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Technologies for energy recovery from waste biomasses: a study about Tuscan potentialities

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Abstract: Biomass is a form of renewable energy that can be used to provide high energy outputs, to support and in same case replace conventional fossil fuel energy sources. There are many kinds of energy conversion processes in relation both with biomass chemical - physical characteristics and with the form in which the energy is required. In this work the potentialities for energy recovery of the waste biomasses derived from the agro industrial activities of the Tuscan region (Italy) are analyzed: in particular waste derived from food crops (cereals, beet, sunflower, olive tree, citruses, vineyard,…), zoo technical activities, and wood. The data obtained are examined to make a comparison between the various energetic and economic results employing different kind of energy systems commonly used in biomass energy conversion. The technologies analyzed are the thermochemical processes combustion, gasification, Fischer Tropsch (FT) diesel fuel production and the biochemical process of anaerobic digestion. Each process requires a proper energy conversion plant. For the above mentioned processes, the conversion plants hypothesized are: for the direct combustion the steam turbine plant, for the gasification the Integrated Gasification Combined Cycle (IGCC), for FT biodiesel the compression ignition engine and for anaerobic digestion the gas engine. These conversion technologies were analyzed also from an economical point of view. This analysis was carried out by taking into account costs (harvest and collection, eventually pre-treatment, transportation cost) and incomes (energy saving and sale. Finally the environmental impact is considered studying the avoided emission of CO2 in relation with the avoided use of fossil energy for the power production.

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Keywords: agricultural residues; integrated gasification combined cycle (IGCC); bio-syngas

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1. Introduction

Climate change concerns coupled with high oil prices, peak oil and increasing government support are driving increasing renewable energy legislation, incentives and commercialization.

Renewable energy effectively uses natural resources by technologies range from solar power, wind power, hydroelectricity/micro hydro, biomass and biofuels for transportation; the term biomass in particular include organic animal and vegetal provenance materials that could be utilized for energetic and compost aims.

The capitalization of the biomass is particularly interesting for agricultural land in which the amount of “green materials” is copious and farming industry is an important economic field: in this areas the utilization of residual biomasses, deriving from vegetal cultures and animal breeding, for the energy recovery is an attractive way to recycle wastes and environmental conservation.

Moreover the utilization of wastes biomasses does not tamper with food agricultural activities, and gives economic benefits deriving from the energy saving and the free availability of the residual farming activities materials.

A potentialities study of using residual biomass for electric power production was carried out for Tuscany region and in particular for Pisa district. This study was based on statistical data that were elaborated to evaluate the amount of electrical energy per year that might be generated using the existing technologies.

2. Methodology

2.1 General Line

Data for the SAU (Farmed agricultural terrains) were obtained by the 5th general farming census (ISTAT)[1] and revisited for the counting of the residual biomass amount derived from different kinds of cultures[2].

A selection of the useful technologies of energetic conversion of biomass [3] was carried out, the electrical efficiency [4] and the yield of the interesting product [5] was detected and applied on the various technological case.

The economic feasibility was studied from the point of view of the evaluation of the incurring cost for the plant installation, the process management [6, 7], the electric power selling price and the incentives provided by[8].

Finally an assessment of the fossil CO2 emission avoided [9] and a global balance sheet for the district was lead.

2.2 Assumed technology

Biomass can be converted into useful forms of energy using a number of different technologies. There are many factor that influence the choice of conversion process and in particular, there are two principal conversion line: thermo-chemical and biochemical-biological [3]. Amongst the thermo-chemical conversion processes, four options can be considered: combustion, pyrolysis, gasification and liquefaction; as for biochemical processes, digestion (production of biogas) and fermentation (production of ethanol) can be taken into account.

In this work the considered technologies were: combustion, gasification, liquefaction via gasification matched with Fischer Tropsch (FT) synthesis and anaerobic digestion conversion processes because of their greater development and commercial availability.

The energy conversion plants applied to the various conversion process are: IGCC (gasification with air, oxygen and steam like oxidative medias), diesel engine (FT-process), Steam turbine (combustion) and gas engine (anaerobic digestion). For each conversion system the electric efficiency was analyzed (see Table I).

2.3 Tuscany region

Tuscany region agricultural activities were analyzed to identify the cultures farming in the area and the amount of residual biomasses available for the different assumed technologies.

The yield of residual material for typology of cultures was applied to the SAU data and differentiated for the technological target (see Table II): thermo-chemical processes or bio-chemical processes.

Table 1. Electric efficiency of the assumed conversion system[4].

Conversion system	Electric Efficiency
Steam turbine	20%
IGCC	38%
Diesel Engine	38%
Gas Engine	35%

2.4 Pisa district

Pisa district was divided in four parts (zone1, zone 2, zone 3, zone 4) with a maximum radius of 70 kilometres responding to the "short weaving factory" benefits of 1.8 multiplication coefficient related to the green certificate achievement. The data relatives to the hectares of cultures for each municipalities of the district were analyzed and summed to the other belong to the same area (see Table III). Besides for Tuscany region analysis, the tons of residual biomasses were calculated through the yield of wastes given by the different kinds of cultures and related to the proper conversion process.

Table 2. Yield of residual material for typology of cultures (ton/hectare)[2].

Cultures	Thermo-chemical	Bio-chemical
Wheat	2	/
Barley	1.5	/
Sweet corn	2	9
Oat	1.5	/
Beet	20	/
Sunflower	4	2
Soy	1	/
Vegetable garden culture	1	/
Olive	1	1
Citrus	1	1
Apple tree	2	1
Pear tree	2	1
Peach	3	1
Vineyard	2	5

Table 3. Municipalities

Area I	Number of farms
Pisa	449
Calci	476
Fauglia	273
San Giuliano Terme	1257
Vecchiano	655

Area 2	
Bientina	319
Buti	493
Calcinaia	141
Capannoli	371
Cascina	560
Castel Franco di S.	295
Crespina	225
Lari	807
Montopoli in V. d'A.	450
Palaia	505
Peccioli	400
Ponsacco	213
Pontedera	512
San Miniato	1199
Santacroce sullA.	345
S.M. a Monte	753
Vicopisano	437
Area 3	
Casale Marittimo	205
Casciana T.	293
Castellina M.	176
Chianni	348
Guardistallo	237
Lajatico	222
Lorenzana	72
Montescudaio	238
Orciano Pisano	81
Riparbella	322
Santa Luce	256
Terricciola	564
Volterra	588
Area 4	
Castelnuovo in val C.	334
Montecatini in val C.	272
Monteverdi M.	172
Pomarance	431

2.5 Anaerobic digestion residual biomass data analysis

ISTAT data for the typologies and number of animal breeding in each area were integrated with the average animal weight and with the yield of sludge produced by ton of animal weight. The breeds picked out were: cattle, swine, poultry and ovine.

2.6 Economical factors

Economic analysis was gleaned starting from plants installation costs, processes manage costs, electricity output and state aids.

The various data were divided in incomings and outlays to obtain a general balance sheet.

The Net Present Value (NPV) of each assumed technologies has been calculated by the formula:

$$\sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \qquad (1)$$

where:
t: deadline
C_t : cash flow
i: rate of return (assumed 6%)

The Internal Rate of Return (IRR) of the various investment was calculated resolving equation [1] in relation to 'i' variable, assumed the NPV equal to zero.

Finally the payback period was calculated to obtain a general assess of the economic feasibility.

2.7 Environmental analysis

The environmental study was led by counting the amount of CO2 produced by the assumed technology compared with the capacity of emissions of CO2 derived by the use of fossil combustibles to produce the same quantity of electricity.

The amounts of biomass and of fossil combustible calculated were integrated with an emission factors giving the CO2 emission capacity and the saved fossil CO2 production.

3. Results

3.1 Tuscany region results

Research results for the various technologies were compared to spotlight the differences and the range of productivity. On the basis of the elaborated data, the best technologies in respect to the energy yield was the IGCC Steam (1.8 TWh/year), and in general the gasification was more suitable if compared with the other analysed technologies (see Fig 1). The synthesis of FT-Diesel for power generation was rejected because of the negative economic feasibility.

The biggest contribution in percentage for the thermo chemical process was given by cultures (see Fig. 2) like wheat, sunflower and sweet corn for the arable cultures; vineyard and olive for the woody cultures. For the biochemical technologies anaerobic digestion (see Fig. 3) showed good data (0.129TWh/year for the Tuscany region) in particular for waste deriving from sweet corn, vineyard and beet cultures and for swine and cattle farming.

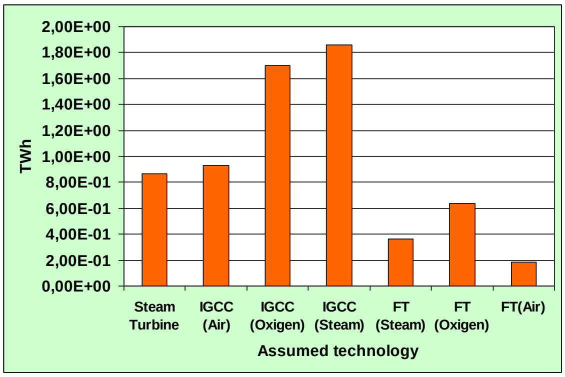

Fig. 1. Comparison between power generations by different technologies.

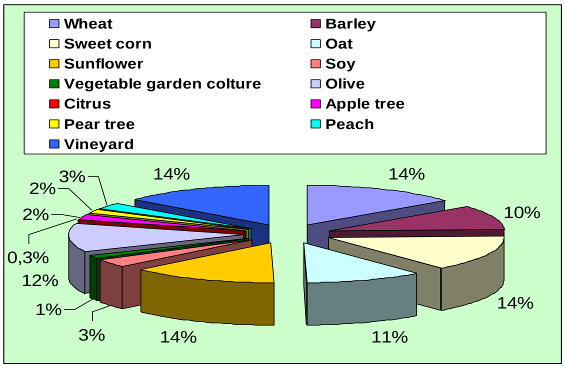

Fig. 2. Percentage of electric output from the different cultures (Steam plant).

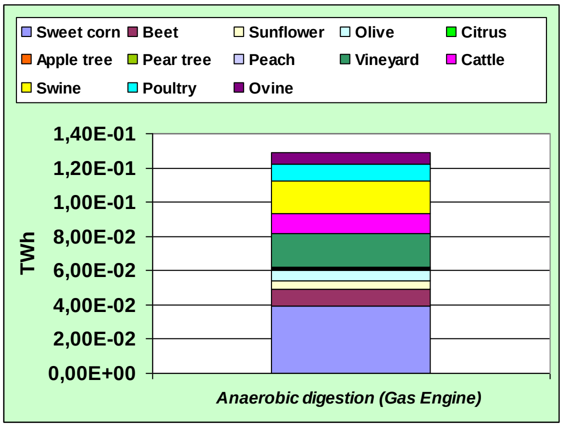

Fig. 3. Electrical output derived by anaerobic digestion.

3.2 Pisa district results

Data obtained from the analysis of Pisa district territory were divided in areas and compared for technology after working out by the same Tuscany region applied methodology.

Power productivities for the various technology and areas (see Fig. 4) were compared in order to describe the potential of each one.

All the four areas gave interesting results in terms of annual energy production (in particular the area 3 that shows the higher value) with a potential of installed power plant that range, in decreasing order, from 10 to 15 MW for the area 3, from 5 to 10 MW for the area 2, from 4 to 10 MW for the area 4 and from 2,5 to 5 MW for the area 1.

The percentage of electric output derived from the different cultures was displayed (see Fig. 5) to point out both the cultures which have the best potentialities then the different cultures distribution in the areas.

Anaerobic digestion also gave a good energy yield that varied from 2,27 GWh of the area 4 to 6,93 GWh of the area 2 (see Fig. 6).

The sweet corn gave a good contribution in all the area, increased by poultry and cattle in the area 1, swine, poultry and vineyard in the area 2, poultry in the area 3, cattle and ovine in the area 4.

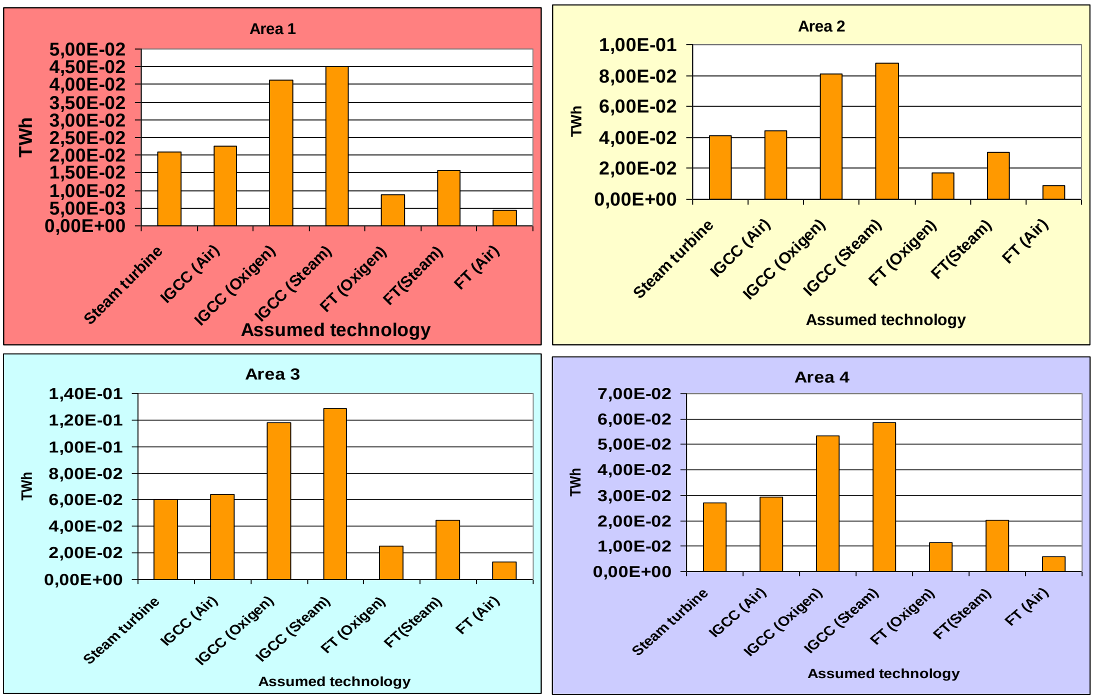

Fig. 4. Comparison between power generation by different technologies for each area.

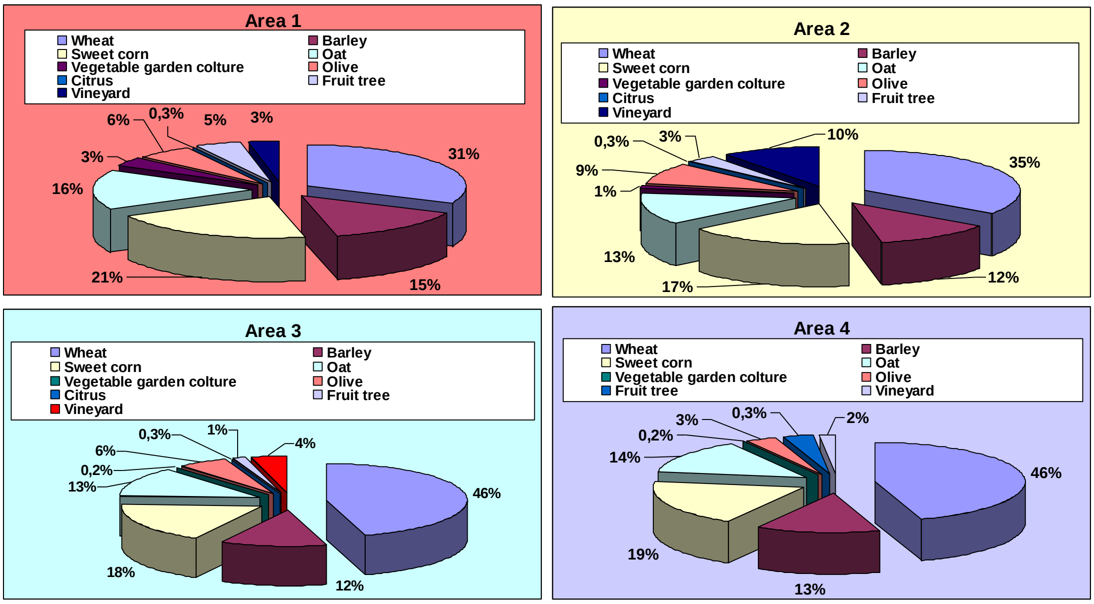

Fig. 5. Percentage of electric output derived from cultures farmed Pisa district areas.

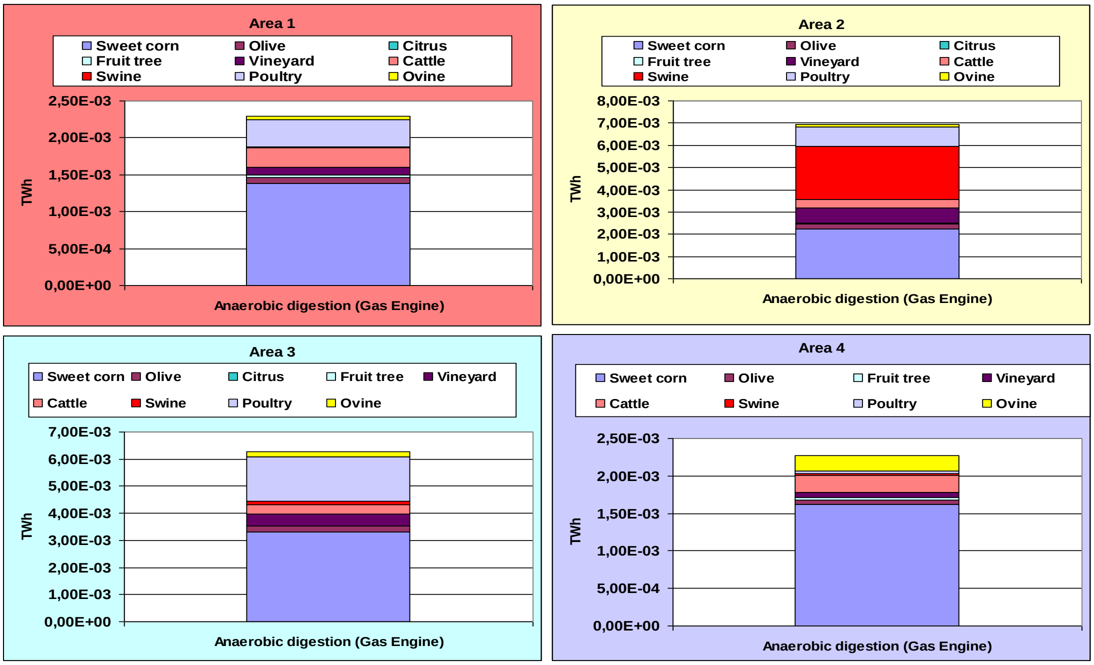

Fig. 6. Electrical output derived by anaerobic digestion

3.3 Economic analysis

Economically all the selected technologies, except for the production of FT – Diesel applied to the energy production, gave good practicality results in every area and showed similar trend (see Fig 7). In particular the suitable technology was the IGCC Steam, succeeded by IGCC Oxygen that showed slightly lower results; Steam turbine and IGCC Air gave similar annual profit (around 2,35E+08 € for Tuscan study) that was significantly lower if compared with the IGCC Steam and Oxygen (around 4,51E+08 € for Tuscan study).

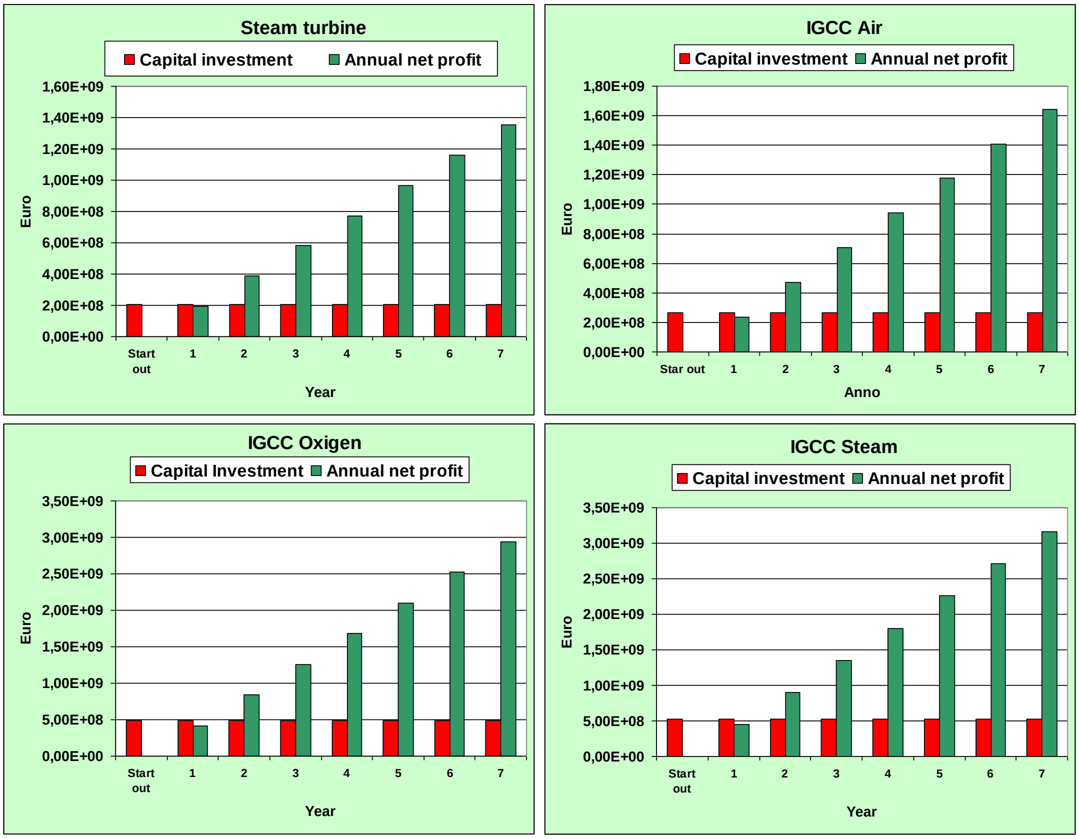

Fig. 7. Comparison between the plant capital investment and the cumulate annual net profit.

The capital investment varied in relation to the analyzed technology, and represented the initial cost of the plant installation; for a 10 MW plant, in example, the capital investment was around 1,85E+07 € for the Steam turbine and around 2,20E+07 € for an IGCC plant, with an average payback period of 2 years. The NPV of the investment was positive for all the technologies – area study and the average IRR is 86%.

The economic analysis of the anaerobic digestion (see Fig. 8) proved that the capital investment (10MW plant) was 4.00E+07 € and the average payback period is 3 years.

The NPV of the investment was positive in all the areas and the average IRR was 50%; for the Tuscany region the potential annual profit resulting from anaerobic digestion was 3,44E+07 €.

3.4 Environmental benefits

The use of residual biomasses can give a contribution to the environmental clean-up of gas carbon causing the greenhouse effect. Tuscany Region, according to Kyoto protocol goal, have to decrease CO_2 emissions from 4E+07 tons of 2000[10] (See Fig. 9) to around 3.4E+07 by 2010[10].

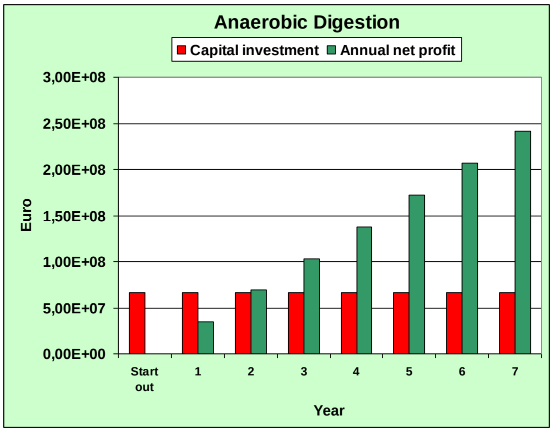

Fig. 8. Comparison between the plant capital investment and the cumulate annual net profit (anaerobic digestion).

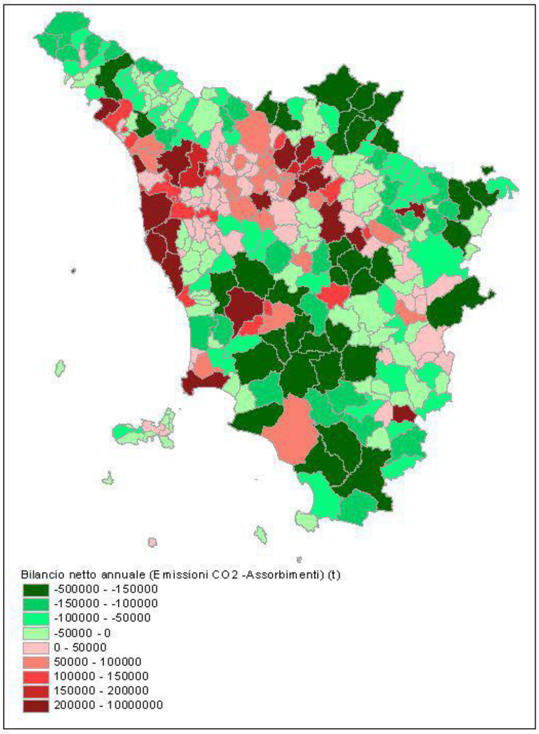

Fig. 9. Tuscany region CO_2 emissions annual net balance (2000) [10].

The technologies analysed in this study, aside from IGCC Air (2,49E+05 tons of CO2 more compared to fossil conversion system emission), allowed to reduce the total emission of CO2 from 4,76E+05 to 6,24E+05 tons/year and skip out fossil CO2 emission from 8,74E+05 to 1,75E+06 tons/year.

4. Conclusions

This work showed the potentiality of energetic capitalization of waste biomasses derived from Tuscany and Pisa district farming activities.

Results explained a good energy capacity that in the better case (IGCC Steam and IGCC Oxigen) exceeded the goal of energetic utilization for the biomass expected by energetic regional plan (800 GWh/year)[11]. Economic analysis gave interesting balance sheet with short payback period and competitive IRR due to the free availability of the residual biomass and to the state funding.

The resulting value of the potential electrical production however requires that small-medium size plant technology would be further developed, despite the non negligible contribution which this kind of plant may provide, because the installed size is relatively reduced (few tenths of MW). Steam turbine power plants, on the other hand, while providing a smaller contribution, still are a viable technology also in this range of installed power.

Environmental appraisal showed that the assumed technology can decrease the annual emission of CO2 of the 2%/year and avoid the fossil CO2 emission of the 6%/year.

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