c,d); 2008 data are estimated.

cated to the cultivation of cardoon amounts to more than 72 thousand hectares, 11% of total available area and corresponding to a potential quantity of biomass of 825 thousand tons, far beyond the needs of the plant (250 thousand tons). The study also identifies the quantity of biomass attributed to each district and that of oilseeds obtainable by cultivating cardoon, which was estimated as 11% of biomass (Table 2). The area to be used for the cultivation of cardoon can be indirectly estimated by dividing planned production by average productivity levels. It amounts to over 22 thousand hectares, of which about 70% concentrate in the districts of Nurra Sassarese Romangia, Mejlogu and Montacuto.

Table 2. Area and production of cardoon in the local districts involved in the project, Sardinia, Italy.

District	Area		Production			
			Biomass		Oilseeds	
	ha	%	tons	%	tons	%
Anglona	1,482.2	6.7	17,340	7.0	1,907	7.0
Gallura	750.4	3.4	7,163	2.9	788	2.9
Goceano	1,066.3	4.8	10,732	4.3	1,181	4.3
Marghine Barbagia	2,163.3	9.8	21,175	8.5	2,329	8.5
Mejlogu	4,741.9	21.5	54,762	22.1	6,024	22.1
Montacuto	3,544.3	16.1	35,786	14.4	3,936	14.4
Nurra Sassarese Romangia	6,791.6	30.8	86,163	34.7	9,478	34.7
Planargia Montiferru	1,529.7	6.9	15,129	6.1	1,664	6.1
Total	22,069.7	100.0	248,250	100.0	27,308	100.0

Source: authors' own elaboration.

3. Methodology: impact evaluation

3.1 The multiregional closed I-O models

The I-O methodology allows the assessment of the overall impact generated in an economy by a shock in the final demand (Miller and Blair, 2009). It is commonly used to assess the socio-economic benefits produced by a given agricultural project or investment (Bonfiglio and Esposti, 2014) and can be very useful whenever the objective is to evaluate the overall impacts generated by linkages along supply chains. The application of this methodology in the field of bioenergy is not new. See for instance English *et al.* (2004), Madlener and Koller (2007), Perez-Verdin *et al.* (2008), Herreras Martínez *et al.* (2013) and Wang *et al.* (2013).

In this study, estimation of the impacts generated by the cardoon supply chain was made by using two closed 37-sector 9-region I-O models: a traditional demand-driven model and a mixed-variable one. The regions analysed are the eight districts where the cardoon will be cultivated in addition to the rest of Sardinia. Unlike the traditional model, the mixed-variable I-O model assesses the impact that a variation of output, rather than of final demand, produces on a given economy. This is possible by making the output of given sectors and the relevant final demands exogenous and endogenous to the model, respectively. In spite of some differences in terms of construction and a higher complexity associated with mixed-variable models, the mechanism through which the effects propagate through-out the sectors is the same so making the results perfectly comparable (more simply, the relevant impacts can be added). The only difference lies in the nature of initial shock, which is the final demand in a traditional model while it is the output in a mixed-variable model.

Both models are closed with respect to the household sector. This allows us to estimate three kinds of effects: direct, indirect and induced effects. The former coincide with the initial variation of final demand (or output in the case of a mixed-variable model) whereas indirect effects derive from the existence of backward linkages among sectors. Supposing an increase in the final demand (or output) of a given sector, these effects are those which are indirectly produced by the initial increase. This variation causes an increase in purchases from other sectors, which are therefore forced to adjust their level of production to a higher level of input demand. In addition, induced effects come from increases in labour income that translate into an increase in household consumption and, in turn, in the output of sectors which adjust to a higher level of final demand. Finally, both models present the benefits of a multiregional approach, particularly the capability of capturing spatial effects among industries located in different regions, i.e. interregional spillover and feedback effects. The former are changes in exporting regions induced by regions that purchase inputs from outside to satisfy internal requirements, while the latter are those effects that return to the importing regions since they can also be exporting regions for others. For instance, the region that has been initially involved by a variation of final demand (or output) could purchase inputs from another region. This latter could increase the level of production to satisfy external requirements. This increase is part of spillover effects. Moreover, the exporting region could in turn purchase inputs from the importing region. The change in output that this brings about in the importing region represents a feedback effect.

Since the traditional I-O model is well known in literature, here we shortly present only the mixed-variable one. Consider an economy made by two regions (R, T) and three sectors (i,j = 1, 2, 3), of which two are intermediate sectors and one is an institutional sector represented by households. Now suppose that we want to estimate the impact of an output variation in sector 1 of both regions. The model can be formulated as follows:

$$\begin{bmatrix} Y_1^1 \\ X_2^1 \\ Y_1^2 \\ X_2^2 \\ y \end{bmatrix} = \mathbf{M}^{-1}\mathbf{N} \begin{bmatrix} X_1^1 \\ Y_2^1 \\ X_1^2 \\ Y_2^2 \\ y_x \end{bmatrix} \text{ with } \begin{cases} \mathbf{M} = \begin{bmatrix} -1 & -a_{12}^{11} & 0 & -a_{12}^{12} & -k_1^1 \\ 0 & \left(1-a_{22}^{11}\right) & 0 & -a_{22}^{11} & -k_2^1 \\ 0 & -a_{12}^{21} & -1 & -a_{12}^{22} & -k_1^2 \\ 0 & -a_{22}^{21} & 0 & \left(1-a_{22}^{22}\right) & -k_2^2 \\ 0 & -h_2^1 & 0 & -h_2^2 & \left(1-h_3\right) \end{bmatrix} \\ \mathbf{N} = \begin{bmatrix} -\left(1-a_{11}^{11}\right) & 0 & a_{11}^{12} & 0 & 0 \\ a_{21}^{11} & 1 & a_{21}^{11} & 0 & 0 \\ a_{11}^{21} & 0 & -\left(1-a_{11}^{22}\right) & 0 & 0 \\ a_{21}^{21} & 0 & a_{21}^{22} & 1 & 0 \\ h_1^1 & 0 & h_1^2 & 0 & 1 \end{bmatrix} \end{cases} \tag{1}$$

where Y_i^R indicates the final demand of sector i in region R, X_i^R the output of sector i in region R, y is the total labour income and y_x the labour income paid by other institutions for services offered by households. Looking at matrices **M** and **N**, a_{ij}^{RR} a regional input coefficient, i.e. products of sector i in region R purchased as inputs from sector j in region R and a_{ij}^{RT} an interregional trade coefficient expressing products of sector i in region R purchased as inputs from sector j in region T. In other words, it represents exports from sector i in region R to sector j in region T, or rather imports of sector j in region T from sector i in region R. Yet, h_i^R is a labour income coefficient, expressing the share of labour income on sector i's output and k_i^R is a consumption coefficient, expressing the share of income paid by households for purchasing commodity i produced in region R.

To determine the output impact on the overall economy generated by a variation of output of sector 1 in both regions ΔX_1^1 and ΔX_1^2 the matrix $\mathbf{M}^{-1}\mathbf{N}$ is multiplied by the vector $\left[\Delta X_1^1, 0, \Delta X_1^2, 0, 0\right]^{-1}$. To calculate the impact in terms of value added, model (1) must be modified as follows:

$$\begin{bmatrix} Y_1^1 \\ V_2^1 \\ Y_1^2 \\ V_2^2 \\ V_3 \end{bmatrix} = \left(\mathbf{M}\hat{\mathbf{v}}^{\mathbf{-1}}\right)^{\mathbf{-1}}\mathbf{N} \begin{bmatrix} X_1^1 \\ Y_2^1 \\ X_1^2 \\ Y_2^2 \\ y_x \end{bmatrix} \tag{2}$$

where V_i^R is value added of sector i in region R, V_3 equals value added received by households for services offered to households themselves (domestic services), $\mathbf{v} = \ 1, \mathrm{v}_2^1, 1, \mathrm{v}_2^2, \mathrm{v}_3$ v_i^R is value added of sector i in region R per output unit and v_3 is value added received by households for domestic services per labour income unit. Note that the model does not give information on variation of value added in sector 1 whose output is exogenous. To find the corresponding change in value added, the following formula, based on a linear relationship between output and value added, is applied: $\Delta V_1^R = \Delta X_1^R / v_1^R$.

Analogously, for assessing the impact in terms of employment, model (1) becomes:

$$\begin{bmatrix} Y_1^1 \\ E_2^1 \\ Y_1^2 \\ E_2^2 \\ E_3 \end{bmatrix} = \left(\mathbf{M}\hat{\mathbf{e}}^{\mathbf{-1}}\right)^{\mathbf{-1}}\mathbf{N} \begin{bmatrix} X_1^1 \\ Y_2^1 \\ X_1^2 \\ Y_2^2 \\ y_x \end{bmatrix} \tag{3}$$

where E_i^R is employment of sector i in region R, E_3 equals employment in the household sector for services offered to households themselves (domestic services), $\mathbf{e} = \ 1, \mathrm{e}_2^1, 1, \mathrm{e}_2^2, \mathrm{e}_3$ e_i^R is the employment of sector i in region R per output unit and e_3 measures employment in the household sector for domestic services per labour income unit. Like income model, even employment model does not give information about sector 1 whose output is exogenous. To find the relevant change in employment the following formula is applied: $\Delta E_1^R = \Delta X_1^R / e_1^R$.

3.2 Data and regionalisation procedure

The starting point for the construction of the multiregional I-O models is a 2008 37-sector I-O table of Sardinia (Italy) produced by IRPET (Regional Institute of Economic Planning of the Tuscany).[1] The table, evaluated at basic prices, was first aggregated into 35 sectors to guarantee correspondence with sectoral and territorial detail of the available employment data.[2] Next, it was disaggregated into the territories under study using a three-stage regionalisation procedure (Bonfiglio, 2006).

The first stage consists in applying a location quotient to estimate regional input coefficients[3] and total imports of each region from the rest of Sardinia. We used the Augmented Flegg *et al.* Location Quotient[4] (AFLQ) (Flegg and Webber, 2000) since it shows to be superior in comparison with other location-quotient-based techniques. Its superiority is mainly related to its capability to minimise the differences between estimated and true multipliers and thus to estimate more reliable impacts (Bonfiglio and Chelli, 2008; Bonfiglio, 2009). This is due to its specific properties. In fact, it has been designed to solve an important drawback of traditional location quotients, i.e. the overestimation of I-O coefficients (and so underestimation of regional imports), through better modelling of regional and sectoral specialisation. A more reliable estimation of regional imports is particularly important in multiregional I-O models where trade relationships between regions play a significant role.

The AFLQ was calculated using 2008 estimated employment data at a municipal level (then aggregated at a district level), distinguished by sector. Given the lack of official information on employment disaggregated at municipal and sector levels for the year 2008 (i.e. the reference year of the I-O table), data on employment, with the exception of agriculture, have been estimated using 2001 data on employees of local units coming from the last available census (ISTAT, 2001a). Data on non-agricultural workers were then updated to reflect 2001-2008 changes in levels of working-age resident population at a municipal

[1] In Italy, there are no official regional I-O tables. For this, they are generally derived starting from the national I-O table published by ISTAT and by integrating all existing superior data at a regional level to increase their reliability. As to Sardinia, it was decided to use an I-O table built by IRPET, which has a long and recognized experience in the construction of I-O tables at both regional and multi-regional levels, which are perfectly consistent with the system of ISTAT/Eurostat territorial economic accounts.

[2] Specifically, sector "Manufacture of chemicals and chemical products" has been aggregated with sector "Production of pharmaceutical, chemical-medicinal and botanical products" and sector "Publishing, audiovisual and broadcasting activities" with sector "Telecommunications".

[3] The location quotient was directly applied to sectoral flows, which have been preliminarily regionalised using employment ratios at a sectoral level.

[4] The AFLQ is based on the use of a parameter that allows reduction in the tendency of I-O coefficients, derived through location quotients, to overestimate local production. In this study, we chose a value of 0.36, since it has the highest probability of being the most reliable in different regional contexts (Bonfiglio, 2009).

level.[5] About the agricultural sector, the 2001 figures have been replaced with information on family and continuous non-family employees resulting from the 2010 census on agriculture (ISTAT, 2012b). Employees were finally adjusted by a nonlinear optimization technique[6] using 2008 data on total employees related to 45 labour local systems (ISTAT, 2012d) and employees by sector resulting from regional economic accounts (ISTAT, 2012c) as constraints.[7]

The second stage uses a gravity model to allocate total imports among regions. The model assumes that the probability of attraction exerted by a given region is an indirect function of the distance from other regions[8] and a direct function of its ability to attract flows of goods and services, approximated by its sectoral size in terms of employment. The first two phases are repeated recursively for all districts under consideration then obtaining a preliminary version of a (35-sector) x (9-region) I-O table of Sardinia.

The last stage consists in inserting all available superior data and applying a nonlinear optimization technique to remove possible discrepancies with the starting I-O table. This technique was applied to the entire multiregional table including the quadrants of primary payments, distinguished in value added and other payments, and of final demand, disaggregated into household consumption and other components.

As regards primary payments, value added at a municipal level has been preliminarily estimated using employment coefficients (ratios between municipal workers and regional workers operating in given sectors) adjusted using the simple location quotient. Estimates were then adjusted by applying a nonlinear optimization technique constrained to information on value added by sector resulting from the regional I-O table and superior data on value added at a provincial level distinguished by macro-sectors (ISTAT, 2011). The value added by municipality and by sector thus obtained was then aggregated by district and added into the table as superior data. Labour income, which is a part of value added, was estimated starting from regional economic accounts, since the relevant information is missing in the regional I-O table. Specifically, it was calculated by multiplying sectoral value added reported in the regional table by the ratio between labour income and value added resulting from economic accounts. It was therefore assumed that the incidence of labour income on value added is the same in all districts. The other components of value added were calculated as a residual. To estimate the remaining payments, the ratio between sectoral value added by district and total sectoral value added was used.

Regarding the quadrant of final demand, household consumption was initially derived by multiplying value added by the ratio between household consumption and value add-

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[5] As for the year 2008, we used ISTAT pre-census data on resident population in municipalities.

[6] Non-linear optimization procedures used in this study adopt a cross-entropy method (Golan *et al.*, 1994), which is based on the minimization of the entropic distance between the initial matrix of estimates and the final matrix under given constraints in terms of accountancy and related to availability of superior data.

[7] 2008 ISTAT data on employment of Sardinian local labour systems slightly differ from those resulting from regional economic accounts. The difference is about 9 thousand employees in less. To ensure consistency between the two information sources and thus ensure convergence of the optimization procedure, sectoral data from economic accounts have been adjusted to make the total coincide with that of local labour systems.

[8] The distances between districts used in the gravity model were calculated as geodesic distances between centres of each area. We adopted geodesic distances rather than other commonly used distances such as simple straight lines in order to take account more appropriately of higher distances due to shape of the Earth. For the calculation of distances, we used geographic data at a municipal level, which come from the ENEA archive (ENEA, 2002).

ed by sector resulting from the regional I-O table, while the other components of final demand were estimated using value added ratios.

The result of this optimization procedure is a balanced table, consistent with the regional one, from which sectoral outputs by district can be easily derived by adding up columns. Outputs were then used to convert intersectoral flows into input and trade coefficients.

In order to estimate both the impacts related to the production of biomass for the power plant and those associated with the production and use of oilseeds, we also added two new sub-sectors connected with the cultivation of cardoon in each district involved: the biomass and the oilseeds sectors. Therefore, the final multiregional I-O table is a 37-sector table.

The addition of new sectors requires the computation of the relevant coefficients (regional input coefficients, interregional trade coefficients, employment, labour income, value added and household consumption coefficients). In this regard, we used the balance sheet for the whole production of cardoon provided by the project and distinguished by territorial area. It provides data about revenues from the sale of oilseeds and biomass, direct payments, purchase of seeds, fertilisers, chemicals, mechanical and transport services, financial costs and profits. Regional input coefficients have been derived by dividing purchases of inputs by outputs, which equal total revenues. Value added coefficients have been calculated by dividing the sum of financial costs and profits by outputs. As the balance sheet does not distinguish between the two products, biomass and oilseeds, we estimated the coefficients of these two sub-sectors by applying output (revenues) ratios to the coefficients of the cardoon. Moreover, it was assumed that the inputs necessary for the cultivation of cardoon are purchased locally within each district. This implies that interregional trade coefficients (extra-local purchases or sales) of these new sectors in each district are null.[9] The relevant employment and labour income coefficients are zero because the project assumes that the cultivation of cardoon will rely on agricultural contractors. Impacts in terms of labour income and employment related to the cultivation of cardoon are thus produced indirectly through purchases of mechanical services from the agricultural sector. Also the corresponding coefficients of household consumption are null since the project does not contemplate the direct sale of products from the cultivation of cardoon to consumers. As regards oilseeds sub-sector, the project establishes that the relevant output is entirely used to produce bio-polymers. We modelled this activity by including the expected intermediate sales from oilseeds sub-sector of each district to sector “Rubber and plastics” located in the district of Nurra Sassarese Romangia within the multiregional I-O table.

3.3 Alternative scenarios

The hypothesis that maximizes impact (corresponding to the full-additional scenario) assumes that the cardoon will be cultivated on unutilized and suitable land and therefore

[9] In the cases where a sector producing inputs necessary for the cultivation of cardoon was not present in a district, it was supposed that inputs are purchased from an existing sector of the closest district. In these cases, interregional trade coefficients are not null.

will not cause any substitution of other crops. In this case, the benefits of the cardoon supply chain will be full since the cardoon adds to existing agriculture. However, this hypothesis is hardly tenable for most local districts. In fact, according to 2010 agricultural census data, only in the district of Gallura there is potentially available area that can be used for cultivating cardoon (that is, unutilized agricultural area plus set-aside land) (Table 3). In all other districts, in order to assure adequate provisions to the biomass power plant, it would be necessary to replace existing crops. On average, about 33% of the area that is necessary for the cardoon should be subtracted from other uses.

Table 3. Available unutilized agricultural area and required cardoon area in the various districts of Sardinia (Italy), 2010.

Area	Available Area (ha)			Utilized Agricultural Area to be replaced	
	Unutilized agricultural Area	Set-aside	Total	ha	% of area for cardoon
Anglona	1,176.22	0	1,176.22	305.99	20.6
Gallura	2,230.51	757.52	2,988.03	0	0.0
Goceano	411.93	74.73	486.66	579.68	54.4
Marghine Barbagia	988.05	152.68	1,140.73	1,022.52	47.3
Mejlogu	2,479.14	0	2,479.14	2,262.77	47.7
Montacuto	1,083.76	587.48	1,671.24	1,873.06	52.8
Nurra Sassarese Romangia	4,866.44	1,603.49	6,469.93	321.68	4.7
Planargia Montiferru	561.27	80.28	641.55	888.16	58.1
Total	13,797.32	3,256.18	17,053.50	7,253.90	32.9

Source: authors' own elaboration on ISTAT (2012b).

The full-additional scenario supposes that when the biomass power plant will be operative, after a limited initial period where alternative biomass will be imported, all necessary and suitable land for feeding the plant will be available owing to progressive release of abandoned land. It is evident that this process of progressive release might not be complete when the plant will become operational, thus making substitution necessary.

In order for substitution to occur, however, there should be convenience in cultivating cardoon. One possible reason could be related to higher profitability compared with other crops. However, such convenience can be hardly represented within the adopted approach, since, in the I-O models we used, agricultural sector aggregates several activities. Moreover, prices are included within I-O flows and are supposed to be constant. Nonetheless, there could be other important reasons of convenience in cultivating cardoon. One relates to supply contracts, which are likely to be stipulated with farmers in order to assure constant provision to the industrial site of Porto Torres. These contracts will fix prices and quantities over given periods, so reducing the risk of market volatility. This risk reduction could induce farmers to replace even crops that are averagely more profitable but particularly subject to price volatility. Convenience could also be explained with the relative simplicity in cultivating cardoon. In fact, several operations can be easily mechanized and can be attributed to contractors specialized in offering mechanical services. This process of productive deactivation could be favoured by progressive ageing of farmers operating in the area under study. Under these hypotheses, substitution can be effectively modelled by the approach adopted (see section 3.4).

Crop substitution can have compensating effects with respect to the gross benefits generated by the cardoon supply chain. In principle, these effects can even offset all gross benefits and, therefore, they have to be carefully taken into account in performing impact evaluation.

To measure both gross and net impacts associated with a different degree of crop substitution, three scenarios were simulated:

1. *Full-additional scenario* (no substitution): it is based on the hypothesis that the cardoon adds to existing agriculture by occupying unutilized land suitable area.
2. *Partial-substitution scenario*: it assumes that a part of the area, which is necessary for the cultivation of cardoon, will be taken from already used agricultural area. This represents the most realistic hypothesis.
3. *Full-substitution scenario*: it supposes that all the area to be allocated to cardoon comes from currently used agricultural area.

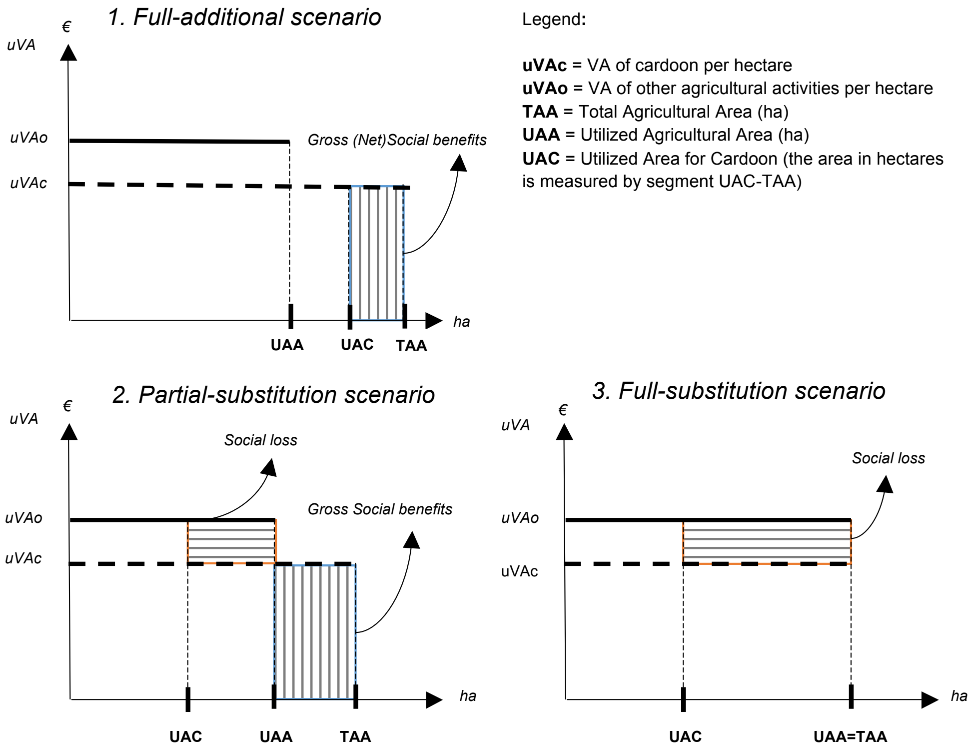
Simulating different levels of substitutions also allows the identification of a break-even point, i.e. that level of substitution at which the benefits of the cardoon supply chain are offset by the implicit (or opportunity) costs generated by the replacement of agricultural activities. For lower costs there are still benefits whereas for higher costs there will be increasing losses.

A graphical illustration of these scenarios may be helpful to clarify the key differences among them (Figure 2). This representation only considers value added (VA) impacts and assumes that the value added per hectare associated with the cardoon is lower than that related to other agricultural activities. If TAA (Total Agricultural Area) is higher than UAA (Utilized Agricultural Area) and the available area for new activities (TAA – UAA) is larger than UAC (Utilized Area for Cardoon), we have the full-additional scenario where all the VA impacts generated by the cardoon (represented by a solid area) are additional and correspond to the gross (net) social benefit generated by the project.

A second and more general case occurs whenever TAA-UAA>0 but UAC>(TAA-UAA), identifying the so-called partial-substitution scenario. In this case, the new activity generates an economy-wide impact in terms of VA that is partly additional and, for the remaining part, competitive with the benefits produced by the agricultural activities replaced by the cardoon, so generating a loss that compensates gross benefits. The net social benefit can thus be either positive or negative. The larger the competitive land (i.e. the greater the area subtracted by the cardoon and measured by UAA−(TAA-UAC)), the lower the net social benefit. A special case occurs when the additional VA equals the lost social VA thus making the net social benefit equal to zero. The break-even point measures that degree of land substitution that makes this special case occur.

A third case arises whenever TAA equals UAA. In such a circumstance, all the UAC replaces units of UAA and we have the full-substitution scenario where there might be a social loss produced by the replacement of existing agricultural activities with the cardoon.

Figure 2. Diagram describing the three scenarios adopted.



The level of substitution simulated in these scenarios is measured as a percentage of reduction in the output of the agricultural sector, corresponding to the value of the UAA potentially allocable for the cultivation of cardoon in replacement of existing activities. Reduction in output was estimated by multiplying the hectares used for the production of cardoon by the average unit value of agricultural output. The latter, which is a measure of land productivity (in value) and differs in the various districts, was obtained by dividing agricultural output, deriving from the multiregional I-O table, by the UAA surveyed in 2010.

3.1 Modelling impacts

Estimation of impacts in terms of value added and employment was made by applying the two multiregional I-O models described previously. Under the full-additional scenario, we used a traditional demand-driven model to assess the impact produced by requirements for inputs (such as biomass, machinery maintenance, water, waste disposal, transport, etc.) that are necessary to guarantee the functioning of the plant. It is assumed that the power plant purchases inputs only from the sectors of the district where it operates (Nurra Sassarese Romangia), except for purchases of biomass, which, instead, comes from various districts. Furthermore, it was supposed that only a share of total fixed and variable expenses made by the power plant concern the local economy and thus produce local impacts. Project expenses addressed to local sectors and necessary for managing the power plant were allocated to corresponding I-O sectors using ISTAT Ateco 2007 classification (ISTAT, 2009). They were modelled as positive changes in final demand of the sectors involved. We also adopted a mixed-variable model to evaluate the impact generated by the production and sale of oilseeds, modelled as a positive change in the output of oilseeds sub-sectors related to the cultivation of cardoon in each district. Total impact of the cardoon supply chain is thus the sum of these two impacts.

Under substitution-based scenarios, we used the mixed-variable model to estimate the effects of a decrease in agricultural output corresponding to the level of substitution. This impact offsets that estimated under the full-additional scenario. The parameters used and related to agriculture are average values represented in the I-O table. This hypothesis seems consistent since how farmers will react in terms of land allocation is unknown. As already remarked, they are likely to substitute worse activities in terms of profitability, provided that there will be substitution, but could even replace more profitable activities for reasons related, for example, to market volatility and risk aversion, technical simplicity and ageing. Moreover, the activities replaced could be more or less integrated with the rest of economy, thus having different I-O coefficients. Therefore, the average coefficients represented by the I-O table allow us to take account of these extremes avoiding unrealistic hypotheses about the kind of agricultural activities that could be replaced.[10] In this way, however, the effects generated by substitution and estimated by the model could overestimate the actual impact; hence, they should be considered as an upper limit of potential effects induced by substitution.

4. Results

The impacts induced by the cardoon supply chain on the local economy under different scenarios significantly differ across districts. With reference to value added impacts, in the case of no substitution, the project generates an annual increase of 20.4 mio €, equivalent to an average of 0.07% of 2008 value added of Sardinia (Table 4). Most impact, however, is absorbed by the district of Nurra Sassarese Romangia. This is because, in this area, there are most project operations related to the functioning of the biomass power plant in addition to the cultivation of cardoon. The other districts are instead involved only by the provision of biomass and oilseeds. Nevertheless, this project can be particularly important for less developed areas, such as Mejlogu and Montacuto, as indicated by the relevant and relatively higher shares of local value added generated by the cardoon supply chain.

Under the hypothesis of partial substitution, about 30% of the benefits generated in terms of value added would be lost. Goceano is the district with the highest decrease in benefits. In this district, the loss of value added equals 27% of initial benefits produced by the cardoon. All the other territories would continue to benefit from the cardoon, par-

[10] In any case, within an I-O model, the replacement of agricultural activities having average characteristics can also be justified economically by assuming redistribution of the components of value added due to a reduction in profits, which become lower than the profits related to the cardoon, and a corresponding increase in other components such as labour costs, net taxes and depreciation. In this way, coefficients remain unaltered but there are incentives to substitution.

ticularly Gallura and Nurra Sassarese Romangia, owing to a higher availability of unutilized land. It is interesting to note that Gallura would lose about 3% of benefits although there is no substitution in this district. This occurs for the spatial interdependence among regions: a decrease in production in a region can generate negative effects in other regions because of reciprocal sectoral linkages.

Table 4. Impacts produced by the cardoon supply chain in terms of value added, Sardinia, Italy.

Area	Benefits per scenario				Break-even point (% of hectares replaced)	Substitution elasticity of impact
	Full Additional (000 €)	% VA (2008)	Partial Substitution (% of full impact)	Full Substitution (% of full impact)		
Anglona	856.1	0.21	77.8	-7.5	93.0	1.075
Gallura	463.9	0.08	97.2	-34.5	74.4	1.345
Goceano	494.5	0.27	-26.9	-134.2	42.7	2.342
Marghine Barbagia	971.6	0.24	70.0	35.3	154.6	0.647
Mejlogu	2,508.7	0.64	15.7	-78.0	56.2	1.780
Montacuto	1,602.0	0.40	30.4	-32.8	75.3	1.328
Nurra Sassarese Romangia	9,166.0	0.22	93.9	4.0	104.1	0.960
Planargia Montiferru	653.4	0.28	6.6	-62.0	61.7	1.620
Rest of Sardinia	3,766.1	0.02	90.8	69.5	327.9	0.305
Sardinia	20,482.3	0.07	71.4	-2.2	97.8	1.022

Source: authors' own elaboration.

Under the full-substitution scenario, the value added impact generated by the cardoon supply chain would be neutralised, also producing a loss that is equivalent to 2% of initial benefits. Most districts would be penalized. This is particularly true for Goceano, where the loss of value added is 134% of the initial benefits produced by the cardoon in this district. The areas that instead would maintain benefits are Marghine Barbagia, which preserves 35% of benefits, Nurra Sassarese Romangia, which restrains 4% of positive impacts, and the rest of Sardinia, with about 70% of benefits.[11] The break-even point indicates that the overall benefits of the cardoon supply chain would be neutralised in correspondence to about 98% of substitution.[12] In other words, only if in each district 98% of the hectares that are necessary for the cultivation of cardoon were taken from already cultivated land, the benefits of the cardoon supply chain would be eroded completely. For lower values, there will be net benefits.

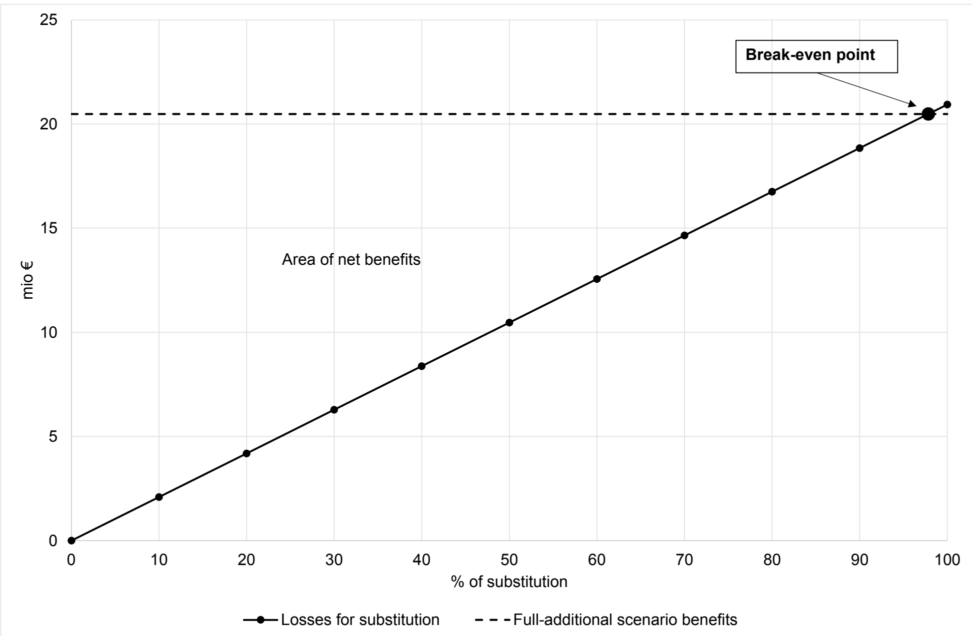
[11] The capability of the rest of Sardinia to maintain, in the case of substitution of agricultural activities, a high percentage of impacts produced by the cardoon supply chain is related to the fact that this area is only indirectly affected by the substitution that happens in the districts.

[12] Since there is proportionality between levels of substitution and reduction in value added/employment (this can be easily observed in Figures 3 and 4), the break-even point can be calculated by dividing the impact estimated under the full-additional scenario by the reduction in value added/employment associated with a decrease by 1% in agricultural output due to substitution (i.e. slopes of the straight lines represented in Figures 3 and 4).

At a district level, it can be observed that the break-even point is mostly under 100%. As expected, it is higher in those cases where there are higher net benefits. In Marghine Barbagia, Nurra Sassarese Romangia and the rest of Sardinia the break-even point is higher than 100%. This apparently odd result is an indicator of how far we are from offsetting the benefits and, therefore, of how large these benefits are. For instance, a value of 154.6% (i.e. the result obtained for Marghine Barbagia) means that if the hectares replaced in each district were 54.6% larger than the hectares that are actually required for cultivating cardoon, local benefits would be eventually offset. This is consistent with the result that, in those districts, a part of benefits remains even under the full-substitution scenario.

Substitution effects and the break-even point can also be displayed graphically. It can be noted that, as the level of substitution increases, the area of net benefits tends to shrink proportionally (Figure 3). The critical area (that is, that degree of substitution at which benefits are entirely offset and there are losses) is particularly small. In fact, the break-even point is collocated almost at the end of the straight line that displays the reduction in value added due to increasing substitution. The so-called "substitution elasticity of impact" indicates the percentage of reduction in benefits due to 1% of substitution of agricultural activities (Table 4).[13] It is also a measure of the degree of sensitivity

Figure 3. Benefits and losses in terms of value added generated by the cardoon supply chain in Sardinia, Italy.



Source: authors' own elaboration.

[13] This elasticity is calculated by dividing the loss of benefits induced by 1% of substitution by the benefits generated by the full-additional scenario (and then multiplied by 100).

of the economy to substitution. The higher this indicator, the higher the level of sensitivity of the economy to possible replacement of agricultural activities for the cardoon. As regards value added, the substitution elasticity of impact for all Sardinia is 1.022. This value indicates that per each percentage point of reduction in agricultural output due to substitution (or per each 1% of hectares that are replaced), the overall value added generated by the cardoon supply chain diminishes by 1.022%. In the case of full substitution, the reduction in benefits would thus amount to 102.2%. This means that the benefits obtained under the full-additional scenario are entirely offset (100%) and an additional loss (2.2% of those benefits) is also generated. The substitution elasticity of impact ranges from 0.305, in the rest of Sardinia, to 2.342 in Goceano, which therefore reveals to be the most sensitive to possible substitution.

With reference to employment, full-additional scenario generates an increase in employment of about 400 employees, which corresponds to 0.06% of total employment (Table 5). Also in this case, most impact concentrates on the district of Nurra Sassarese Romangia, although benefits, relatively to local economy, are again higher and more significant in less developed areas. On the contrary, substitution causes higher negative impacts than those recorded for value added. This can be explained by relatively higher employment multipliers (lower productivity) and relatively lower value added multipliers (low profitability) that characterize agriculture in the districts considered. In fact, under partial substitution, 40% of overall benefits are lost or rather about 160 jobs are no more created. The areas that show the highest employment impact are in particular Gallura, Nurra Sassarese Romangia, the rest of Sardinia and, to a lower extent, Anglona and Marghine Barbagia with just 18% of the benefits estimated. The other areas, especially Goceano and Planargia Montiferru, experience losses.

Table 5. Impacts produced by the cardoon supply chain in terms of employment, Sardinia, Italy.

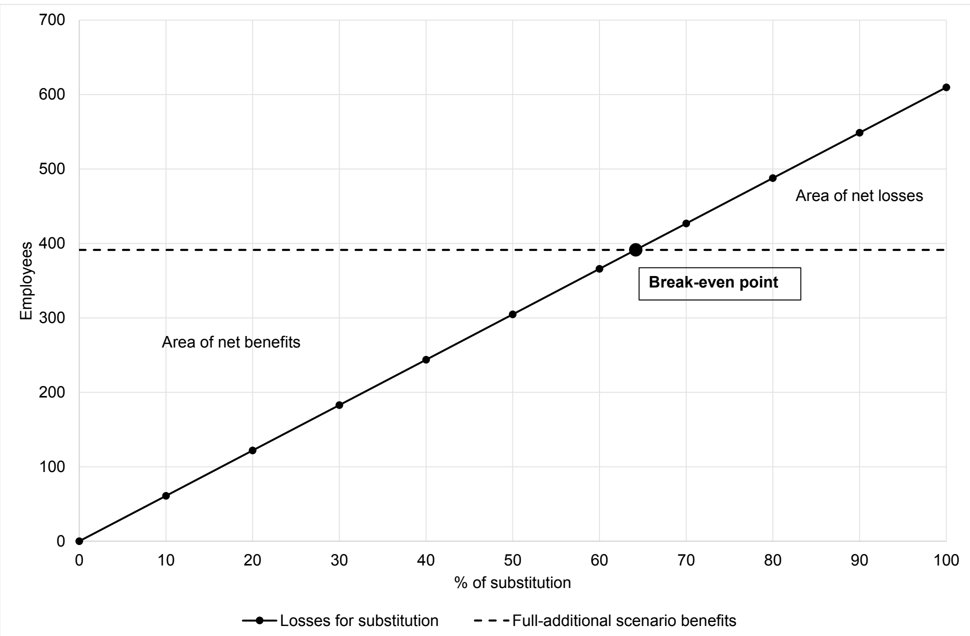
Area	Benefits per scenario				Break-even point (% of hectares replaced)	Substitution elasticity of impact
	Full Additional (employees)	% empl. (2008)	Partial Substitution (% of full impact)	Full Substitution (% of full impact)		
Anglona	11.4	0.17	51.5	-135.0	42.6	2.350
Gallura	8.5	0.06	93.8	-104.5	48.9	2.045
Goceano	5.4	0.15	-149.4	-361.0	21.7	4.610
Marghine Barbagia	20.8	0.21	18.3	-74.5	57.3	1.745
Mejlogu	24.6	0.38	-74.2	-267.2	27.2	3.672
Montacuto	20.1	0.27	-31.0	-150.2	40.0	2.502
Nurra Sassarese Romangia	212.8	0.25	92.3	-37.8	72.6	1.378
Planargia Montiferru	12.6	0.25	-113.6	-269.6	27.1	3.696
Rest of Sardinia	75.1	0.02	90.6	68.6	318.1	0.314
Sardinia	391.3	0.06	60.0	-55.8	64.2	1.558

Source: authors' own elaboration.

In the case of full substitution, on the contrary, there would be a net loss of more than 200 employees. All areas would be penalized except for the rest of Sardina that will maintain about 69% of employment impact. In line with these results, the break-even point is 64%, by far lower than that of value added. It indicates that it is sufficient to replace less than two-thirds of the agricultural area necessary for cultivating cardoon to see the benefits of the cardoon supply chain disappear. In all districts, the break-even point is under 50%, with the exception of Marghine Barbagia (57%) and Nurra Sassarese Romangia (73%). Graphically, the break-even point related to Sardinia is collocated about in the middle of the straight line, which describes the decrease in employment caused by increasing substitution. For this, two separate areas are clearly identified: an area of net benefits (to the left of the break-even point) and a more limited area of net losses (to the opposite side) (Figure 4). Finally, as expected, the substitution elasticity of impact is higher than that of value added and equals 1.558. It varies from 0.314, in the rest of Sardinia, to 4.610 in Goceano (Table 5).

These results can be very helpful for policy makers in evaluating more correctly the socio-economic implications of the construction of a biomass power plant in Sardinia. Firstly, they measure possible negative effects in addition to potential positive impacts for the economy. In fact, they indicate to what extent crop substitution induced by the introduction of the cardoon in Sardinia will produce compensating effects with respect to the

Figure 4. Benefits and losses in terms of employment generated by the cardoon supply chain in Sardinia, Italy.



Source: authors' own elaboration.

gross benefits generated by the cardoon supply chain. Compensation in terms of value added may vary from 30% to 100% with possible but restrained reductions in the current levels of value added, while that related to employment may go from 40% to full offset and a relatively significant reduction. Secondly, they give important information about the sensitivity of different areas to potential substitution effects. In other words, they assist policy makers in identifying territorial contexts where possible negative impacts induced by the introduction of the cardoon could be more significant locally. From this point of view, Goceano as well as Planargia Montiferru and Mejlogu are the areas that would suffer to a greater extent from the replacement of existing agricultural activities with the cardoon in terms of both value added and employment.

5. Concluding remarks

This study assessed the economy-wide impact produced by the supply chains, in particular that of the cardoon (biomass and oilseeds), activated by a biomass power plant within the local economy of Sardinia, an Italian region. For this aim, two multiregional closed I-O models were adopted. The areas considered are eight districts where the cultivation of cardoon will be introduced. Three different scenarios were analysed in relation to the degree of substitution of existing agricultural activities: full-additional, partial and full-substitution scenarios.

Under the hypothesis of no substitution, results show positive and locally significant impacts in terms of value added and employment, though limited in comparison with the overall economy size. They are the sum of direct, indirect and induced effects generated by intersectoral and interspatial linkages of the Sardinia economy. In addition, findings show that in the case of a partial substitution, which represents the most realistic scenario, most benefits will be maintained especially in terms of value added. With reference to employment, however, negative effects would be higher. Full substitution would exacerbate these impacts, by producing net losses in most districts in terms of value added, and in all districts in terms of employment. From a territorial standpoint, results also show that there are specific areas that are more sensitive to negative effects induced by substitution of existing agricultural activities with the cardoon.

The present analysis offers valuable policy implications since it gives objective and empirical support to public choices concerning the suitability or desirability of private investments and, eventually, the need and the extent of a public contribution in this respect. In particular, this study provides policy makers with useful information to assess the impact that the implementation of a biomass power plant can have on the economy of Sardinia. In fact, it takes into account not only its potential benefits but also those opportunity costs (substitution effects) that this project can generate.

Nonetheless, results should be taken with caution. Firstly, they can be affected by the data used, in particular the coefficients of the adopted multi-regional I-O models. The latter represent estimates, as far as they can be representative, of real economic flows recorded in a given period and may therefore change over time. Secondly, and more importantly here, results depend on the approach we adopted to compute economy-wide impacts, which suffers from some limitations. In particular, two aspects should be stressed. A first aspect is concerned with the hypothesis that the cardoon will replace "average" agricultural activities, represented, within the I-O model, by coefficients of the entire agricultural sector, which aggregates activities having different production characteristics. This assumption may overestimate negative impacts induced by substitution. A second aspect is related to the hypothesis that the introduction of the cardoon and possible substitution of other agricultural activities do not generate any effect on prices as the I-O approach is based on constant prices. This assumption may be consistent only with small changes within the economy and, therefore, with small impacts generated by the new investment. Although overall results seem to confirm this, there is however the possibility that effects are locally overestimated since results show relatively significant impacts related to some specific areas.

Finally, it is also worth reminding that an important concern about this kind of power plants and, therefore, a major challenge for policy makers is about their negative social and environmental implications in addition to overall socio-economic impact. From this point of view, the adopted approach is not helpful unless it is being appropriately adapted and extended towards an integrated assessment of all impacts, including the environmental ones, generated by this kind of investments.

Further research is therefore needed to cope with these data and methodological limitations by suggesting suitable extensions and modifications of the approach here adopted.

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