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Energy self-sufficiency and sustainable development in a closed mountain area

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Abstract

The present paper presents the first results of a study for defining the environmental energy plan of the Province of Belluno, placed in a mountain territory in North-East of Italy. In the plan, the energy consumptions and the potential of renewable energy sources in this tipically mountainous area were first analyzed. The aim of the study was to identify the best strategies of intervention to ensure the sustainable development of the territory. The most energy-consuming sectors have been analyzed and some first possible response interventions have been proposed. The industrial and tertiary sectors have very few possible interventions worthy of note, but the residential sector can be greatly improved. At the same time, the field of energy production has been analyzed, the current state has been studied in detail and the improving potential has been evaluated, focusing on renewable energies, especially on small size hydroelectric power plant and on photovoltaic energy.

Key words

energy consumptions, sustainable development, renewable resources

1. Introduction

The province of Belluno is a territory of about 3670 km^2 , along the 46° line of latitude, in the very North-East part of Italy. It is a typically high and low land territory that includes a large part of the Dolomites mountains. This area is divided into 69 municipalities and has a total population of 213,000 inhabitants.
The first part of the work consisted in the analysis of all the energy consumptions, that have been classified according to energy vectors and to economic sectors. The following results were obtained by the authors on the basis of the analysis and periodical reports done by the national and local authority. National data regarding fossil fuels and natural gas came from the Ministry of Economic Development. Data concerning electrical energy are derived from GSE (Energetic Services Manager), TERNA (Italian leading grid operator for energy transmission), AEEG (Authority for Electrical Energy and Natural Gas) and ENEA (National Agency for New Technologies, Energy and Sustainable Development). Also studies by ISTAT (Italian National Statistical Analysis Institute) were used as well.

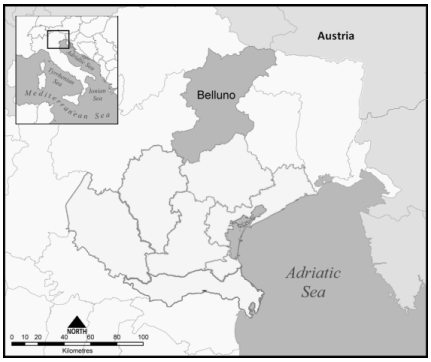

Figura 1: Geographical location of the province of Belluno

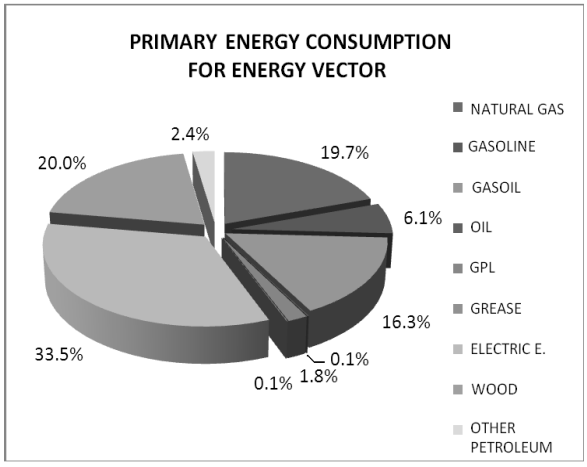

Figure 2: Energy consumptions in the province of Belluno divided by energy vectors

In Figure 2 the partition of energy consumption into energy vectors, in terms of primary energy, is shown. It can be noticed that electricity has the major impact (33.5%), followed by wooden biomasses (20.0%), natural gas (19.7%) and gasoil (16.3%). Analyzing the energy consumptions for the half-decade from 2004 to 2009 (Fig. 3) it is evident a contraction in the energy demand, primary due to the energetic and economic crisis that have reduced the use of fossil fuels, and to the energy policies aimed at reducing consumption into the residential and transportation sectors.

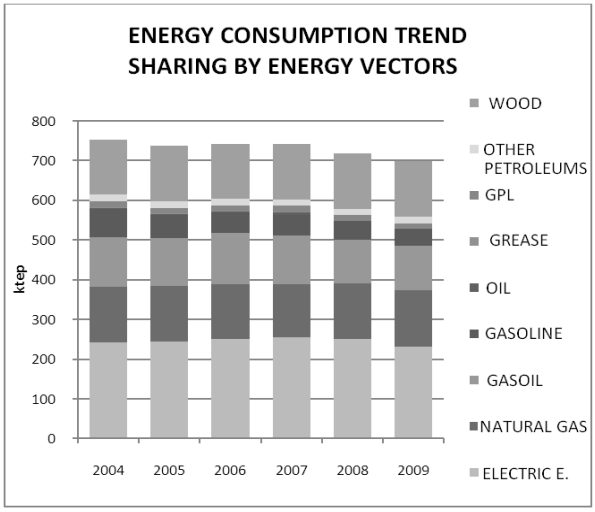

Figure 3: Trend of energy consumptions sharing by energy vector from 2004 to 2009

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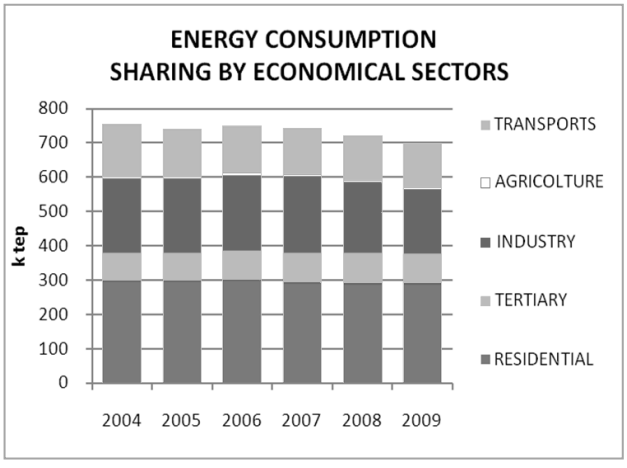


Figure 4: Trend of the energy consumption divided by economical sectors from 2004 to 2009

The Figure 4 shows the energy consumption divided into economic sectors for the five analyzed years. The reduction in the energy demand of industry and motorization is still more evident, while the tertiary sector has a moderate rising.

2. Energy consumption and generation

The first classification in the energy consumptions analysis has been carried out by looking at electricity and petroleum products.
Regarding the electrical energy demand of the analyzed territory, in 2009 the overall consumption was about 1010 GWh [2]

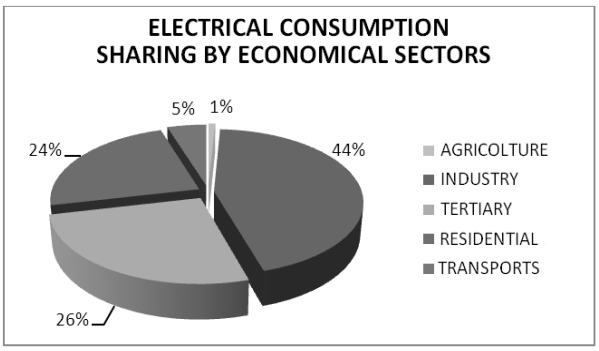


Figure 5: Electrical energy consumption in the province of Belluno divided by economical sectors [2]

The Figure 5 presents the division of the electrical energy demand into economic sectors. As can be seen, the major consumption is due to the industry (44%). In the last half-decade it has decreased because of the global economic behavior. The service sector demand represents around 26% of the total amount of electricity, followed by residential sector (24%); transportation and agriculture present marginal energy needs, i.e. 5% and 1% respectively.
In the analyzed period, except for the tertiary sector that registered a moderate but continuous rising, the industry decreased consumptions, while the other sectors have had uniform energy demands (Fig. 6).

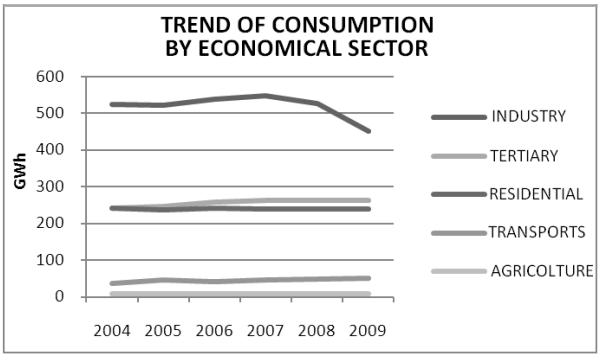


Figure 6: Trend of the electrical energy consumptions divided by economical sectors during the years from 2004 to 2009 [2]

The province of Belluno has several hydroelectric plants for the electric generation, and it is self-sufficient. Currently there are 31 high power operating plants, for a global installed power of about 560 MW and with a

theorical yearly productivity of 2235 GWh. There are other additional 28 mini- and micro- plants for a total installed power of 7.9 MWh and an yearly productivity of about 40 GWh.
It is clear that Belluno produces over two times the electrical energy demanded; due to the overall Italian strong dependency on fossil fuels, there are several studies and projects aimed to increase, especially through mini-hydroelectric power plants, the electrical production, thanks to the favorable conditions of the territory. The province of Belluno is particularly interesting also for the abundance of wooden biomasses, which is currently used for heating, but there are two power plants where wood in combusted for electricity generation (overall power 26 MWe) with an yearly productivity of about 155 GWh.
As for natural gas and petroleum the Province of Belluno depends completely of abroad. The total amount of fossil fuels used during the 2009 for satisfying the energy demand of the province is shown in Table 1 [1].

Table 1. Consumption of petroleum materials in terms of primaty energy, for the year 2009

	UNITS OF PRODUCT	CONSUMPTION [tep]
GASOLINE	3.319	3.983
GASOIL	9.000	9.720
GPL	450	496
ELECTRIC ENERGY	450	103.500
NATURAL GAS	66	54.120
BTZ	3.000	2.940
CARBON	3.320	2.457
COKE	904	670
OTHERS PETROLEUM	12.384	12.136
SECONDARY GAS	622	746
TOTAL		**190'767**

Table 2: Electrical and thermal energy consumpion of the residential sector

CONSUMPTION OF THE RESIDENTIAL SECTOR YEAR 2009 [GWh]	
ELECTRIC ENERGY	**239**
THERMAL ENERGY FOR COOKING	**54**
THERMAL ENERGY FOR HEATING	**1587**
THERMAL ENERGY FOR DHW	**135**

Natural Gas is used in combination with biomasses for thermal energy generation, while a large part of the petroleum materials demand (70%) is due to transportation (Fig 6).
The demand of Natural Gas during the 2009 has been of about 167 Mln of Sm^3, that could be assigned for a 20% to tertiary sector, while the other part could be divided equally to residential and industrial sectors (Fig. 8).

Figure 7: Consumption of petroleum materials divided by economical sectors

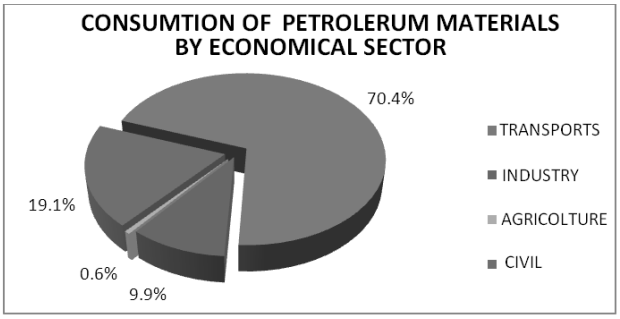


Figure 8: Consumption of natural gas divided by eonomical sectors

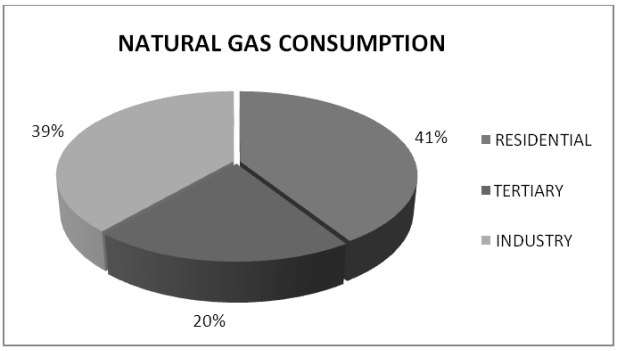
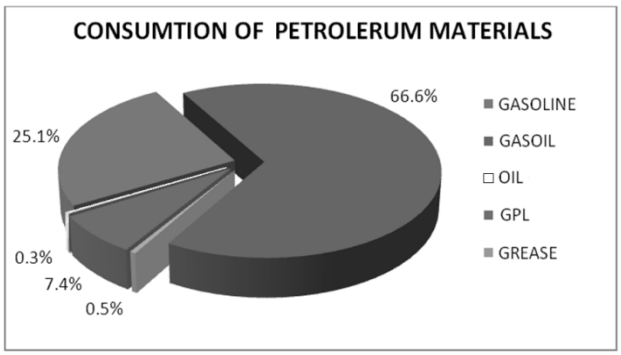


Figure 9: Consumption of petroleum materials divided by energy vectors



The percentage of petroleum materials consumptions is shown in Figure 9. The gasoil is the fuel mostly used (67%), as it is consumed both for heating and for vehicle motion, followed by the gasoline (25%), used for transportation, and LGP (7%), mainly used for heating. The trend of consumption from 2004 to 2009 shows a slow substitution of gasoline by diesel, but also gasoil and LGP demand are decreasing.
The analysis of the energy demand of the residential sector is shown in Table 2. It can be noticed the electrical and thermal consumptions for different uses (heating, cooking and hot water generation). The typical highland territory and the latitude cause a severe winter climate (the average is around 3450 degree day).

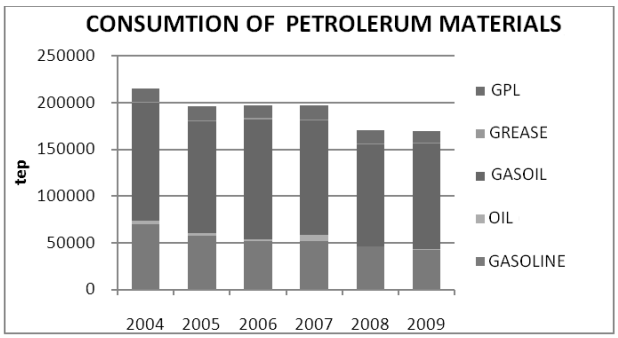


Figure 10: Trend of the consumptions of petroleum materials from 2004 to 2009, in terms of primary energy

Table 3: Energy consumption of residential sector divided by energy vectors in term of primary energy

	UNITS OF PRODUCT	CONSUMPTION [tep]
GASOIL	18.300 [t]	19.763
GPL	12.000 [t]	13.200
ELECTRIC E.	238,5 [GWh]	54.855
NATURAL GAS	70 [Mln Sm^3]	57.400
WOOD	308.516 [t]	138.832
TOTAL		**284.050**

The Table 3 shows how the heating demand is satisfied essentially by natural gas, gasoil and wood. In fact Belluno has a well settled natural gas network, that serves 37 municipalities (overall 69 municipalities are present). If methane is not available, gasoil is used, while GPL use is less popular.

The large use of wood in the mountainous area is due to the local tradition. Previous studies made in this province estimate the consumption of wood for domestic heating in about 308,000 tons. Through a questionnaire submitted to a sample group of 5,000 people the diffusion of wood and the way it is used have been investigated [5]. A distinction has been carried out between highland and valley areas, the result of the analysis is shown in Figures 11 and 12.

In the valley areas (Fig. 11) the 78% of people uses wood for heating, and for the 46% this is the primary energy source to satisfy the heating demand. In the highlands (Fig. 12) the percentage rises and the people that use wood reaches the 96%, while this is the primary source for the 58% of sample. Another study [4] made by ARPA (Regional Agency for Environment Protection) analyzes the systems for the combustion of wood. Traditional wood stoves are the 54% of the installed plants, open fireplace are only the 4% and high efficiency combustion systems reach the 42%; compared to.

Regarding the biomass availability in the territory, several studies have been carried out in the last years, and several projects are in progress to determine the potential of a local network of production, procession and commercialization of wood. Suitable areas have been evaluated according to their altitude (less than 1550 m above sea level), the slope of the hill sides, and the proximity to a route practicable by heavy lorries. Moreover the analysis of the productivity of these areas have been developed under the conservative hypothesis of considering just the annual variation of woods, without damaging the forestry asset. Although this estimation leads to a limited productivity, results can be underestimated due to the restrictive choices carried out in the research.

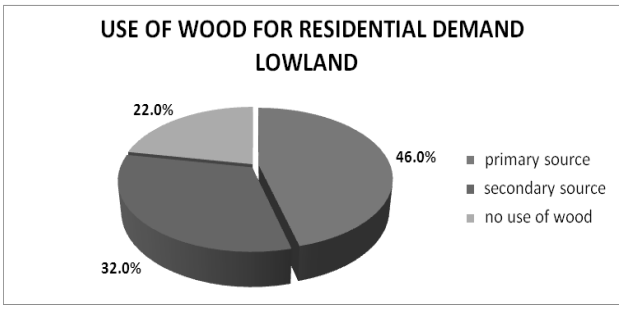


Figure 11: Use of wooden biomass in residential sector in lowland territories

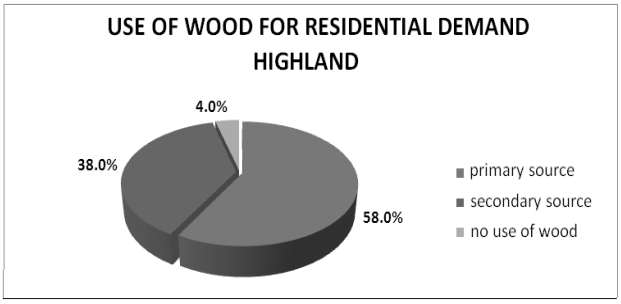


Figure 12: Use of wooden biomass in residential sector in highland territories

Despite the decentralized position with respect to the national primary industrial centers, the province of Belluno has a rich and well settled industrial activity. It absorbs about 27% of the global energy consumption of the territory. Pulling sectors are eyeglasses industry, optics, textile sector, steel industry, woodworking and carpentry. Analyzing the same half-decade as before, a decrease in the energy consumption can be noticed, which is due to the economic crisis.

Belluno is characterized by a strong tourist vocation and services sector, hotels and all the business linked to summer and winter accommodation has a great importance for the local economy. Tertiary sector is the only one that had no decrease in terms of energy consumptions; on the contrary it is gradually growing. Almost 13% of the global energy consumption is used to satisfy the tertiary sectors demand.

3. Potential of renewable resources

After the analysis and the sharing of consumptions divided by economic sectors , the following step of the work had the goal of estimating the current use of renewable resources and on the estimation of their potential for a sustainable development of the area of Belluno.
As already explained, wooden biomasses and hydroelectric plant are the most interesting renewable energy sources. The orography conformation of the territory and the surrounding Dolomites mountains make this area not appropriate for exploitation of wind power. Anyway there are three experimental wind power plant, with a power of about 20 MWe each, realized for on field research on small wind turbines.
The solar energy is quite diffusely exploited. Solar thermal plants are used for hot water generation and sometimes as integration for low temperature dwelling heating systems. Photovoltaic cells installations are even more numerous: there are domestic plants on roofs and also large plants on ground, or on the top of industrial buildings. Photovoltaic systems have gained popularity since 2005, thanks to the State incentive campaigns.
On the basis of Atlasole database [6], at the end of May 2011 in Belluno area there were 1,260 on grid photovoltaic plants for a total installed power of 13,917 kWe. There are also several off-grid installations used to serve isolated buildings, like pastures and mountain huts, but the real number and location are unknown as well as the installed power.
Regarding solar thermal plants there is no official database; the most authoritative survey was made by ARPAV in 2007 [7]. According to this survey, there were 1089 thermal solar installations, and the number was duplicating in the previously three years.
In order to analyze solar systems plants potential, an estimation of the amount of the suitable areas that could be covered by solar collectors (both thermal collectors and photovoltaic cells). The analysis was based not considering the photovoltaic plants installed on the ground, since the Region Veneto (where the province of Belluno is placed) had a very intensive construction activity and hence a wide occupation of the land in a not sustainable way.
The areas of the roofs with an appropriate orientation and slope have been accounted, both for residential and for industrial buildings [12]. On the basis of the provincial technical cartography, for each municipality the area for suitable installations has been estimated. Appropriate coefficients to account the orientation of the roof, the shading due to other buildings and building components and the area needed for thermal solar installations, have been introduced.

The relationship used for this evaluation is the following [8]:

Where the coefficients used have the following meaning, while the values used are showed in Table 4:

C_{RT} considers the geometry of the roof, i.e. the useful flap;

CF considers the presence of chimneys, roof windows and possible obstacles;

C_{ST} concerns the precautionary presence of solar thermal panels;

C_{COV} represents the coverage ratio;

C_{SH} takes into account any shading.

Table 4: Values for the coefficients used in equation (1) to calculate the suitable area for solar systems [8]

COEFFICIENT	CIVIL	INDUSTRIAL
C_{RT}	0,50	0,75
C_F	0,70	0,90
C_{ST}	0,90	1,00
C_{COV}	0,45	0,45
C_{SH}	0,46	1,00

The usable area, evaluated by the equation (1), has then been addressed to the installation of solar thermal or photovoltaic systems. The criterion for the selection was to ensure a potential of 50% coverage of the thermal energy demand for the generation of DHW for residential buildings via solar collectors ie., an extimated area of about 180.000 m^2. The remaining surface could be used for installation of photovoltaic systems, about 590.000 m^2. This value must also be increase of the usefull area due to not residential buildings, about 700.000 m^2. Based on the estimates made by GSE [9] on the theorical pruductivity of photovoltaic systems, for a conventional panel, monocrystalline silicon, exposed at the typical latitudes of North Italy (1080 = 1kW_p kWh_e / year), it is possible to assume an average production of energy equal to 130 kWh_e/m^2. The JRC (Joint Research centre of the European Commision) makes available the data of solar radiation for each location in Europe, and produces for each geographical coordinate:

- optimal radiation, H_{ott}, (i.e. the angle that allows to receive the maximum radiation over one year
- incident radiation at a fixed slope, θ H_{fix}. This angle has been chosen equal to $\theta = 20°$ for residential buildings and $\theta = 30°$ and the industrial sector.

Both the values were calculated for each municipality of the terrytory of Belluno.
The percentage breakdown for the type of panel installed, is calculated on the basis of a report by GSE [9]. For Belluno area the values used were: 13% for monocrystalline panels (MC), 74% for policrystalline panels (PC) and 13% for thin film panels (FS).
Using the equation (2) [8] the potential of electricity which can be produced via photovoltaic systems, Π [MWh / year], has been evaluated. This etimation has been carried out for each municipality in the province, differentiating between the roof areas of residential and

industrial buildings. Subsequently the results obtained has been referenced geographically.

(2)

Symbols used in the previous equation are:

η_{TH} the atmospheric losses that consider heat loss and life time of the panel;

η_{AZ} the yield azimuth;

η_{INST} losses for the installation of the inverter, the electrical panel and for dust;

η_{MOD} performance of the module. It depends on the panel type (monocrystalline, polycrystalline and thin film).

The values found in the literature [8],[9] for the system loss factors and used in the estimation of the productivity of energy, are presented in Table 5. The analysis results show that using all the available area, and according to the hypotesis, about 15% of the electricity annually consumed by the province of Belluno could be produced.

Table 1: values for the loss factors used in the estimation of fotovoltaic productivity, equation (2)

	MC	PC	FS
η_{mod}	0.15	0.12	0.06
η_{TH}	0.90	0.90	0.90
η_{AZ}	0.90	0.90	0.90
η_{inst}	0.84	0.84	0.84

Table 2: Electrical energy productivity evaluated through the equation (2). The estimated values are presented separated for the civil buildings and for the industrial ones. The total value is the sum of the previuos one. The productivity is given both for the optimum angle of radiance incidence and for the fixed angle chosen for the evaluation.

CIVIL		INDUSTRIAL		TOTAL	
GWh (θ_{ott})	GWh (θ=20)	GWh (θ_{ott})	GWh (θ=30)	GWh (θ_{ott})	GWh (θ_{fix})
72.63	70.67	74.15	73.86	146.8	144.5

4. Conclusions

The work carried out to identify the major items of energy consumptions and to estimate the potential of renewable energy, makes it possible to identify the best strategies for a sustainable development of the area and for reducing the environmental impact of human activities. The first step should always be the reduction of overall energy consumption, and particularly in the residential setor a lot of work can be developed to reduce the heating/cooling requirements (higher insulation for buildings, upgrading of heating and air-conditioning systems, introduction of solar thermal systems and of heat pumps). The use of heat pumps would drastically reduce CO_2 emissions, in an area where air quality problems are significant. This is particularly interesting due to the fact that locally the amount of electricity produced is higher than the consumtpion. According to this, it is important to note that solar thermal systems help to reduce the current 6% of the consumption in the residential sector, used for the generation of DHW. Also photovoltaic systems increase in electricity production could encourage the diffusion of heat pumps, in an area where they would be powered only with energy from renewable sources.
Only a limited portion of land is suitable for the use of geothermal heat pumps; however it could be possible a larger exploitation for these systems. Another possibility for the residential sector could be the creation of biomass district heating networks. The centralized combustion would allow a better control of emissions compared to inefficient systems often still widespread in dwelling buildings.

Acknowledgments

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