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An Example of Reclamation Consortium Energy Self-Sufficiency using Biomass from Riparian Vegetation

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Nowadays, energy self-sufficiency cannot ignore the environmental sustainability of how it is achieved. On the other hand, one of the largest waste disposal components of a reclamation consortium is represented by residues derived from habitat maintenance. These residues are mainly formed by riparian vegetation that, from an energy point of view, can represent a renewable biomass. Some practical problems arise when passing from a theoretical approach to the development of an effective supply chain, the main of which is the biomass availability. Since the riparian ecosystem is characterized by a wide variety of landforms and biological communities, the functional supply chain must consider seasonal variability, different biomass composition depending on the land, and, hence, a mean biomass feedstock availability. The presented study has been conducted in a reclamation consortium of Northern Tuscany in Italy and examined the main characteristics of the feedstock and estimating its availability. This information has been used to propose different possible supply and utilization chains: a network of small-scale plants, biomass gasification involving external local utilizers or more complex scenarios dedicated to the production of syngas. Among the two final possible supply chains identified, gasification for syngas production and anaerobic digestion for biogas production, the first option resulted to be more profitable. The possible application to the consortium energy balance has been analyzed and commented, evidencing different technical factors that can influence its value.

1. Introduction

Finding new sources of non-cultivated biomass is essential to avoid consuming food crops land for producing energy feedstock (Meyer et al., 2014). Possible alternatives can be found in residues derived from the maintenance of habitats, that is, wastes from mowing operations (Spinelli et al., 2016). On the other hand, vegetable barriers both in the form of anthropic buffer strips or natural riparian vegetation represent important elements to control the hydrogeological risk of water bodies. The shape, size, and composition of such buffers can vary considerably, so that is not possible to delineate standard values. The "greening" payment in the CAP reform recognizes the role of these barriers in possible areas in which biodiversity and environmental services are safeguarded (Cormont et al., 2016). By standing between agriculture and water bodies, the riparian buffer strips play a multifunctional role in pesticide capture, nitrogen and phosphorus maintenance, habitat improvement, soil erosion protection, flood mitigation (Borin et al., 2013).
In Italy, the residues of ditches and streams managed by the reclamation consortia are disposed of along the courses or in landfills as special waste (del Giudice et al., 2017). Nonetheless, different studies have evidenced how bioenergetic buffers can expand the range of ecosystem services by being effective in removing Total Dissolved Nitrogen, while also constituting an interesting biomass production (10.8 Mg DM ha^{-1} for miscanthus, 17 Mg DM ha^{-1} y^{-1} for willow) (Ferrarini et al., 2017). The production of renewable biomass (*Arundo donax* L.) from a reclamation consortium showed that, in the winter cut, the riparian vegetation assured yields (43.4 Mg DM ha^{-1} y^{-1}) comparable with the dedicated cultivation in cropping systems (del Giudice et al., 2017). Clearly, this comparison is strongly dependent on the operative conditions of the riverbanks. Christen & Dalgaard, (2013) estimated a net energy yield of "bioenergy" buffers to be between 32 and 69% of the net energy yield of winter wheat in combined heat and power and a gross margin in the range of 15-44% of the gross margin obtainable

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from the production of winter wheat. Therefore, the recovery of biomass for energy conversion would positively affect the economic balance of management costs.
The Northern Tuscany Consortium (CTN) operates on an area of over 360,000 hectares located in the northernmost part of Tuscany. The reclamation consortium performs the ordinary maintenance of waterways and hydraulic works in the area through the cutting, mowing, and shredding of riparian vegetation according to sustainable environmental criteria. The concurrence of violent atmospheric events, mainly in spring, and the large availability of maintenance residues on the side of the riverbeds triggers a transport mechanism of such quantities of mowing on Versilia beaches, with consequent negative impacts on the tourist-seaside economy. For this reason, the collection of such maintenance residues and the consequent disposal in landfills has become mandatory, entailing additional transport and disposal costs. In this framework, reusing such biomass for energy feedstock would mean avoiding disposal costs and potentially reducing energy acquisition for the network.
Hence, this work proposes a first feasibility analysis of possible solutions for the enhancement of the available biomass. The study was divided into the following phases: analysis of the maintenance activities in progress at CTN, evaluation of the quantity and quality of the biomass potentially produced by the ordinary and extraordinary maintenance of CTN, and, finally, identification of possible chains of energy use of the considered feedstocks.

2. Energy from biomass

This paper examines the potential production of second-generation biomass chains, i.e. those not impacting the agri-food chain. Among these, main resources come from agricultural residues (cereal straw, green residues), forest and wood processing residues (debris, twigs, waste), together with dedicated energy crops, both tree species, such as poplar from SRF, and herbaceous, such as panic, thistle, sorghum, common reed, miscanthus. Few species have been identified to be best suited for energy purposes, compatibly with their adaptation to the climate in the Italian territory. Productivity and ease of crop management are also important factors, essential for making dedicated crops economically advantageous. Hence, in the following, we consider some specific types of biomasses already quite developed on the Tuscan territory. Tuscany is a region particularly suited for the establishment of biomass chains for energy use, as also demonstrated by the raw data on the availability of agricultural and forestry residues in the region. Residues from herbaceous crops were evaluated at 395 kt per year, about 4% of the 9400 kt on a national scale; residues from tree crops instead amount to 225 kt, equal to 7% of the 3400 kt on a national scale. Given the large, wooded area available (almost 50% of the territory), the contribution of forest residues for energy uses is worth approximately 1 Mm^3. Recchia et al. (2010) estimated a quantity of 4950 Mg DM y^{-1} of woody and herbaceous biomass in the Greve, Ema, Pesa, and Elsa basins corresponding to 60,540 GJ y^{-1} of energy potentially produced by riparian vegetation management. Furthermore, in Tuscany, as olive and vine crops are widespread, the availability of pruning residues, pomace, and stalks is also very important (Biagini et al., 2014).
To identify the quality of biomass available from ordinary and extraordinary maintenance operations in riparian areas, an examination of the types of biomasses used for energy production and their characteristics is needed. The classification of biomasses is not unique due to the abundance of materials they include. The IEA proposes a classification method based on the availability of biomass in a given space and also based on the type of logistics they require to be. In addition, the estimate of the potential supply of biomass from forest cultivation has already been addressed at the Tuscan level by various authors (Grilli et al., 2020; Sacchelli et al., 2013), and in regional projects such as BIOSIT (2003), BioPower in Tuscany (2015) (Biagini et al., 2016).
The choice between biomass energy production processes (thermochemical or biological) is made based on the characteristics of the available biomasses: nature and composition (immediate and elementary analysis, composition by macromolecules), water content entering the plant, presence of inorganic elements such as chlorine, sodium, nitrogen, potassium, phosphorus, zinc, etc., required size (dimensions with which the biomass is fed to the reactors), energy content (lower and upper calorific value), and ash composition.
The choice of technology is depending on two main criteria. The first one is the use of the energy produced, i.e. if the production of electricity is stand-alone or in cogeneration, the thermal-electrical power ratio and the destination of the produced thermal energy, for space heating or as process heat. The second important criterium is the plant size in terms of hours of operation per year to define adequate structural oversizing, the optimal level of coverage of energy needs, the variability of energy loads over time (seasonal, monthly, daily), and the reliability levels and guarantees of continuity of the service to be provided.
Based on these general criteria and the availability and type of biomass of the CTN, in the next section, the supply chains of interest for this study are defined and described.

3. The CTN case study

3.1 Data and information available

The CTN operates on an area of over 360,000 hectares located in the northernmost part of Tuscany, comprising the reclamation areas of Versilia Massaciuccoli, Auser Bientina, and by the Unions of the Municipalities of Lunigiana and Valle del Serchio. From an average of the last three years, the CTN uses 2,700 MWh per year of electricity, of which 94% for the dewatering pumps and 5.4% for the offices. Consumption for other users is negligible, so the cost of electricity is approximately 500k€ / year.

The quality and quantity of available biomass obtained from maintenance activities were traced by analyzing the data contained in the CTN Geographical Information System (GIS). The data made available by CTN consist of linear and punctual GIS data of the green maintenance activities in their activity region (Figure 1).

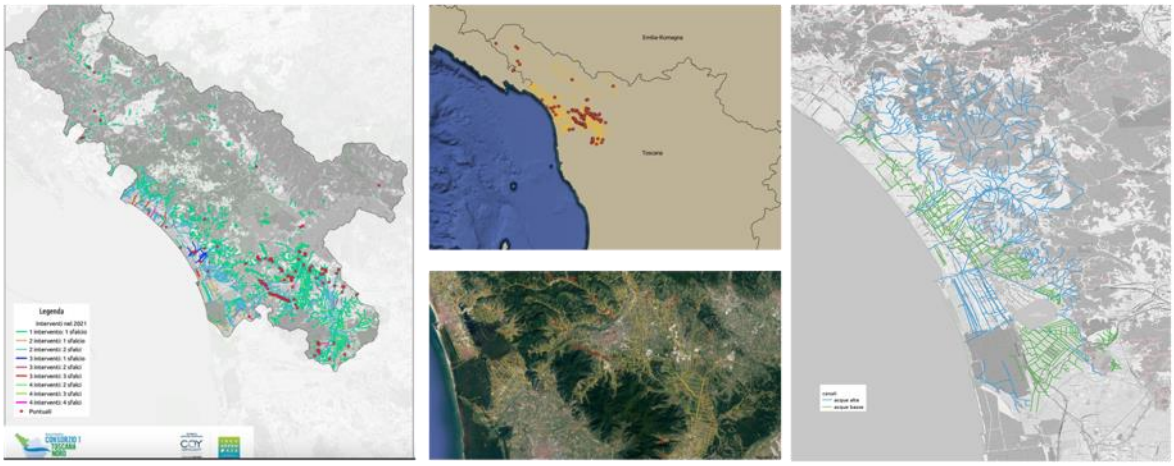

Figure 1 CTN Geographical Information System

To model the overall potential quantity of available biomass, the area of operation of the CTN has been divided into three macro-areas, according to the similarities in terms of biomass distribution: 1) "Plain Zone": Versilia and Massa plains, Bientina swamp; 2) "Foothills Zone": Hilly and mountainous area of Lucca and Massa, Pistoia Mountain area; 3) "River Zone": Lunigiana and Middle Serchio Valley. For the availability of biomass during the year and its distribution on the CTN territory, the considered biomass species have been classified as follows: A) herbaceous cuttings, B) *Arundo donax* L., C) sedge (*Cladium mariscus*), D) biodola (*Sparganium erectum*), E) shrubby vegetation cuttings, F) tree cuttings (alders, poplars, pines, and plane trees).

The summary of the quantities harvested after mowing with the spring harvest of 2021 amounts to a total of around 56,800 kg, mainly herbaceous biomass, which was transferred to authorized recovery plants (approximately 65 €/ton). To define the amount of each type of biomass spanned along the three macroareas, such quantity of biomass registered in Versilia, is considered as a reference for the other areas. Interviews with CTN technical personnel revealed that the presence of B can be estimated in a percentage of 10-15% of what is mowed. The remaining part is herbaceous plant cuttings. The presence of B in such a large area is concentrated in a few stretches of waterways where is prevalent. In the canals around Lake Massaciuccoli, there are, in addition to B in the above percentages, also C and D in similar percentages.

3.2 Aggregation of data and quantification of available biomasses

The total quantity of biomass available was calculated using non-primary data based on the spring harvest of 2021 which took place in Versilia and extrapolating the other quantities according to the following assumptions:

i) the total massive quantity of autumn mowing is assumed to be one third compared to the spring one and with equal distribution of the types of biomasses;
ii) the Massaciuccoli area is estimated as one third of the Versilia area and the quantities of C and D can be estimated as 15% of 33% of the cut. Furthermore, the presence of these biomasses is unique in the territory;
iii) the length of the maintained watercourses related to the 56,800 kg considered, that is, the Versilia region alone, can be attested to 5 km. Consequently, a biomass density of 11,360 kg/km is used as a parameter for data extrapolation in Massa plain and Bientina swamp, adopting the lengths of the watercourses maintained in each area (high waters and main low waters) and calculated from the GIS as a metric.
iv) the partition of biomass as a percentage in the macro-area "River Zone" is considered the same as in Versilia, but the herbaceous biomass portion is substituted with a shrubby one. Furthermore, the total quantity of biomass of the "River Zone" is compared to that of the "Plain Zone" by a factor equal to 1/5.

v) analogously to what is done for the “Plain zone”, also the distribution of biomass in the “River zone” is calculated based on the lengths of the maintained channels taken from the GIS.

vi) for the hilly and mountain areas, 35 trees (the number of trees cut in 2021) per area is assumed, i.e., 105 trees in the whole "Foothills Zone". Each tree is assumed to weigh 10 tons and the number of cuts is considered annual and not seasonal. This number is highly conservative being the average number of trees maintained every year above 100.

From these assumptions and considerations, the availability of biomass during the year, divided into the two seasonal maintenance activity periods, and spread for the three macro-areas identified for the study is shown in Table 1. Ultimately, from a conservative assessment, about 1,300 tons per year of various types of biomasses are available, with calorific values in the range of 16-18 MJ/kg for cuts of trees, reeds, and woody material in general (types B, E, F) and with high moisture content for grass clippings and aquatic plants (A, C, D).

Table 1 Conservative Biomass Availability calculated for the CTN case study

		Spring						Autumn						
Macroarea	**Areas**	**TOT (kg)**	**A**	**B**	**C**	**D**	**E**	**TOT (kg)**	**A**	**B**	**C**	**D**	**E**	**F**
Plain Zone	Versilia	56,800	42,600	8,520	2,840	2,840	0	18,933	14,200	2,840	946.7	946.7	0	0
	Massa	56,800	48,280	8,520	0	0	0	18,933	16,093	2,840	0	0	0	0
	Bientina	56,800	48,280	8,520	0	0	0	18,933	16,093	2,840	0	0	0	0
Foothill Zone	Lucca	175,000	0	0	0	0	0	175,000	0	0	0	0	0	350,000
	Massa	175,000	0	0	0	0	0	175,000	0	0	0	0	0	350,000
	Pistoia	175,000	0	0	0	0	0	175,000	0	0	0	0	0	350,000
River Zone	Lunigiana	6,816	0	1,022	0	0	5,794	2,272	0	340.8	0	0	1,931	0
	Serchio	27,264	0	4,090	0	0	23,174	9,088	0	1,363	0	0	7,725	0

3.3 Energy supply chains from riparian biomass

Based on the analysis carried out, the possible supply chains identified are two: gasification at atmospheric pressure to produce syngas (B, E, F) and anaerobic digestion for biogas production (A, C, D). Biogas and syngas are used to produce electrical and thermal energy (cogeneration) in alternative engines.
The basic hypothesis is that the possible supply chains are concentrated in a single production site, or that the amount of biomass available throughout the territory is transported to the established processing site. The average and conservative distance included in the individual supply chains is 150 km. The daily quantity of biomass available for treatments was calculated by taking as a reference the total annual quantity (Spring + Autumn mowing) and dividing by 8,000 working hours per year. From Table 1, the reference input numbers for the two supply chains are: 3,389 kg/day for gasification and 579 kg/day for anaerobic digestion.
The evaluations on the potential processes for energy production from CTN riparian biomass have been developed based on the experience with gasification and digestion processes acquired in regional and national projects (see Simone et al., 2011 and reference therein).

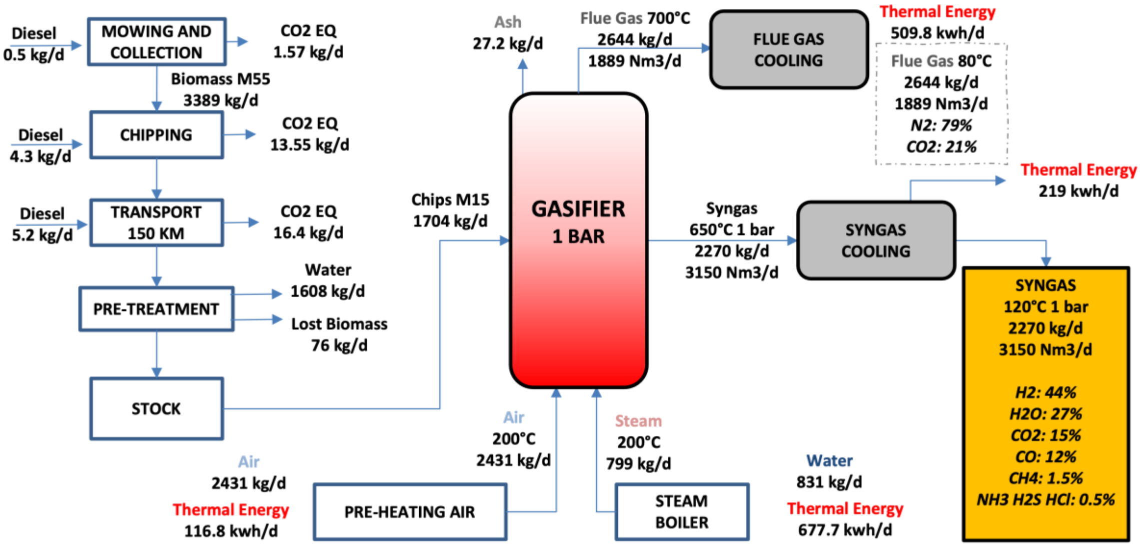

Figure 2 Gasification supply chain. M55 means a humidity percentage of 55% and the syngas composition is given in massif percentage.

3.3.1) Gasification at atmospheric pressure for the production of syngas

Based on the properties of the available biomasses and previous modeling findings (Biagini et al., 2014, 2016), white poplar was used as the reference biomass for gasification for yield calculations. **Errore. L'origine riferimento non è stata trovata.** shows the quantitative assessments relating to the supply chain while Table 2 collects the main assumptions/data used for the gasifier. Overall, 2,270 kg/d of syngas is obtained with input power to the energy generation system of approximately 145 kW. The reference humidity of the initial biomass was 55% while 5% is used in the pre-treatment/drying process. Given the size and powers involved, the technical-economic pre-feasibility analysis considered the gasification technology with downdraft reactor and internal combustion gas engine. The gasification process produces about 2.4 kWth for each kWe produced (45 kWe corresponds to 110 kWth).

Table 2: Assumptions made for the Gasification example

Biomass entering the gasifier composition (mass fraction)	ash	C	H	N	Cl	S	O
	1.88	48.78	5.99	0.18	0.01	0.05	43.11
Biomass entering the gasifier: Enthalpy [kJ/kg]	6966						
Excess air [%]	25						
Steam to biomass ratio [%]	75						
SYNGAS	T[°C]	P [Pa]		Enthalpy [kJ/kg]		PCI[1][kWh/m3]	
	650	101325		7270		8.35	

Calculated as PCI of CH4 times its mass fraction in the syngas

3.3.2) Anaerobic digestion for biogas production

Having insufficient specific data regarding the composition of the biomass treated (mostly herbaceous plant cuttings), the anaerobic digestion of algae is used as a reference for yield calculations (Barontini et al., 2016). Overall, considering the flow rate of 580 kg/day entering the digestion supply chain, a flow rate of 191 Nm^3/d of biogas at 60% methane with a thermal power equal to 46 kW is obtained. This stream, not particularly significant given the limited availability of wet biomass, can be added to the syngas current produced by the gasification plant once a cost-benefit assessment for installing an anaerobic digester on CTN areas has been developed. For the sake of brevity, the anaerobic digestion chain is not shown. Another possibility is to dry the wet biomass using the thermal waste from the gasification plant and feed it to the gasifier, after pre-treatment (pelletizing, briquetting) together with other size residues and non-optimal characteristics for the gasification plant.

3.4 Technical-economic feasibility

A preliminary assessment of the technical-economic feasibility of a gasification plant that uses the biomasses identified (types B, E, F) is here reported. The plant is modular with a size of 50 kWe and 100 kWt per module, which can also be used in tri-generation configuration, i.e., capable of producing electricity, heat, and cooling, and providing thermal and electrical energy up to 7,500 h/y. The assessment is carried out considering the incentives granted by the GSE for this type of plant since Italian legislation (DM 6 Luglio 2012 e s.m.i) provides for an incentive value divided according to the size of the plant and the type of account renewable energy used, with the possibility of obtaining any additional premiums. Plants powered by biomass type b (by-products of biological origin) have access to an all-inclusive incentive rate for 20y equal to 252 €/MWh and, for powers up to 200 KW, do not require formal registration. Therefore, the costs assumed in the preliminary assessment are as follows: gasification plant and cogeneration unit + dryer: 300,000 €, operation and maintenance costs: 15,000 €. The cost of biomass is not considered since currently the biomass obtained from maintenance operations is disposed of). The main financial assumptions made are: 15y of operating life, 10y as amortization period, 50% of the capital as bank loan with an interest rate of 5% and an inflation rate of 2.8%, and, finally, a discount rate of 8.00%. With these figures and with an applicable rate of 0.297 €/kWh (biomass by-product), annual revenue from the sale of electricity produced results in 96,375 €. The annual production of thermal energy is 900,000 kWht of which 150,000 kWht is used for drying the biomass and the remaining 750,000 kWh made available by the end-user, corresponding to energy for approximately 50,000 €/y of methane (as a saving considering a cost of 0.75 €/Smc).

With the conservative assumptions made, the investment has a very limited pay-back time (2y), which goes down to 1y if fuel savings are also considered for the use of residual heat. The 375 MWh/y provided by the plant under the conservative assumptions made, would satisfy 15% of CTN's electricity consumption. Furthermore, since this type of plant is modular, installation of subsequent modules can be planned, taking advantage of the optimization of the pruning and maintenance collections. Obviously, the possibility of using cogeneration thermal energy must be carefully evaluated, which in the face of additional plant costs (e.g., local district heating network) can significantly influence the (economic and environmental) sustainability of the initiative.

4. Conclusions and future developments

The purpose of this work was to perform a first feasibility analysis for possible solutions on the recycling and valorization of biomass produced by the activities of a reclamation consortium (CTN). The study aimed at analyzing the maintenance activities in progress at CTN and evaluating the quantity and quality of biomass potentially produced by the ordinary and extraordinary maintenance of the CTN. Given an estimated annual availability of biomasses portioned in the different species considered, identification of their potential energy use has been performed. The estimates on biomass availability can be considered conservative as the quantities that can actually be recovered may be greater. On the one hand, there is a need to better define the quantities available concerning accessibility for collection and environmental requirements, on the other hand, the quantity available could be increased by introducing solutions to encourage the growth of species with a higher energy content on the banks of the rivers. Based on available information, the most technologically and economically interesting solution is the gasification of shrub and woody biomass. Given the sizes involved (50-100 kW) the modularity of the technology guarantees operational reliability and good yields. The analysis carried out on a 50 kWe module shows a short return on investment and convenient NPV.

The amount of energy obtained in this configuration is sufficient to cover 15% of the electricity needs of CTN. It can reasonably be assumed that, with an optimized collection system and with synergies with local stakeholders, it is possible to reach up to 45-50% of the CTN electricity needs. Moreover, consortiums can be developed with the municipalities that manage urban green, or even with local farms in reclamation areas (peaty soils) that could be interested in the cultivation of specific biomass, i.e., perennial crops, that could also prevent the problem of subsidence often generated by intensive land use.

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