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An assessment of the potential and sustainability of Renewable Energy Sources in Friuli Venezia Giulia

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Abstract

In reference to the current energy strategy of the EU, that favours a "neutral" approach to energy source, the aim of the work was to understand which renewable energy sources (RES) and related technologies may best contribute to address the "energy problem", with particular reference to biomass (biofuels, biogas and biomass for combustion), in the Region Friuli Venezia Giulia, Italy.The results indicated that Hydropower, Wind power, Solar PV (all roofs), Solar PV (parks), and Biogas could replace 30.6% of current gross energy consumption, with Wood heating contributing to an additional 7.1%. Assuming that Energy saving might still reduce total consumption by 26%, the sum of all RES (transport biofuels excluded) would amount to 50.9% of future gross energy inputs.

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*Keywords:*Biomass; Biofuels;Biogas;Combustion; Sustainability.

1. Introduction

The current energy strategy of the EU favors a "neutral" approach to technologies, implying that no single technology or energy source is preferred or especially promoted. In fact, according to the Energy Roadmap 2050

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(European Commission, 2011), no single technology will be able to deliver the desired amount of change required to facilitate the transition towards a decarbonized economy in 2050; instead, a full portfolio of energy sources and technologies will be needed, and that will probably include solar, wind, and bioenergy (Moneti, Delfanti, Marucci, Bedini, Gambella, Proto &Gallucci, 2015). However, in order to develop R&D projects, it is necessary to understand which renewable energy sources (RES) and related technologies may best contribute to address the "energy problem". This will avoid spending money on useless research and will enable researchers to concentrate their efforts on the most promising technologies (Proto, Zimbalatti, Abenavoli, Bernardi&Benalia, 2014). At this point, it should be recalled that the "energy problem" has arisen because of:

- declining fossil fuel sources, coupled with increasing energy demand; this may lead to increasing energy prices, and represent a substantial threat for the economy;
- the high dependency of the European economy on imported (fossil fuel) energy; which is another threat for the economy;
- greenhouse gas (GHG) emissions from fossil fuels, that are affecting the climate, i.e. producing a threat for the environment.

In order to effectively respond to such challenges, any RES technology will have to fulfil five basic requirements:
1. be cost-competitive with fossil fuel alternatives;
2. be locally available;
3. be continuously produced and/or storable;
4. have a positive GHG balance;
5. have no adverse effects on the environment and the well-being of society.

Cost-competitiveness is, of course, a primary requirement that may be difficult to evaluate in times of quickly changing prices. To the purpose of the present study, current prices in April, 2014, were used. The RES must be locally available in sufficient amounts, if it is to contribute to security of energy supply. If large imports of biomass fuels are necessary to replace imports of fossil fuels, there will be no beneficial effects on the economy, and import dependency will continue. A substantial dependency from imports exists even for solar power and wind power: in fact, most of the production cost is investment, and nearly all basic equipment is produced abroad.

Table 1. Requirements for sustainable production of energy from renewable energy sources (RES).

To respond to the overall objectives, a RES should		
1	be cost-competitive with fossil fuel alternatives	
2	be locally available	
3	be continuously produced and/or storable	
4	have a positive GHG balance	
5	have no adverse effects on the environment and the well-being of society	
	5.1	biomass production must not be at the expense of important carbon sinks in the vegetation and in the soil
	5.2	the production of biomass for energy must not endanger the food supply and local biomass applications (energy supply, medicines, building materials)
	5.3	biomass production must not affect protected or vulnerable biodiversity and will, where possible, have to strengthen biodiversity
	5.4	in the production and processing of biomass, the soil, and soil quality must be retained or even improved
	5.5	in the production and processing of biomass ground and surface water must not be depleted and the water quality must be maintained or improved
	5.6	in the production and processing of biomass the air quality must be maintained or improved
	5.7	the production of biomass must contribute towards local prosperity
	5.8	the production of biomass must contribute towards the social well-being of the employees and the local population

Energy should be continuously produced and/or technologies for storage should be available. Otherwise, we will have to rely on other RES as well, or even on fossil sources. This is a major problem for intermittent sources (wind and solar). Currently, no suitable solutions for electricity storage exist apart from pumping in hydropower plants, which is not sufficient. It should be recognized that no single "smart grid" will ever be smart enough to deal with energy shortages, without a sufficient storing capacity.A positive GHG balance is required to respond to the climate change threat. It should be acknowledged that no single technology may ever be completely "CO_2-neutral", since it will always require some input of energy in the production process, or in the production and end-of-life disposal of the equipment. In any life cycle assessment (LCA), any input energy should considered as a source of GHG emissions, regardless of whether it derives from a fossil source (with related GHG emissions) or from a RES (because this implies the use of a GHG reduction credit; i.e., the removal from the energy market of some amount of GHG reduction potential, that is not used to replace fossil fuels but is consumed in the process). Because of this, GHG emissions during the production process are related with EROI (Energy ratio Output / Input, or Energy Return Of Investment) according to the formula:

$$\text{Reduction of GHG emissions}(\%) = 100 \cdot \left[1 - \left(\frac{1}{EROI}\right)\right] \quad (1)$$

All GHG sources must be considered (carbon loss from soils and land use change included).

The fifth requirement can be further analyzed.To the purpose of the present study, it has been expanded into eight sub-criteria, 5.1 to 5.8 in table 1 (Van Damm, Junginger, Faaija, Jürgens, Best & Fritsche,2008). All of thesewill be considered in the following analysis, and necessary explanations will be given there.

2. Promising RES technologies for Friuli Venezia Giulia

Nine groups of renewable energy technologies were considered in the present analysis:

1. Biogas (electricity only) from agriculture (animal wastes, crop residues and maize silage) and urban wastes;
2. Woody biomass for combustion only (firewood in logs, chips and pellet);
3. Giant reed (second-generation) for bio-ethanol;
4. Maize corn (first-generation) for bio-ethanol;
5. Wind power;
6. Solar Photovoltaic (PV) on all roofs;
7. Solar PV - parks 0.5% (i.e., 0.5% of the whole regional area used for PV solar parks);
8. Hydropower (assuming that the production might be increased by 5% by installing new plants, mainly micro-hydropower <500 kW);
9. Energy saving (deriving from energy efficiency or simply from reduced consumption).

Other technologies were not considered, such as:

- concentrating solar power (CSP); unlike PV solar power (that uses both direct and diffuse radiation), CSP requires direct sunlight that it scarcely available owing to the rain climate with high RH of the air during most of the year;
- solar thermal; it would have only a very small, hardly significant share in final energy consumption if used just for hot water production in households; the potential might be higher for the heating of buildings, but no specific studies exist so that any evaluation is difficult;
- biodiesel was omitted for the sake of conciseness, since the results would be very similar to (or even less favorable than) those of the bioethanol technologies included in the analysis.

3. Sustainability analysis

None of the technologies did fulfil all of the five basic requirements for sustainability, excepting Hydropower (table 2).All energy sources are assumed to be locally available; however, Woody biomass for heating is partially dependent on imported wood, i.e. residues from the wood industry accounting for approx. 40% of current consumption. See further in this analysis how the potential production will be estimated and expressed in % of total final energy consumption in the Region. The GHG balance was considered positive, or "partially" positive, depending on the expected reduction in GHG (at least 75%, or at least 50%, respectively). For comments on cost-competitiveness and continuity / storability, please see further in this study.

The last column "is sustainable for the environment and society" derives from a more detailed analysis of the eight sub-criteria (as defined in table 1), and reports "yes", "maybe" or "no" when at least 7, at least 6, or less than 6 of these criteria were fully met, respectively. Details about the eight sub-criteria are not reported here. Current production of Biogas from agriculture (animal wastes, crop residues and maize silage) and urban wastes is not cost-competitive and needs public financial support (subsidies). Production of biogas is nearly continuous but is not easy to store, e.g. in order to meet variable demand of electricity. Use of maize silage is permitted (up to 30% of the feedstock), and waste heat is not recovered: thus, the average EROI is only 2.1 (GNAS, 2012) and related reduction of GHG emissions is 52%. Adverse effects on the environment and the well-being of society have been reported (poor air quality around plants; decrease in soil fertility owing to the removal of crop residues; local protests over existing or newly planned biogas plants; and most importantly, increase of agricultural prices because of competition for the land used for maize cultivation).

Table 2. Checklist of basic requirements for RES technologies in Friuli Venezia Giulia.

	locally available	cost-competitive	continuous or stored	with positive GHG balance	sustainable (environment and society)
Biogas (electricity)	yes	no	in part	poor	no
Wood heating	in part	yes	yes	yes	maybe
Giant reed ethanol	yes	no	yes	yes	no
Maize corn ethanol	yes	maybe	yes	no	no
Wind power	yes	yes	no	yes	yes
Solar PV - all roofs	yes	yes	no	yes	yes
Solar PV - parks 0.5%	yes	maybe	no	yes	maybe
Hydropower (1)	yes	maybe	yes	yes	yes
Energy saving	yes	no	yes	yes	maybe

(1) Hydropower refers to "New" Hydropower, i.e. additional installations.

Woody biomass (firewood in logs, chips and pellet) is in most cases cost-competitive even without public subsidies, and has a positive GHG balance (EROI = 10). Under the current assumption (20% increase over current consumption levels), no adverse impacts on carbon sinks, ecosystems and biodiversity are to be expected. In fact, 40.5% of the forest area in Friuli Venezia Giulia is protected by the law and not available for logging; and only 32.6% of the potentially available increment in the remaining forests is currently being harvested. However, increased use of wood for heating may affect the price of wood for construction and furniture, and may worsen air quality, because of an increase in gaseous emissions, mainly particulate matter (PM) and other noxious compounds (PAH)such as hydrocarbonsfromoil andpolyaromatic hydrocarbons. An additional threat derives from the fact that current biomass supply is nearly 40% dependent on wood residues from the furniture industry, i.e. from largely imported material; thus, any decline in industrial production or difficulty in imports might adversely reflect on firewood availability. Giant reed ethanol is still not cost-competitive with gasoline, but its production is supported by existing legal obligations following the 10% target share for biofuels in transport fuels to be reached in the year 2020 according to Directive 2009/28/EC (current share is about 4.5% in Italy). Second-generation ethanol is credited with a high EROI (5.4) and a 80% GHG reduction. Conversely, Maize corn ethanol is nearly cost-competitive, but has a much lower EROI of 1.2 under Italian conditions, and the associated reduction of GHG emissions is less than 20%. Adverse effects on food prices must be expected from both biofuels, because of competition for the same resource, i.e. agricultural land. In this study, it was assumed that 25% of all arable land could be used for producing bio-ethanol. Such assumption is highly hypothetical, and was made in order to assess how much the regional balance would benefit from the resulting biofuel production. Energy crops were assumed here to replace existing food crops; thus, any change of destination of unused agricultural land has been excluded from the present analysis. Adverse effects on soil quality may derive from increased cultivation of maize and giant cane and associated decrease in the organic matter content of soils. No beneficial effects are expected from bioethanol industries as to local prosperity (jobs, higher income, creation of local companies).The area suited for wind power installations (i.e., average wind speed at least 4 m/s) is very small in Friuli Venezia Giulia (less than 1%). The resulting electric energy is not continuously available, and cannot be efficiently stored until new technologies for storage are developed. The same constraint would affect Solar PV. Adverse effects on ecosystems (disturbance of bird migrations) and the landscape are probable.Solar PV has already reached "socket parity" for small end-users (households) that consume all the electricity they produce, but still not "grid parity" for bigger, net producers. Socket parity is owing to the existing gap between the purchase price and the production cost of PV electricity, which has strongly decreased in recent years (leading, by the way, the Italian Government to abolish any subsidies on production in 2013 (but incentives for investments are still in place). However, "grid parity" has not been reached yet, i.e. the cost of electricity generation from solar PV is still higher than generation from fossil fuels, especially natural gas (+50% approx.), which makes solar PV still not competitive, without public support, for net producers, e.g. big solar parks, despite the fact that PV modules placed on the bare ground are cheaper to install and to manage than those installed on the roofs of buildings. However, Solar PV production is intermittent by nature; this will make it difficult for the grid to absorb increased amounts of PV electrical generation, unless sufficient storage capacity is developed, which is difficult to predict at the moment owing to the high cost and low efficiency of currently available storage technologies. Solar parks would have a large impact on the landscape; because of the total area assumed here (3 750 ha), they would become nearly so common as vineyards (18 000 ha). PV panels placed on the ground may affect soil quality since the growth of vegetation is undesirable and will probably lead to increased runoff and increased use of chemical weed control.It is acknowledged that all potential sources for Hydropower have been already been exploited. Additional production (+5%, as assumed here) may derive basically from micro-plants, which are generally not cost-effective at the moment.

Table 3. Percentage of requirements that were met, not fully met, or not met by the RES considered in this study.

	criteria 1 to 4 (basic)			criteria 5.1 to 5.8 (environment and society)			all criteria (weighted averages)		
	fully met	not fully	not met	fully met	not fully	not met	fully met	not fully	not met
Biogas (electricity)	25	50	25	37.5	50.0	12.5	31.3	50.0	18.8
Wood heating	75	25	0	75.0	12.5	12.5	75.0	18.8	6.3
Giant reed ethanol	75	0	25	62.5	12.5	25.0	68.8	6.3	25.0
Maize corn ethanol	50	25	25	62.5	12.5	25.0	56.3	18.8	25.0
Wind power	75	0	25	75.0	25.0	0.0	75.0	12.5	12.5
Solar PV - all roofs	75	0	25	100.0	0.0	0.0	87.5	0.0	12.5
Solar PV - parks 0.5%	50	25	25	62.5	25.0	12.5	56.3	25.0	18.8
Hydropower	75	25	0	100.0	0.0	0.0	87.5	12.5	0.0
Energy saving	75	0	25	75.0	12.5	12.5	75.0	6.3	18.8

Energy saving is, of course, continuously available and has 100% reduction of GHG emissions. Here, additional energy saving is considered not cost-competitive without public support (if it were, it would have been introduced already). Additionally, there is a basic uncertainty about how much energy saving can be obtained from improved processing methods ("more of economic value from less of energy"), and how much will have to derive, on the contrary, from simply compressing our current energy consumption. The latter may have indeed adverse effects on the well-being of the society, with possible negative effects on the local economy and social well-being.

The percentages of requirements that were met, not fully met, or not met by the RES considered in this study are shown in table 4. A distinction is made between basic requirements (criteria 1 to 4 in table 1) and environmental or societal requirements (criteria 5.1 to 5.8 in table 1). In the last three column, the percentages represent weighted averages (i.e., the four criteria 1 to 4 are considered to have, taken together, the same weight or relative importance as the eight criteria 5.1 to 5.8 taken together).

4. Assessment of the energy potentials

An estimate of the maximum production from each of the RES was performedan please note that:

1. Biogas: our estimate derives from the potential biogas production from agriculture in FVG assessed by Dell'Antonia et al. (2013); doubled to include municipal wastes;
2. Woody biomass: current 650 kt/year estimated firewood (ARPA FVG, 2013); increased by 20% to account for possible increases in the harvested fraction of net annual increment of forests (currently, just 32.6% of the potentially available increment in non-protected forests);
3. Transport biofuels: the assumption of using 25% of arable land for biofuels is highly hypothetical, since it would probably increase corn prices and related costs of animal breeding at unacceptable levels; cultivation of giant cane would certainly be at the expense of former food or fodder crops;
4. Wind power: Friuli Venezia Giulia has very little potential, since areas with average wind speed > 4 m/s, as the minimum required by wind turbines, represent just 1% of the whole territory (7500 km^2);
5. Hydropower: current hydropower (1409 GWh in 2005), increased by 5%; it is acknowledged that all suitable sources have already been exploited, so the additional 5% only refers to micro-hydropower, < 500 kW;
6. Energy saving: according to the maximum estimate in the Italian Energy Strategy (2013).

Energy potentials were calculated in ktoe/year, using the following conversions:thermal energy: 1 ktoe = 4.187 × 107 MJ;electricity, final energy: 1 ktoe = 1.163 × 107 kWh;electricity, gross energy: 1 ktoe = 2.975 × 107 kWh (i.e., the energy content of the fossil fuel used for electricity generation, assuming 39% generation efficiency; in order to reflect the amount of fossil fuel energy that the RES could replace).

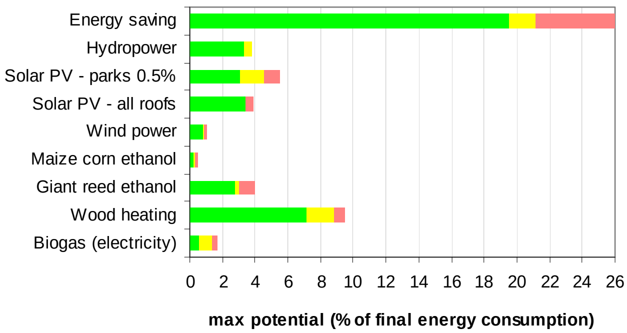

Fig.1. Maximum potential of several RES technologies (% of final energy consumption). The yellow and red bars reflect the uncertainties or challenges associated with the deployment of each RES.

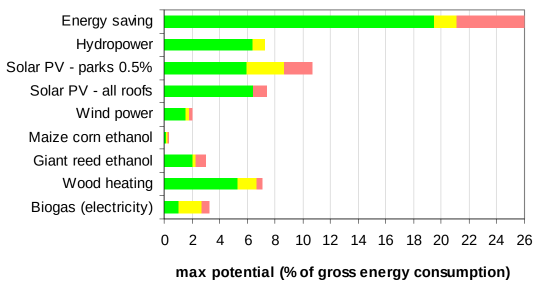

Fig. 2. Maximum potential of several RES technologies (% of gross energy consumption). (% of final energy consumption). The yellow and red bars reflect the uncertainties or challenges associated with the deployment of each RES.

Potentials were expressed as the percentages in final energy consumption (Fig. 1), and gross energy consumption (Fig. 2) in Friuli Venezia Giulia (3 352 ktoe/year, and 4 465 ktoe/year, respectively in the year 2008; ISTAT-ENEA, last statistic available).

5. Discussion and conclusions

The energy production estimates and the sustainability analysis may be combined as in Fig. 1 to reflect both the potential of each RES, and the uncertainties or possible threats associated to their actual deployment in Friuli Venezia Giulia. In Fig. 1, each bar represents the maximum energy production (% of final energy consumption) following the assumptions described above; while the green, yellow and red portions of each bar reflect the percentage of basic requirements that are met, not fully met, or not met, respectively.

Fig. 1 suggest that Energy saving will be the most important RES in the next future, according to projections (up to 26% of final energy consumption). The next two most promising technologies are Woody biomass (9.5%) and Solar PV (9.4%; including Solar PV parks, 5.5%, and Solar PV - all roofs, 3.8%).

Maize corn reed ethanol would represent 68.5 ktoe/year, i.e. 9.9% of all transport fuels consumed in Friuli Venezia Giulia in 2008 (692 ktoe), or 2.0% of total final energy consumption (3352 toe). However, this would not imply a reduction in fossil fuel consumption of the same magnitude. In fact, producing 68.5 ktoe of bioethanol would increase fossil fuel consumption to cover the energy requirements of the agricultural and industrial stages of the whole process (i.e., approx 77% of the final energy content of the biofuel), so that the actual net gain would be only 0.5% (as reported in Fig. 1). Because of this, first-generation transport biofuels do not seem to represent a suitable option for the region.Giant reed ethanol would perform better. It would represent 164.4 ktoe/year, i.e. 23.7% of all transport fuels consumed in Friuli Venezia Giulia in 2008 (692 ktoe), or 4.9% of total final energy consumption (3352 toe). Because of the better EROI (5.4), the actual net gain would still be 4.0% (as reported in Fig. 1). However, this would be only possible at the expense of sacrificing 25% of all arable land, with probable very strong effects on food and fodder prices. In short, even second-generation transport biofuels do not seem to be a suitable option for the region.The full potential from all RES (excluding Energy saving and, for the reasons just explained, Transport biofuels), would represent 25.5% of the current final consumption; or, 34.3% of future consumption (reduced by 26% below current levels, thanks to Energy saving). This conclusion can be taken assuming that all problems, related to those sustainability criteria that are presently not met (and reflected by the yellow-red bars in Fig. 1), could be positively solved in the next future. The present estimates (34.3%) can be compared with the target share (19.1%) of RES in final energy consumption set for 2020 by the "burden-sharing" Decree 28/20121 (i.e.: 6.6% for Heating and cooling; 6.1% for Electricity; including the national target share of 6.4% for Transport, set by the National Renewable Energy Action Plan, 2010). Our analysis shows that a potential exists for Friuli Venezia Giulia to progress well beyond the 2020 objectives.In Fig. 2, all electricity sources have been converted in the amounts of thermal energy that would be required to produce them with fossil fuels, assuming a conversion efficiency of 39%, i.e. the current average in Italy (equal to 9,21MJ/kWh). Then, they have been calculated in % of total gross energy consumption in 2008 (i.e., 4465 ktoe, including all fossil fuels used for electrical generation, mainly natural gas and coal). Thus, Fig. 2 better reflects the ability of renewable electric generation to replace current fossil fuel consumption. The results indicate that Hydropower (increased by 5%), Wind power, Solar PV - all roofs, Solar PV - parks 0.5%, and Biogas could replace 30.6% of current gross energy consumption, with Wood heating contributing to an additional 7.1%. Assuming that Energy saving might still reduce total consumption by 26%, the sum of all RES (transport biofuels excluded) would amount to 50.9% of future gross energy inputs.This suggest that Friuli Venezia Giulia, even in the case of strong political support of RES, will remain highly dependent, in the next future, on traditional and/or imported energy sources. While this will certainly pose substantial threats and constraints on future economic development, it will be nevertheless necessary to make the best of alFig.l available RES and related technologies, in order to reduce the impact of rising fossil fuel prices and/or reduced security of supply.

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