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Transport cost estimation model of the agroforestry biomass in a small-scale energy chain

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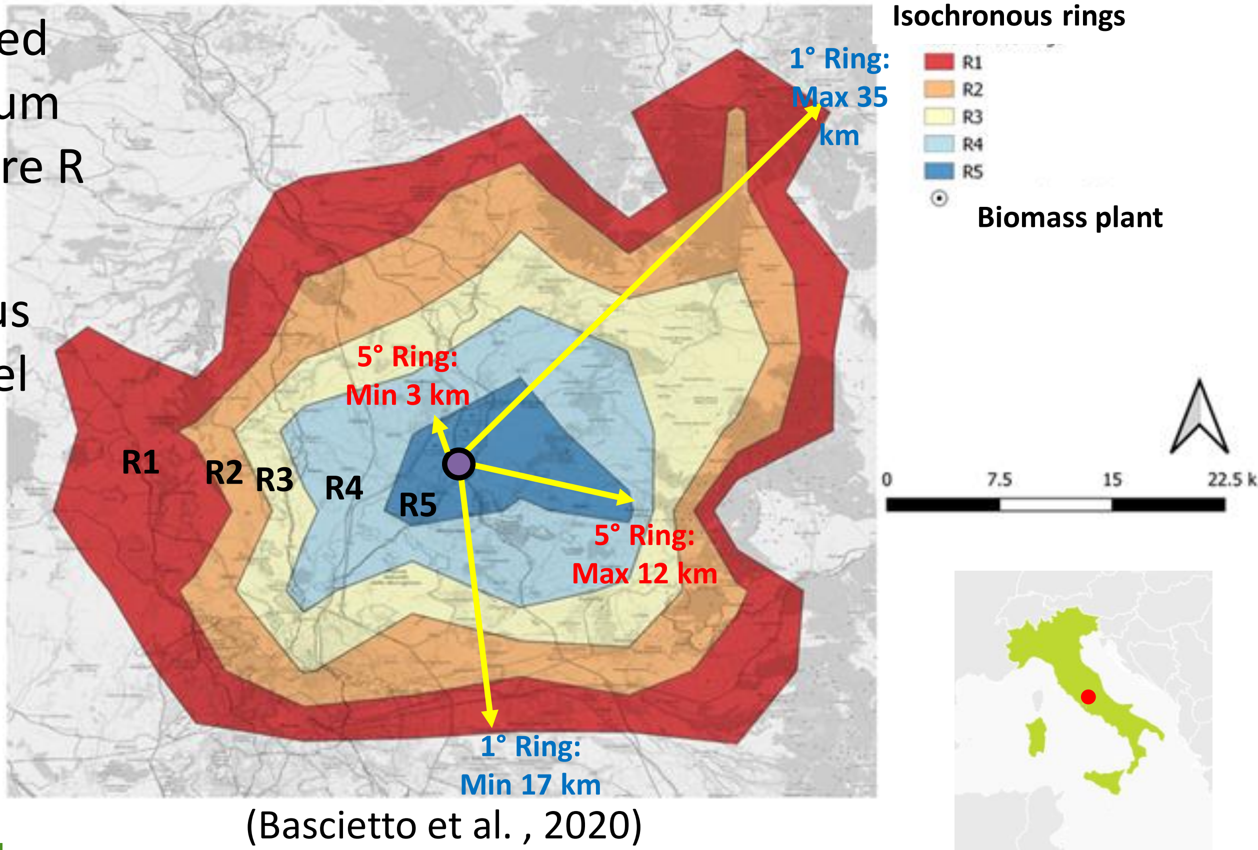
Objectives of the study

- Implementation of a geographic model to evaluate in a context of the small local energy supply chain:
  - quality and quantity of residual biomass available on the territory;
  - cost-effectiveness of the logistics of agroforestry biomass transport;
  - economic sustainability of the recovery and transport of the different residual biomass sources in relation to the travel time from pick-up point to power plant.
- Verify the possibility of energy valorization of the residual biomasses spread throughout the territory in a small biomass plant

Methods

- Study area: North-East of Rome (Italy), surrounding a biomass power plant of the CREA farm, for a total of 2,276 km^2
- Identification of the external borders of the investigated area through the maximum travel time, using software R osrm package
- Mapping of 5 isochronous rings on the base of travel time range:
- R1, 50-60 min;
- R2, 40-50 min;
- R3, 30-40 min
- R4, 20-30 min;
- R5, 0-20 min.



(Bascietto et al. , 2020)

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Residual biomass estimation

- Sampling of the land cover area visualized by satellite images in Google Earth software
- Identification of the different types of biomass by photo-interpretation
- Estimation of the residual biomass, by applying judgment coefficients of experts, for different biomass sources, identify in 8 classes (Corine Land Cover, 2018)
- Attribution of 4 productive coefficients on areas with different levels of soil cover, measured for each class of residual biomass (value in Mg ha^{-1} y^{-1}), as reported in table

Biomass class	*A3*	*A2*	*A1*	*A0*
Green Urban Areas (GUA)	4.00	3.00	2.00	0.00
Sport and Leisure Facilities (SLF)	2.50	1.90	1.30	0.00
Vineyards (VIY)	3.00	2.55	2.10	0.00
Fruit Trees and berry Plantation (FTP)	3.50	2.75	2.00	0.00
Olive Groves (OGR)	4.00	2.90	1.80	0.00
Complex Cultivation Patterns (CCP)	2.00	1.50	1.00	0.00
Land principally Occupied by Agriculture (LOA)	3.50	2.75	2.00	0.00
Forest class (FOR)	1.05	0.90	0.75	0.00

Biomass recovery and transport cost

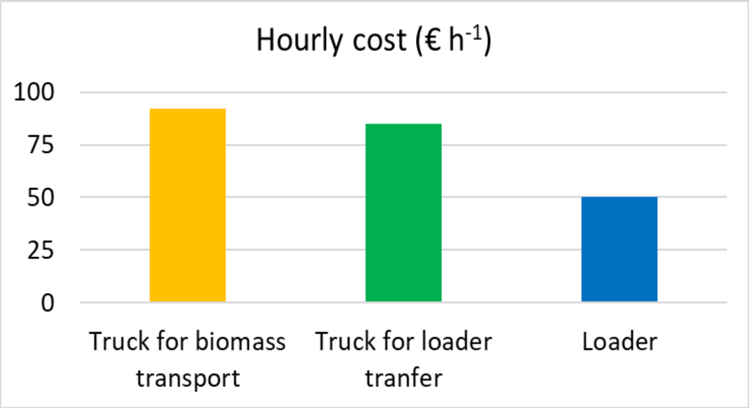
Based on:

- ✓ Cost evaluation of the biomass transport operation (transfer from pre-processing sites to the main processing plant, loading and unloading)
- ✓ hypothesis was that farmers supply pruning biomass for free to avoid incurring in the fees charged for the disposal of this material in landfills

- ✓ Both the farmer and the power plant manager benefit from the deal: the first one does not pay for the disposal; the second one does not pay for the raw material recovered

Machines used and hourly costs

- ✓ Truck for biomass transport, 309 kW of engine power, 26 m^3 of volume, about 8 Mg of biomass pruning residues
- ✓ Forest loader for loading biomass on the truck, 88 kW of engine power
- ✓ Truck for transferring loader, 280 kW of engine power



- ✓ It is considered that the forest loader must be transferred daily to the workplace and brought back with a dedicated truck
- ✓ The hourly costs were performed using an analytical method

Transport cost evaluation model

The evaluation of the transport cost refers to the product unit (€ Mg-1) and includes the cost of transport, loading, unloading and daily transfer of the loader.

Analytical equation adopted:

$$CTB = \frac{[(Ttr\ x\ Ctr)+(Tlu\ x\ Clo)+(tcl\ x\ Ctl)]}{bl}$$

where:

CTB	*biomass transport cost per Mg (€ Mg^{-1});*
Ttr	*roundtrip travel time, obtained doubling the return travel time of the loaded truck (h);*
Tlu	*time required for loading and unloading operations (h);*
Ctr	*hourly cost of the truck (€ h^{-1});*
Clo	*hourly cost of the loader (€ h^{-1});*
tcl	*transferring coefficient;*
Ctl	*hourly cost of the truck dedicated to the transfer of the loader (€ h^{-1});*
bl	*average load of biomass transported (Mg).*

Incidence of different types of biomass on the costs

To consider the influence of different types of biomass on the cost of loading and transport, three corrective coefficients applied (table below).

lc = load coefficient, it is used to increase the loading time according to the loading difficulty attributed to the different biomass classes

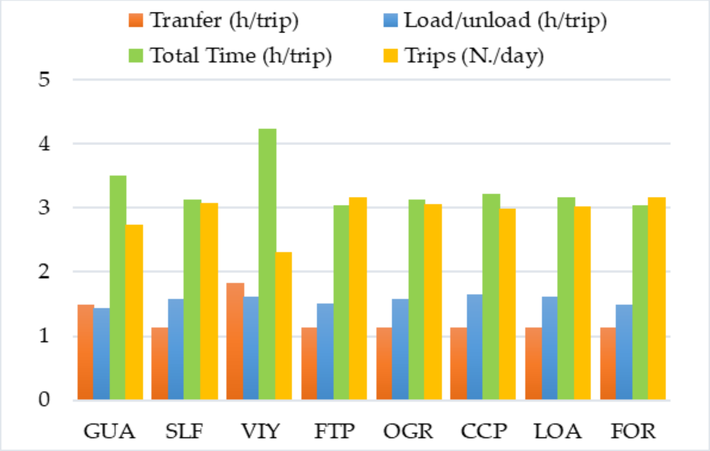
yc = yield coefficient, considers the increase on loading time according to the different yield for each biomass class

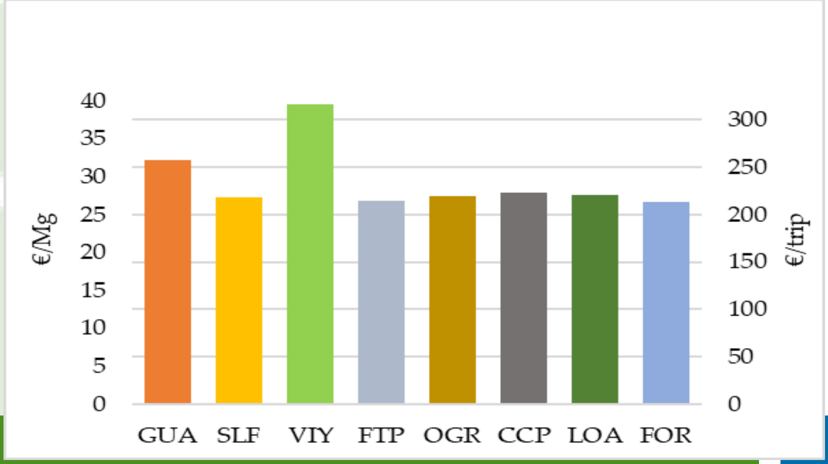
tc = loader transfer coefficient, according to the number of daily trips made by type of biomass: the higher the estimated number of daily trips, the lower the coefficient value

Biomass type	Coefficients		
	lc	yc	Tc
GUA	1.00	0.14	0.36
SLF	1.05	0.27	0.34
VIY	1.15	0.20	0.43
FTP	1.05	0.22	0.33
OGR	1.10	0.23	0.34
CCP	1.10	0.30	0.35
LOA	1.15	0.21	0.34
FOR	1.00	0.00	0.30

Results

- The average time consumption for the recovery and transport of residual biomass is highest for the vineyard class with 4.23 h trip^{-1}
- It is shortest time for forest class, with 3.04 h trip^{-1}.
- Load/unload time is highest in CCP class with 1.65 h, followed by LOA and VIY with 1.61 h, while GUA requires the lowest time of 1.44 h



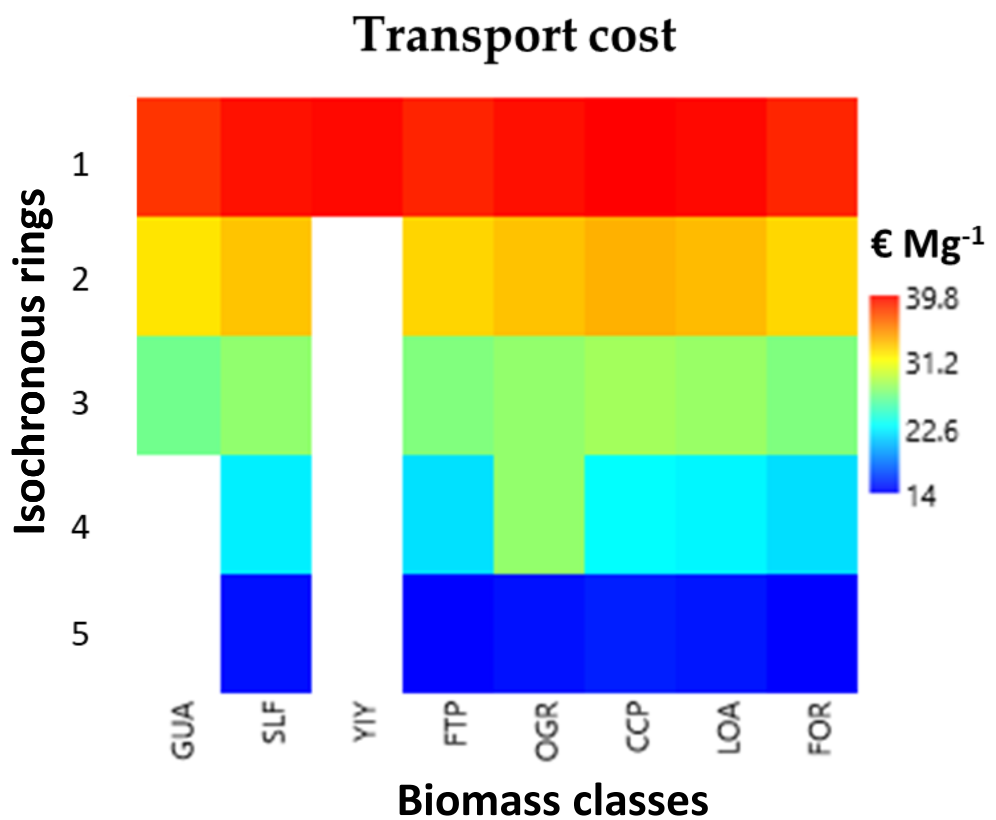


- Consequently, also the average cost is higher for VIY with € 316.31 trip^{-1}, corresponding to € 39.54 Mg^{-1}
- The lowest cost is recorded for the FOR class with € 213.84 trip^{-1}, that is € 26.73 Mg^{-1}

Costs in the isochronous rings for each biomass class

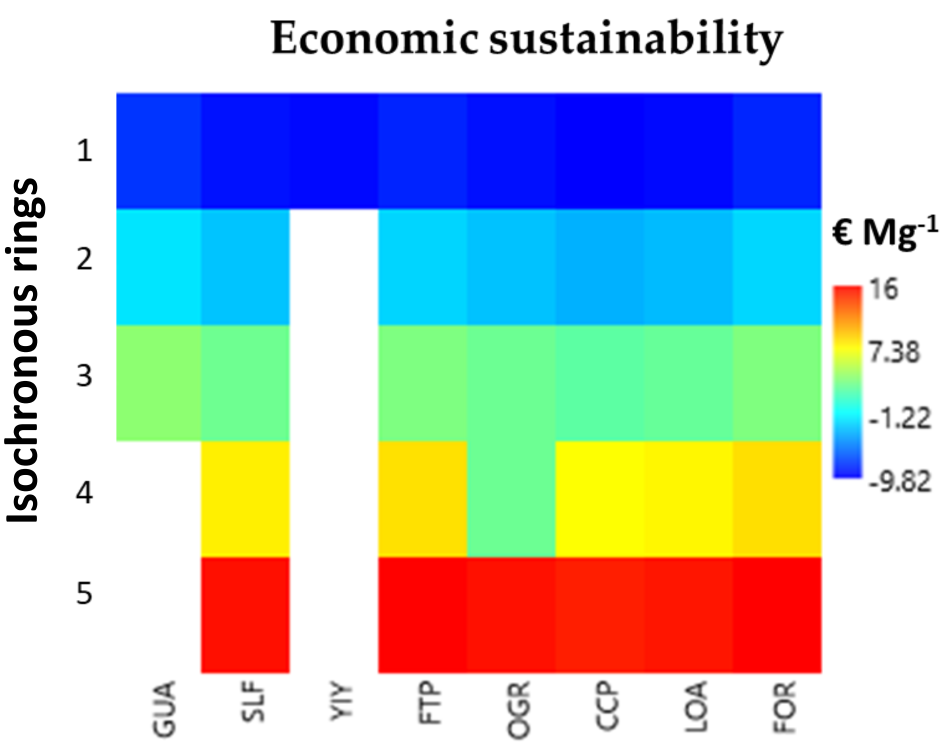
Matrix plot of the biomass transport cost in relation to biomass classes and isochronous rings.

- As expected, the cost increases by proceeding from the 5th isochronous ring (travel time 0-20 minutes) to the 1st (50-60 minutes).
- This is valid for all biomass classes even if with slight differences. The average costs varying from minimum of about € 14 Mg^{-1} in the area of the 5th ring (blue), to maximum of € 39.80 Mg^{-1} in the 1th ring (red).



Economic sustainability

Matrix plot of the economic sustainability of the transport operation in relation to biomass classes and isochronous rings.

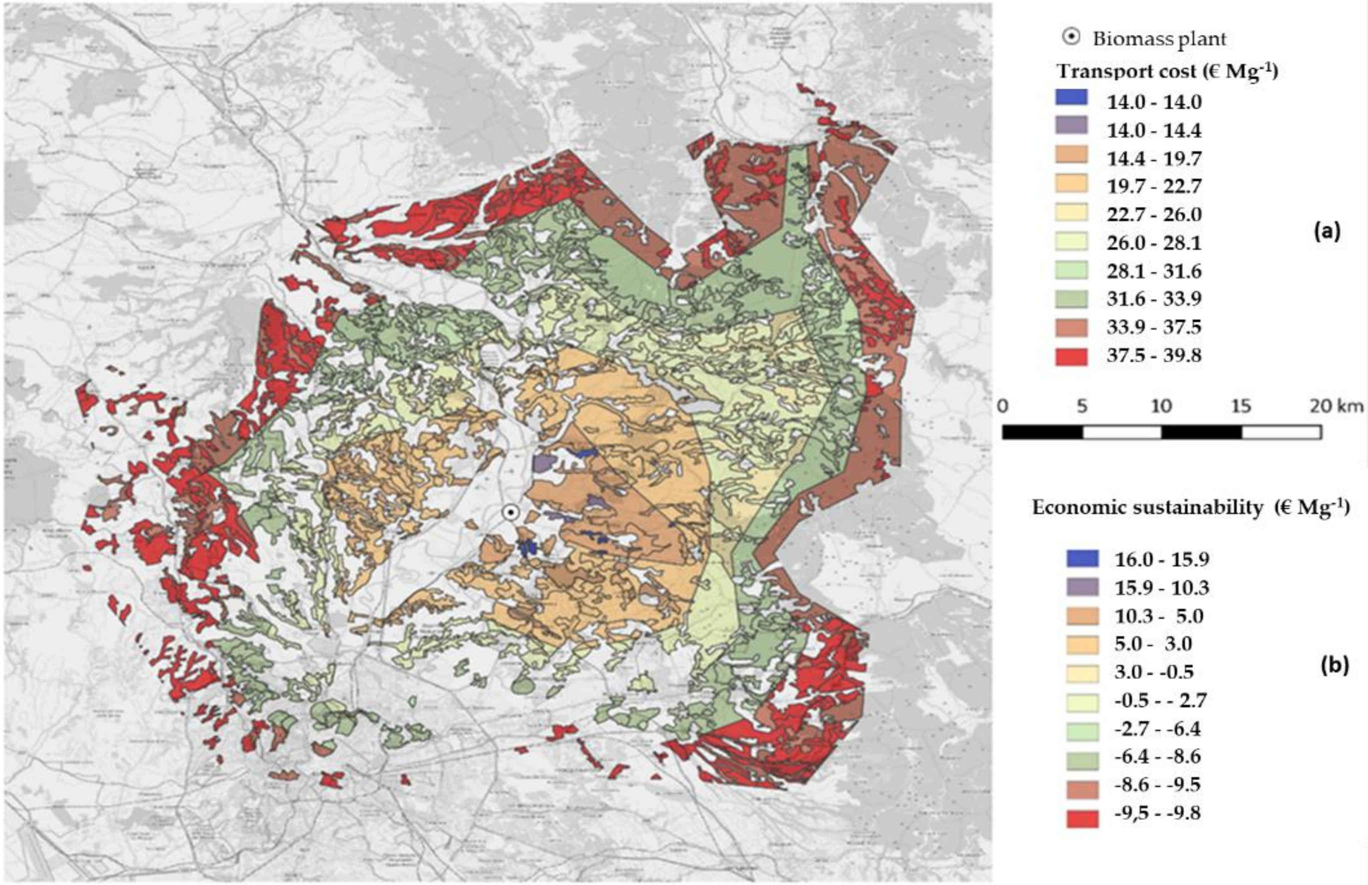


- The economic sustainability is based on the positive difference between the average market value of the chipwood and the cost incurred for transport and chipping.
- The chipping cost is estimated at € 15 Mg^{-1}, the value at € 45 Mg^{-1}
- The red and yellow colors indicate greater economic sustainability (5th and 4th ring (positive values)
- The light green (3rd ring) is the intermediary zone
- Light blue and blue of 1st an 2nd ring represent non-economic areas

Territorial map of the costs and economic sustainability

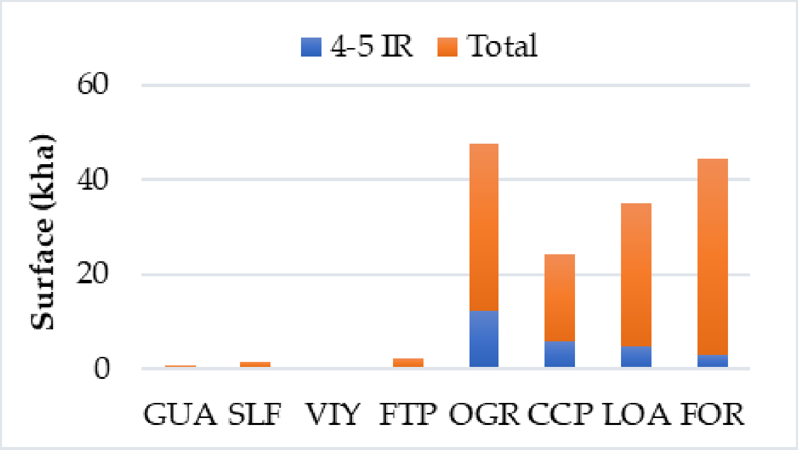
The map associates transport costs and sustainability with the location of the specific area on which, for each isochronous ring, the different classes of biomass are located

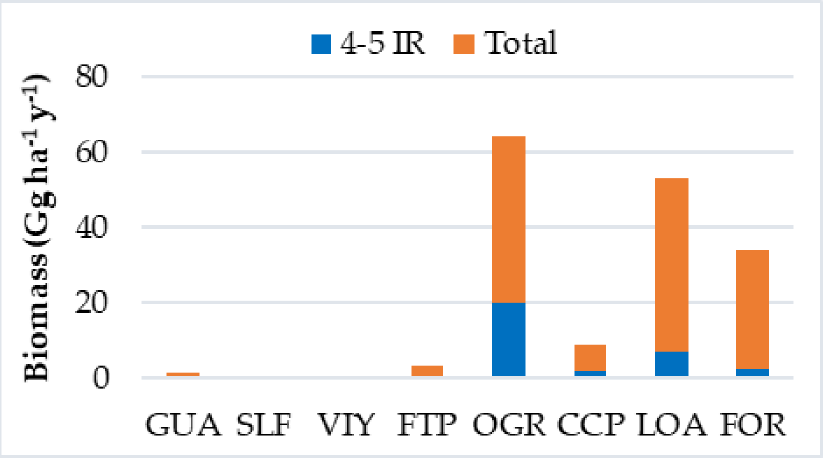
- From this map it is possible to check the transport cost in relation to the distance from the biomass plant
- The economic sustainability conditions occur in the areas ranging from yellow to blue (proximity of the biomass plant)



Surface and residual biomass available

- On a total observed surface of 2,276 km^2, about 130 kha (57% of this total) is represented in the model
- Of this surface only 20% (26.4 kha) falls within the 4th and 5th isochronous ring where the economic sustainability of biomass recovery occurs





- The annual residual biomass potentially available is about 134 Gg
- Only 24% falls within the area of the economic sustainability (5th and 4th isochronous rings) for a quantity of about 32 Gg,
- 62% of which represented by olive grove pruning residues

Conclusions

The study carried out is aimed at the implementation of a geographical model capable of providing a mapping of the costs of transporting biomass in a context of small-scale energy chains

The small-scale energy chain currently represents a model to be encouraged and applied in farms that want to make a qualitative leap towards a bioenergy farm.

The small energy chain model can represent the most suitable solution for the development of sustainable systems based on medium-small plants compatible with the availability of bioenergy that the territory is able to supply.

For the case study examined the economic sustainability for the supply of biomass to feed the plant is verified when the travel distance not exceeding 20 km, with a travel time from the place where the biomass is loaded to the plant, no more than 35 minutes.