Analyzing 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 the Italian region of the Sardinia generated by a new biomass power plant that will be fed with locally cultivated cardoon. The cardoon will also serve the production of biopolymers. The impact is assessed at an economy-wide level using a multiregional mixed-variable closed I-O model that allows taking into account the whole supply chain activated and the cross-regional effects generated by trade across local industries. The effects are computed under alternative scenarios simulating different degrees of substitution of existing agricultural productions with the new activity (the cardoon). Results show how the overall impact may be substantially influenced and even reversed according to the level of substitution.

1. INTRODUCTION: THE AREA UNDER STUDY

This study concerns a project for the construction of a biomass power plant at Porto Torres in Sardinia, an Italian region.[1] 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 the 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.[2] The objective of the project is thus twofold: reducing the used quantity of fossil fuels and stimulating local economy by cultivating cardoon.

The area investigated is the North-western portion of the Italian region of the Sardinia. In particular, the project of industrial conversion involves the commune of Porto Torres, where there will be the production of bioenergy and biopolymers, and eight main local districts that have been identified as possible locations where the cardoon can be cultivated (Figure 1). They are: Anglona, Gallura, Goceano, Marghine-Barbagia, Mejlogu, Montacuto, Nurra-Sassarese-Romangia (where Porto Torres is located) and Planargia-Montiferru. These areas regroup about one hundred communes. Regrouping is made on the basis of common historical, geographical and productive characteristics. The localisation of these areas is motivated by the need to rationalize 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 the Sardinia with the industrial site of Porto Torres and contrast negative dynamics of agro-food sectors in these areas.

What is interesting to stress, in particular, is the substantial diversity of the districts. Some territories, especially coastal, reveal a certain degree of urbanization (Nurra Sassarese Romangia) and a certain presence, though limited, in the manufacturing industry (Marghine Barbagia and Gallura), whereas others, which are the majority, are characterized by a high degree of rurality as demonstrate low population density, depopulation and aging, and high incidence of agricultural activity, though residual and incapable of ensuring the same productivity and profitability as other sectors. A common aspect is that agriculture in these areas has undergone a profound transformation in recent decades especially in the last one, characterized by extensification and progressive abandon. The different territorial characteristics affected the identification of the areas potentially available to the introduction of the cardoon. For this, a study based on Land Suitability Classification (FAO, 1976) was carried out. This study distinguished the available land in five different

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[1] The results presented derive from author's own elaborations and calculations. Detailed project data and information are confidential and cannot be reported in this paper.

[2] The project also contemplates temporary provision of wood chips and the activation of the necessary port operations as long as the local supply chain of the cardoon will not be implemented fully. Considering the objectives of this study, this phase of the project is here neglected.

classes of suitability characterized by different levels of productivity and profitability. It concludes that the area allocable to the cultivation of the 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 identified the quantity of biomass attributed to each district and that of oilseeds obtainable by cultivating the cardoon, which was estimated as 11% of biomass. The area to be used for the cultivation of cardoon can be indirectly estimated by dividing planned production by average productivity levels.

Figure 1: The area under study, Sardinia, Italy (municipality administrative level)
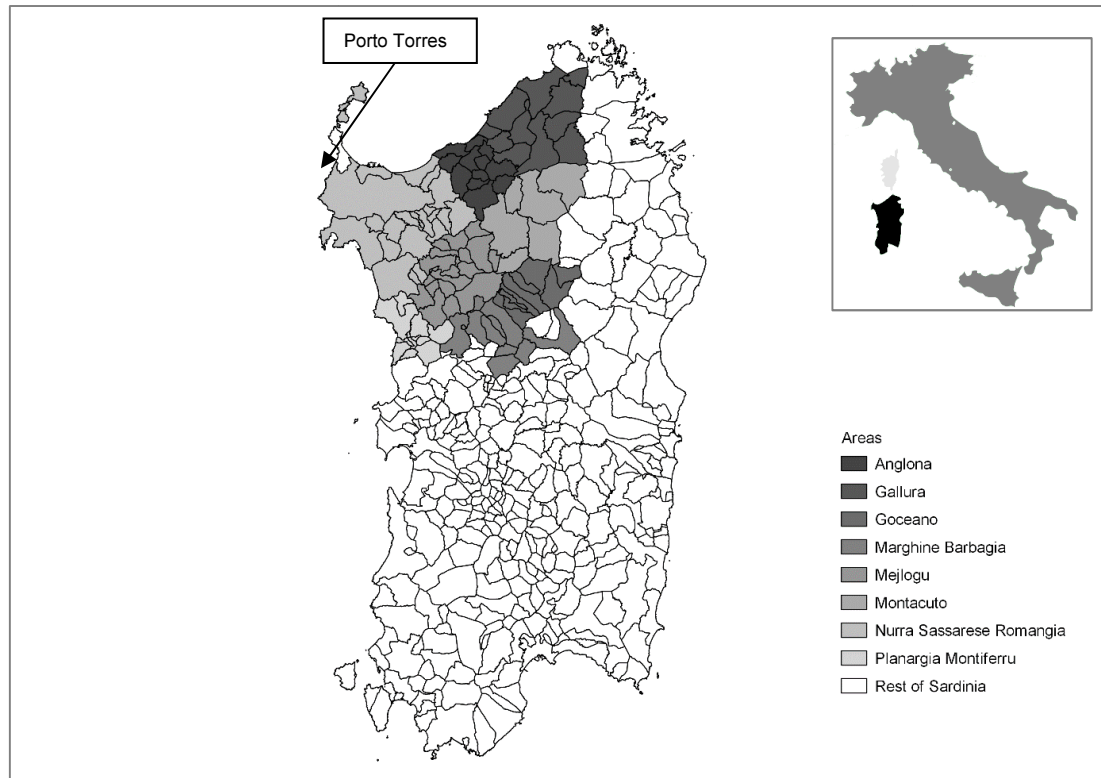
2. METHODOLOGY: IMPACT EVALUATION

2.1. The multiregional closed I-O model

The Input-Output (I-O) methodology allows the assessment of the overall impact generated, within an economy, by a shock in the final demand (Miller and Blair, 2009). It is commonly used to assess the socio-economic benefits induced by a given agricultural project or investment (Bonfiglio and Esposti, 2014a) and can be very useful whenever the objective is to evaluate the 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 impacts generated by the supply chain of the cardoon was made by using two versions of a closed 37-sectors 9-regions I-O model: a traditional demand-driven model and a mixed-variable one. The regions analyzed are eight districts where the cardoon will be cultivated and the rest of the Sardinia region. Different from the traditional model, a mixed-variable version assesses the impact that a variation of output, rather than 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.

The models are closed with respect to 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) whereas indirect effects derive from the existence of backward linkages among sectors. Supposing an increase in final demand in a given sector, these effects are those which are indirectly produced by the initial increase. This variation causes a positive variation of purchases from other sectors that are therefore forced to adjust their levels of production to the higher levels 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 outputs of sectors which adjust to the higher levels of final demand. Finally, the models present the benefits of a multiregional approach, particularly the capability of capturing spatial effects among industries located in different regions, i.e. spillover and feedback effects. Since the traditional version of the I-O model is well known in literature, here we briefly present the mixed-variable one.

Assuming an economy composed by only two regions and three sectors, of which two are intermediate sectors and one is an institutional sector represented by households, and supposing that we want to estimate impact of an output variation in sector 1 of both regions, the model can be formulated as follows:

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\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 & (1-a_{22}^{11}) & 0 & -a_{22}^{11} & -k_2^1 \\
0 & -a_{12}^{21} & -1 & -a_{12}^{22} & -k_1^2 \\
0 & -a_{22}^{21} & 0 & (1-a_{22}^{22}) & -k_2^2 \\
0 & -h_2^1 & 0 & -h_2^2 & (1-h_3)
\end{bmatrix} \\[6em]
\mathbf{N} = \begin{bmatrix}
-(1-a_{11}^{11}) & 0 & a_{11}^{12} & 0 & 0 \\
a_{21}^{11} & 1 & a_{21}^{11} & 0 & 0 \\
a_{11}^{21} & 0 & -(1-a_{11}^{22}) & 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 the region R, X_i^R is the output of sector i in the region R, y is the total labour income and y_x is the labour income paid by other institutions for services offered by households. Looking at matrices $\mathbf{M}$ and $\mathbf{N}$, a_{ij}^{RR} indicates a regional input coefficient, i.e. products of sector i in the region R purchased as inputs from sector j in the region R and a_{ij}^{RT} is an interregional trade coefficient expressing products of sector i in the region R purchased as inputs from sector j in the region T. In other words, it represents exports from sector i in the region R to sector j in the region T, or rather imports of sector j in the region T from sector i in the 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 the 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 $\mathbf{M}^{-1}\mathbf{N}$ has to be 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, the model in equation (1) has to be properly modified (Bonfiglio and Esposti, 2014b). 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: $\Delta V_1^R = \Delta X_1^R / v_1^R$. An analogous adaptation of (1) can be repeated for assessing the impact in terms of employment.

2.2. Data and regionalisation procedure

The starting point for the construction of the multiregional I-O model is a 2008 37-sector I-O table produced by IRPET (Regional Institute of Economic Planning of the Tuscany) for the Sardinia region. The table, evaluated at basic prices, was first aggregated in 35 sectors to guarantee correspondence with sectoral and territorial detail of the available employment data. 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 and total imports of each region from the rest of the Sardinia. We used the Augmented Flegg et al. Location Quotient (Flegg and Webber, 2000) since it shows to be superior in comparison with other techniques (Bonfiglio and Chelli, 2008; Bonfiglio, 2009). The location quotient was calculated using 2008 estimated employment data at a communal level (then aggregated at a district level), distinguished sectorally.

The second stage provides the use of a gravity model to allocate total imports among regions. The model assumes that the probability of attraction exerted by a given region is indirect function of distance between regions and direct function of its ability to attract flows of goods and services, which was approximated by the sectoral size in terms of employment. The first two phases are repeated recursively as many times as there are regions, obtaining a preliminary version of a (35-sector) x (9-region) I-O model of the Sardinia region. The last phase consists in the insertion of all superior data that are available and in the application of non-linear optimization technique to remove possible discrepancies with the starting I-O table.

Finally, in order to estimate both impacts related to the production of biomass for the power plant and those associated with production and sales of oilseeds, we added two new sub-sectors connected with the cultivation of the cardoon: biomass and oilseeds sectors. The relevant data and coefficients were calculated on the basis of the project information.

2.3. Alternative scenarios

The hypothesis that maximizes the impact, which can be here defined as the full-additional scenario, is that the cardoon will be cultivated on unused and suitable land and therefore will not cause any substitution of other crops. In this case, the benefits of the supply chain of the cardoon will be full, since the cardoon adds to existing agriculture. However, analyzing the data of the 2010 agricultural census it results that unused area, also including set-aside and assuming that land all fits the cultivation of the cardoon, is widely available only in the district of Gallura, and just sufficient in that of Nurra Sassarese Romangia. In the other cases, in order to assure adequate provisions to the biomass power plant, it would be necessary to replace existing crops. On average, about 23% of the area that is necessary for the cardoon should be subtracted from other uses.

This crop substitution can have a compensating effect with respect of the gross benefits generated by the supply chain of the cardoon. In principle, this compensation can even entirely effects the gross benefits; therefore, they have to be carefully taken into account in performing impact evaluation. To measure both gross and net impacts associated to different degree of crop substitution, three scenarios are here simulated:

1. **Full-additional scenario** (no substitution): it is based on the hypothesis that the cardoon adds to existing agriculture by occupying unused and suitable area.

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2. **Partial-substitution scenario**: it assumes that a part of the area, which is necessary for the cultivation of the cardoon, will be taken from already used agricultural area. This represents the most realistic hypothesis.

3. **Full-substitution scenario**: on the contrary, it supposes that all the area, which should be allocated to the cardoon, will come 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 supply chain of the cardoon are offset by the costs generated by the replacement of agricultural activities. For lower values, there are still benefits whereas for higher values there will be increasing losses.

Figure 2 provides a graphical description of these scenarios. It assumes the value added per hectare associated with the cardoon is lower than that related to other agricultural production.

Focusing on value added (VA) impacts, 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 evidently 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 productions 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 is a social loss produced by replacement of agricultural productions with cardoon.

The level of substitution simulated in these scenarios is measured in terms of percentage of reduction in the output in the agricultural sector, corresponding to the value of the UAA potentially allocable for the cultivation of the cardoon in replacement of existing activities. Output was estimated by multiplying the hectares used for the production of cardoon by the unitary unit of the agricultural sector. 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.
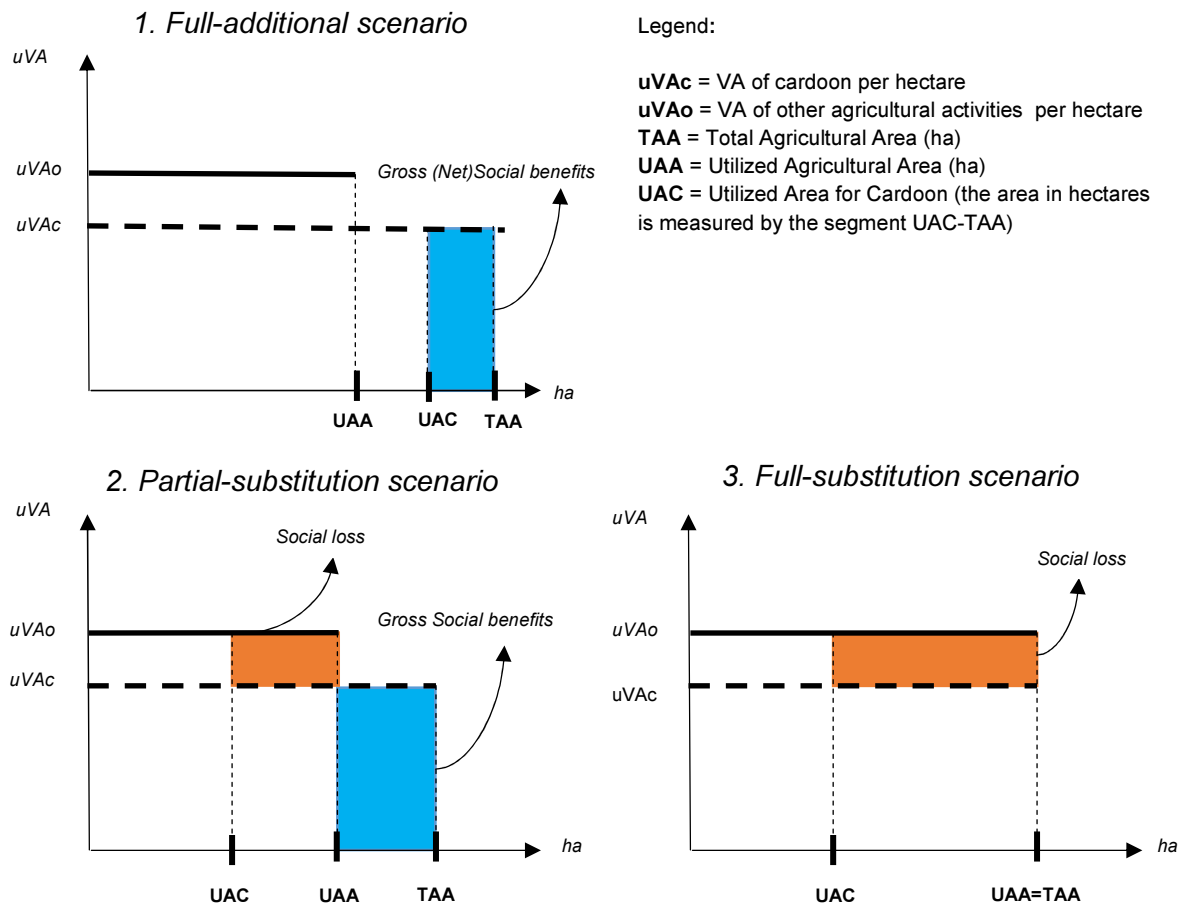
Estimation of impacts in terms of value added and employment was made by applying two versions of the multiregional I-O model described previously. Under the full-additional scenario, we used a traditional demand-driven version to assess the impact produced by the requirement for inputs (such as biomass, machinery maintenance, water, waste disposal, transport, etc.) that are necessary to guarantee the functioning of the plant. We also adopted a mixed-variable version to evaluate the impact generated by the production and sale of oilseeds, modelled as a positive change in output. Total impact of the supply chain of the cardoon 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 negatively compensates those estimated under the full-additional scenario. The parameters used and related to

agriculture are those average represented in the I-O table. This hypothesis is consistent with the consideration that it is unknown how farmers will react with reference to the land allocation. As remarked before, 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, simplicity and ageing. Moreover, the activities replaced could be more or less integrated with the rest of economy, having therefore different structures of I-O coefficients. Therefore, the average coefficients represented by the I-O table allow us to take account of these extremes avoiding making unrealistic hypothesis about the kind of agriculture that could be replaced.[3]

For this reason, the effects generated by substitution and estimated by the model could overestimate the actual impact and should therefore be considered as an upper limit of potential effects induced by replacement.

Figure 2: Diagram describing the three adopted scenarios

1. Full-additional scenario

Legend:

uVAc = VA of cardoon per hectare
uVAo = VA of other agricultural activities per hectare
TAA = Total Agricultural Area (ha)
UAA = Utilized Agricultural Area (ha)
UAC = Utilized Area for Cardoon (the area in hectares is measured by the segment UAC-TAA)

2. Partial-substitution scenario

3. Full-substitution scenario

3. RESULTS

Table 1 shows the impacts induced by the supply chain of the cardoon in the economy of the Sardinia under different scenarios. As can be noted, in the case of no substitution, the project generates an annual

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[3] 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, becoming 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 substitutions.

increase of 20.4 mio € in terms of value added, equivalent to an average of 0.07% of the 2008 value added of the Sardinia. Most impact 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 a biomass power plant in addition to the cultivation of the cardoon. The other districts are instead involved only for providing biomass and oilseeds. Nevertheless, this project can be particularly important for less developed economies such as Mejlogu and Montacuto, as demonstrate the relevant shares of local value added produced by the implementation of the supply chain of the cardoon.

Under the hypothesis of partial substitution, about 30% of benefits generated in terms of value added in the economy would be lost. Goceano is the district that would be penalized to a higher extent. The loss of value added equals 27% of initial benefits produced by the cardoon in this district. All the other territories would continue benefiting from the cardoon, particularly Gallura and Nurra Sassarese Romangia owing to a higher availability of unused land. It is interesting to note that Gallura would lose about 3% of benefits although there is no substitution in this district. This is the results of the spatial interrelationship between regions: a decrease in production in a region can generate negative effects in other region because of sectoral linkages among regions.

Under the full-substitution scenario, the value added impact generated by the supply chain of the cardoon 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 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 the Sardinia, with about 70% of benefits.[4] The break-even point[5] indicates that the overall benefits of the supply chain would be neutralised in correspondence of about 98% of substitution. In other words, if 98% of hectares already cultivated and usable for the cultivation of cardoon were replaced in each district, the benefits of the cardoon would be eroded completely. For lower values, there will be net benefits whereas for higher values there will be negative impacts. This high break-even point confirms the significant impact and the importance of the implementation of the supply chain of the cardoon. In fact, the cardoon should replace almost all existing activities to see its benefits vanish. 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 and lower in the opposite cases. At Marghine Barbagia and Nurra Sassarese Romangia, the break-even point is instead over 100%, meaning that only in the case where there were more hectares cultivated with the cardoon and thus more hectares replaced, there would be a level where benefits are offset by substitution. This is consistent with results associated with full substitution scenario. In fact, even under this scenario a part of benefits of these districts is still maintained.

Substitution effects and the break-even point can also be displayed graphically. From Figure 3, it can be noted that, as the level of substitution increases, the area of net benefits tends to shrink proportionally. The critical area, where benefits are completely annulled 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. Table 1 also shows the so-called "substitution elasticity of impact", which has been calculated by dividing the loss of benefits induced by 1% of substitution by the benefits

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

[5] 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).

generated by full-additional scenario (and then multiplied by 100). It therefore indicates the percentage of reduction in benefits due to 1% of substitution of agricultural activities. It is also a measure of the degree of sensitivity 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.

Table 1. Impacts produced by the supply chain of the cardoon in terms of value added and employment

AREA	Benefits			Break-even point (% of hectares replaced)	Substitution elasticity of impact
	% Var. (2008)	Partial Substitution (% of full impact)	Full Substitution (% of full impact)		
Value Added					
Anglona	0.21	77.8	-7.5	93.0	1.075
Gallura	0.08	97.2	-34.5	74.4	1.345
Goceano	0.27	-26.9	-134.2	42.7	2.342
Marghine Barbagia	0.24	70.0	35.3	*154.6*	0.647
Mejlogu	0.64	15.7	-78.0	56.2	1.780
Montacuto	0.40	30.4	-32.8	75.3	1.328
Nurra Sassarese Romangia	0.22	93.9	4.0	*104.1*	0.960
Planargia Montiferru	0.28	6.6	-62.0	61.7	1.620
Rest of Sardinia	0.02	90.8	69.5	*327.9*	0.305
Sardinia	0.07	71.4	-2.2	97.8	1.022
Employment					
Anglona	0.17	51.5	-135.0	42.6	2.350
Gallura	0.06	93.8	-104.5	48.9	2.045
Goceano	0.15	-149.4	-361.0	21.7	4.610
Marghine Barbagia	0.21	18.3	-74.5	57.3	1.745
Mejlogu	0.38	-74.2	-267.2	27.2	3.672
Montacuto	0.27	-31.0	-150.2	40.0	2.502
Nurra Sassarese Romangia	0.25	92.3	-37.8	72.6	1.378
Planargia Montiferru	0.25	-113.6	-269.6	27.1	3.696
Rest of Sardinia	0.02	90.6	68.6	*318.1*	0.314
Sardinia	0.06	60.0	-55.8	64.2	1.558

As regards value added, the substitution elasticity of impact for all the Sardinia is 1.022. This value indicates that per each percentage point of reduction in agricultural output due to substitution (or, rather, per each 1% of hectares that are replaced), the overall value added generated by the supply chain of the cardoon diminishes by 1.022%. In the case of full substitution, the reduction in benefits would thus amount to 102.2%, meaning that we have both full compensation of benefits and a loss that equals 2.2% of benefits. The substitution elasticity of impact ranges from 0.305, in the rest of the 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. 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 economies. 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 maintain the employment generated are in particular Gallura, Nurra Sassarese Romangia, the rest of Sardinia and, at lower levels, also Anglona and, finally, Marghine Barbagia with just 18% of the estimated benefits. The rest, especially Goceano and Planargia Montiferru, experience losses. In the case of full substitution, on the contrary, there

would be a net loss of over 200 employees. All the areas would be penalized except for the rest of Sardina that will maintain about 69% of employment. In line with these results, the break-even point is 64%, by far lower than that identified for value added. It indicates that it is sufficient to replace no much more than a half of agricultural area, which is necessary for the cardoon, to see the benefits of the cardoon 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 the 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 3). Finally, as expected, the substitution elasticity of impact is higher than that related to value added and equals 1.558. It varies from 0.314, in the rest of the Sardinia, to 4.610 in Goceano.

Figure 3: Benefits and losses in terms of value added (a) and employment (b) generated by the supply chain of the cardoon in Sardinia
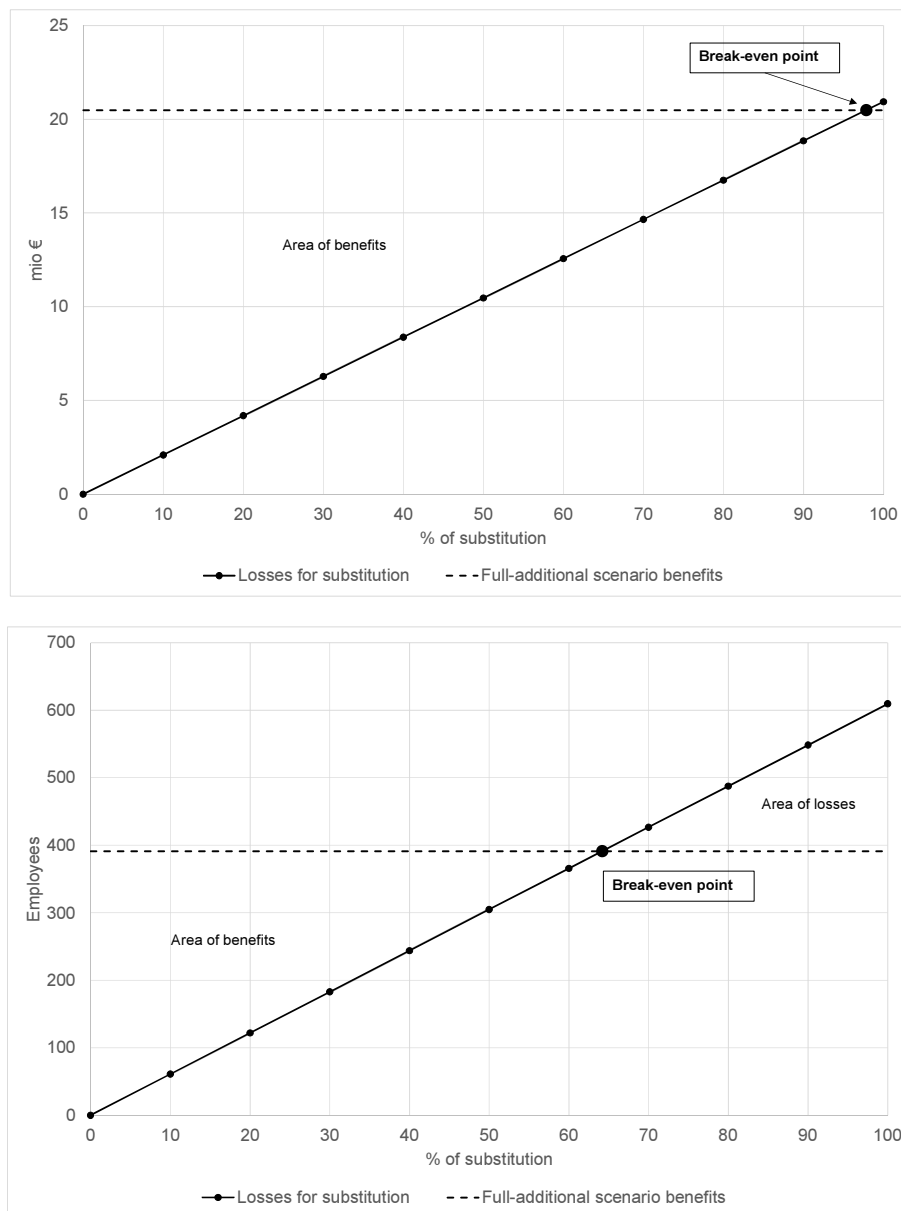
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