Academia Journal of Environmental Science 7(11): 288-300, November 2018
DOI: 10.15413/ajes.2018.0172
ISSN: 2315-778X

Research Paper

Water scarcity footprint: The case study of the Italian electricity mix

Accepted 7th November, 2018

Abstract

Water footprint of energy system is a topic of main concern in the framework of sustainable development. Recently a new framework has been introduced by ISO 14046:2014, integrating water footprint assessment in the Life Cycle Assessment (LCA) methodology (ISO 14040:2006). The goal of the present work is to assess the water footprint of Italian electricity mix, using (LCA) methodology. The case study was aimed also to point out the needs for data improvements. For the Italian electricity mix, more than one hundred types of power plants were considered. In accordance with ISO 14046, first, water consumptions along the entire electricity life cycle were evaluated. Then the impact of the water consumptions on local water scarcity (water scarcity footprint) was assessed. To this end, among impact assessment methods available in literature, we selected AWARE which is the result of a recent process of harmonization carried out by the Water Use Life Cycle Assessment (WULCA) working group. Results were also compared with the results of another impact assessment method. Although the hydropower contributes 18.5% of the national electricity mix, it dominates the overall water consumption (over 66%) and water scarcity footprint (78%). On the other hand, natural gas plants with a contribution to the mix of 28% are responsible for only 3.51% of water consumption and for around 3.6% of water footprint. With a share of 7% in the mix, photovoltaic contribution is 3.5% of the consumption and 2.7% of the water footprint. Imported electricity covers 14% of the mix and accounts for 17% of consumption, but only 8% of the water footprint. The application of the WAVE method leads to similar conclusions. The allocation of impact of hydropower to the various uses in multi-purpose reservoirs remains a topic to be further investigated. Moreover for hydropower a monthly assessment should be implemented in consideration of temporal variability of water consumption and availability. The study provided first results of water footprint assessment of Italian electricity mix according to ISO 14046 and can support water footprint assessment in a wide field of LCA applications, since electricity is often the most water intensive process in the life cycle of industrial products. The use of primary data for cooling systems led to more accurate evaluation and is recommendable for similar studies. The analysis of water consumption by geographic location put in evidence the need for data improvements especially for studies aimed at comparisons between different technologies or alternative fuel supply chains.

Key words: Water footprint, LCA, electricity mix, AWARE.

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INTRODUCTION

Water is essential to energy, in power generation, extraction, transport and processing of oil, gas and coal, and, increasingly, in irrigation for crops used to produce biofuels (International Energy Agency IEA, 2012). According to

World Energy Outlook scenarios (IEA, 2012) there is a general trend toward higher water consumption by the energy sector over 2010-2035. Other studies available in literature foresee a tendency towards the growth of water demand for energy uses. According to Mekonnen et al. (2016), only a substantial increase in the share of solar, wind and geothermal energy will lead to a reduction in the water footprint of the electricity and heat sector in the coming years at a global level. Other estimates at European level forecast, depending on the scenario taken into consideration, 68% increase or 33% decrease in water withdrawals for electricity production between 2000 and 2050 (Flörke et al., 2011). In this framework a deep insight into the aspects concerning the water resource appears important in the evaluation of environmental impact of the energy system.

Although water footprint has been studied for several years, the ISO 14046: 2014 has only recently established a new framework for the calculation of the water footprint according to Life Cycle Assessment (LCA) methodology (ISO 14040:2006).

The goal of the present work is to assess the water scarcity footprint of Italian electricity mix following the ISO 14046 approach. Since the new ISO 14046 approach and the new impact assessment method, AWARE, are used, the work is aimed also to point out methodological issues. In particular, the case study is an occasion to test the extent to which LCA database can be used "as they are" and the importance of primary data in order to identify where to address future efforts to improve data, with particular reference to the localization of processes (the impact of water consumption on the water scarcity depends on the availability of water resource in the location where the consumption occurs).

METHODOLOGY

We assessed the water scarcity footprint of Italian electricity mix according to the methodological approach of ISO 14046:2014. The functional unit is 1 MWh of electricity fed into Italian electricity grid (reference year 2014). The Impact Assessment phase in water footprint methodology is still a subject of debate, in particular relating to the assessment of impacts on water scarcity (or "water scarcity footprint"). An important process of harmonization has recently been undertaken by the Water use life cycle assessment (WULCA) (a working group of the UNEP-SETAC Life Cycle Initiative) which has led, in 2017, to the development of a new method to be used as an indicator of mid-point impact of water scarcity: AWARE - Available Water Remaining (Boulay et al., 2018). AWARE is based on the quantification of the relative available water remaining per area once the demand of humans and aquatic ecosystems has been met. The assumption is that the potential to deprive another user of water is directly proportional to the amount of water consumed and inversely proportional to the available water remaining per unit of surface and time in a region. The resulting characterization factor (CF) ranges between 0.1 and 100 and can be used to calculate water scarcity footprints as defined in the ISO standard (Boulay et al., 2018). CFs are given by the ratio between the Availability minus Demand (of humans and ecosystems) world average[1] and the Availability minus Demand of the specific region. CF units are dimensionless and expressed in m^3world eq/m^3.

In this work, we selected the AWARE method, but since there is still a need for further testing on a wider range of case studies (Boulay et al., 2018), the results have been compared with the results of WAVE method by Berger et al. (2014). Even if the goal was the water footprint assessment of the electricity mix, for a better comprehension of the results, a comparison between the different types of plant was also carried out. Moreover an analysis of water consumption by geographic location was carried out which helped, also, to identify needs for data improvements.

Data quality

A detailed electricity mix was considered which consists of more than one hundred types of power plants, from conventional and alternative energy sources. "Types of plants" means, for thermoelectric sector, a combination of fuel (natural gas, derived gas, diesel, coal, etc.) and technology (conventional, combined cycle, gas turbine, etc.) both for only electricity and cogeneration plants. As we refer to the mix fed into national grid, and not only to electricity production, also net import was included. As regards background data, Ecoinvent v.3.3 (Wernet et al. 2016) database was used. Primary data were collected for plant efficiencies, yield factor of photovoltaic and cooling systems of thermoelectric power plant, and imported fuels (natural gas, petroleum products and vegetable oils). A great effort was dedicated to data concerning the operation phase of thermoelectric plants. The importance of primary data was evaluated by comparing the results with those obtained using Ecoinvent library.

INVENTORY

The Italian electricity mix

Italian electricity mix fed into grid corresponds to net electricity production (gross production minus electricity own use of power plants) plus net import. As shown in Figure 1, the main contribution to the electricity mix (reference year 2014) comes from natural gas power plants (28%), followed by hydropower (18%), net import (14%)

[1] Availability minus Demand world average is the consumption weighted average of Availability minus Demand of the regions over the whole world (0.0136 $m^3/m^2 \cdot$month)

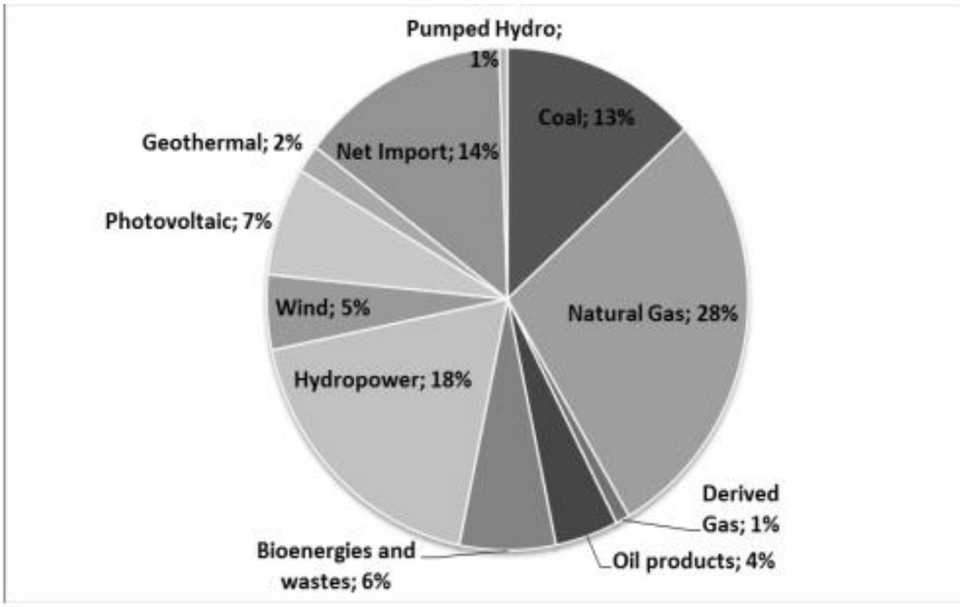

Figure 1. Italian electricity mix by energy source

and coal (13%) power plants. Wind, photovoltaic and bioenergy and wastes, and oil products each are responsible, individually, for less than 10%; while derived gas and geothermal energy cover only a few percentage points of the electricity mix. Figure 2 describes the composition of Italian electricity mix at a detail fuel – technology (technologies are indicated only for contributes major than 1%). More detail for wind (size of plants), photovoltaic (type of installation and technology) and hydropower (run-off and reservoir) is also provided.

For inventory data we made reference to Girardi et al. (2017) and Brambilla and Girardi (2017), who used a set of primary data for efficiencies of thermoelectric plants and for the yield factor of photovoltaic (TERNA, 2014), import mix of natural gas (SNAM, 2014) and import mix of oil products (Ministero dello Sviluppo Economico, 2015). However for an accurate assessment of water scarcity footprint, in the present work other primary data were collected, concerning water consumption for cooling system of power plant, as described in the following paragraph. Moreover, concerning vegetal oil market for electricity production in Italy, information about the types of oils were deduced from the report of the Working Group "Biomasses, Biofuels and Bioliquids, Biogas and Biomethane and Green Chemistry" instituted by Ministry of Agriculture, Food and Forestry (Tavolo di Filiera per le Bioenergie, 2014).

Regarding the geographic origin of vegetable oils reference was made to Ecoinvent v.3.3 data. Hydropower contribution to the mix was partitioned in run-off and reservoir, according to Italian statistics, while for specific water consumption of reservoirs Ecoinvent v.3.3 data was used. Import of electricity has been modelled using an electricity mix of European countries (Ecoinvent dataset of ENTSO-e[2] electricity mix).

Water consumption of cooling systems

Thermoelectric power plants require water for cooling. In once-through cooling systems, water is withdrawn, runs through the condenser and, after it has cooled down the condenser it turns to the river or to the sea with a higher temperature. Otherwise, in a recirculating cooling system (or cooling tower) the water flows in a closed circuit. The water withdrawal of a once-through flow cooling system is much higher compared to a tower cooling system, while the fraction of water consumed (evaporative losses) is much smaller. In Ecoinvent datasets the water consumption for cooling of power plants is calculated as:

$$C_i = (C_{i\_rec} * f_{i\_rec}) + (C_{i\_once\_t} * f_{i\ \_once\_t}) \quad (1)$$

Where:
i: the type of power plant (e.g.: natural gas power plant, coal power plant, etc.);
Ci_rec : specific water consumption (m^3/kWh) of the type of plant *i* in the case of recirculating cooling system;
fi_rec: fraction of plants of type *i* using recirculating cooling system;
Ci_once_t: specific water consumption (m^3/kWh) of the

[2] ENTSO-E, the European Network of Transmission System Operators, represents 43 electricity transmission system operators (TSOs) from 36 countries across Europe. ENTSO-E was established and given legal mandates by the EU's Third Legislative Package for the Internal Energy Market in 2009, which aims at further liberalising the gas and electricity markets in the EU.

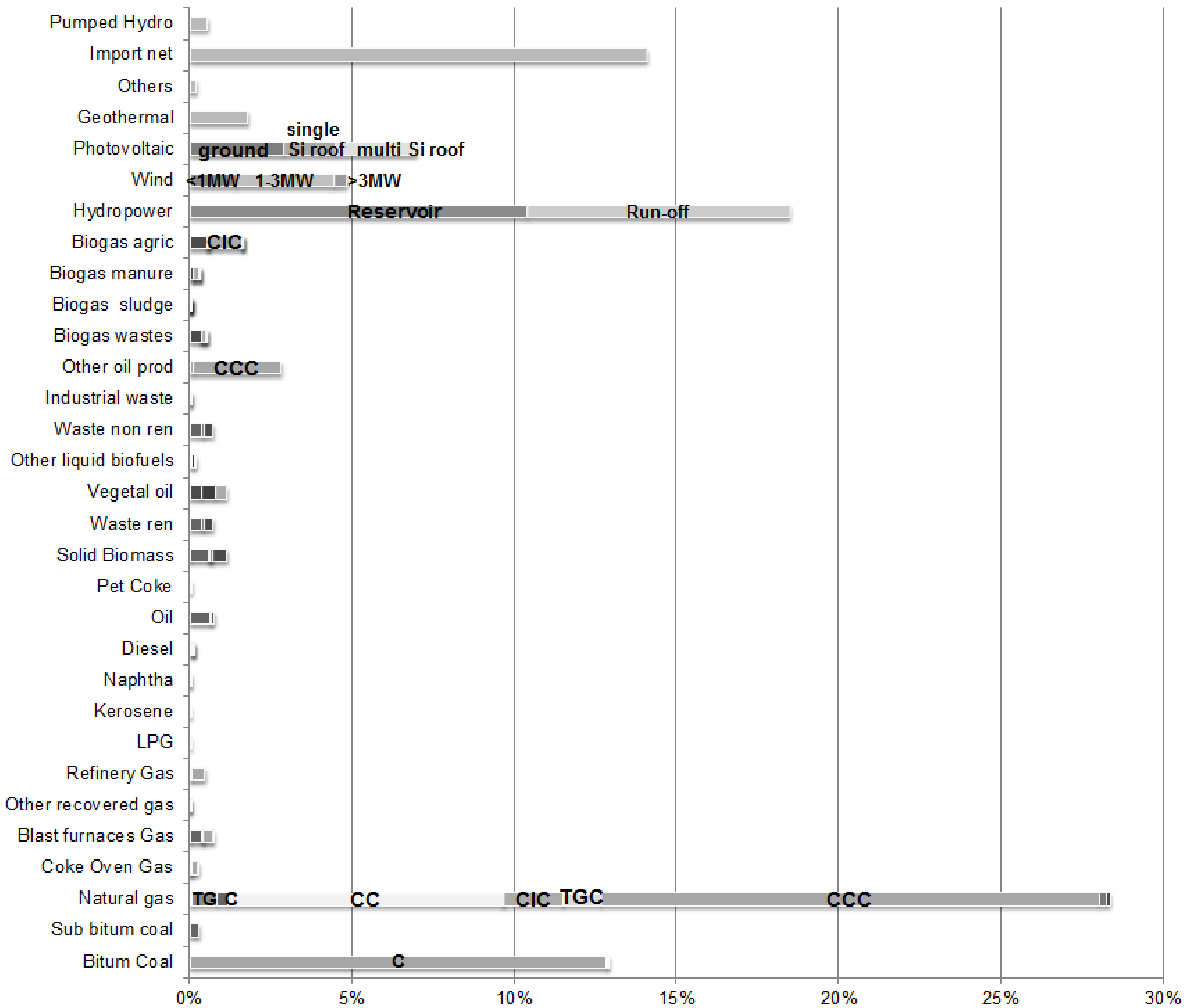

Figure 2. Italian electricity mix by type of power plants (source and technology)[(a)].
(a) CI: Internal combustion; TG: Gas-turbine; C Steam condensing; CC: Combined cycle; RP: Repowered; CIC: Internal combustion-cogeneration; TGC: Gas-turbine- cogeneration; CCC: Combined cycle – cogeneration; CPC: Back-pressure steam; CSC: Steam condensing with bleeding

type *i* in the case of once-through cooling system;
fi _once_t: fraction of plants of type *i* using once-through cooling system.

In Ecoinvent database, specific water consumptions (Ci) makes reference to Scown et al. (2011), while the fraction (fi) of power plants using once-trough or recirculating system comes from Florke et al. (2011), estimates which are valid as average for all the European countries. However, these estimates do not take into account the use of seawater for cooling and then, risk overestimating water consumption for cooling in Italy, since many power plants, located along coastal areas, use sea water (which does not contribute to the water footprint). Therefore for cooling systems of Italian power plants, we took into consideration information coming from the environmental declarations of power plants registered to EMAS – EU Eco-Management and Audit Scheme (Regulation EC No 1221/2009). Information have been organized in a database containing, for each power plant, among other data (such as fuel in input, electricity production, etc.), the type of resource used for cooling (fresh water, sea water, air) and the type of cooling system (once-trough or recirculating). A new repartition between cooling systems was calculated, on the basis of yearly electricity productions, for natural gas and coal power plants (more relevant contributions to the electricity mix),

Table 1. Italian plants by type of cooling system. The percentages from literature (Florke et. al., 2011) and those calculated in the present work are reported.

Type of cooling system	Percentage (Flörke et al. 2011)	Percentage for Natural gas power plants	Percentage for Coal power plants
Once-through using fresh water	73%	40%	0%
Recirculating using fresh water	27%	20%	1%
Cooling system using sea water or air	0%	40%	99%

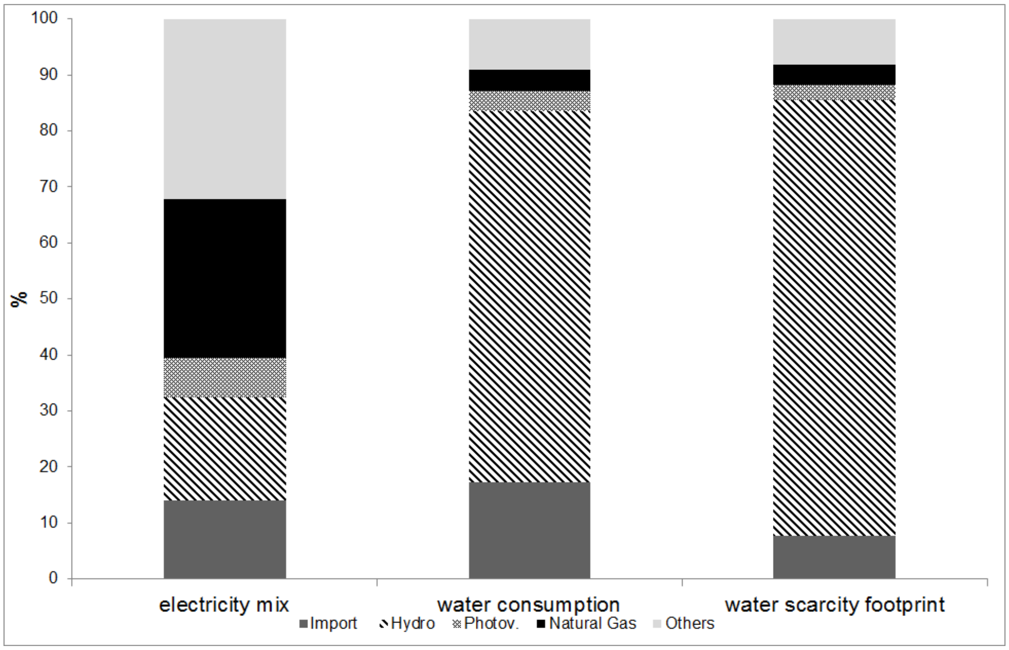

Figure 3. Italian electricity mix, water consumption of electricity and water footprint of electricity by energy source

which is shown in Table 1. Note that for Natural gas power plants our database covers up to 80% of national electricity production, while for coal power plants it covers about 60%. For specific water consumptions of once-through and recirculating cooling system we made reference to Ecoinvent data.

RESULTS

For each MWh of electricity fed into national grid, 4.5 m^3 of water resources are consumed, of which about 3 m^3 are attributable to hydropower and about 0.8 m^3 to imported electricity. Hydroelectric and import present the main share to water consumption of the Italian electricity mix, while much lower but still appreciable contributions are provided by natural gas and photovoltaic plants. The results depend on two factors: the specific consumption of the type of power plant per unit of electricity produced (e.g, specific consumption of hydroelectric, specific consumption of natural gas power plants, etc.) and the share in the Italian electricity mix of the specific type of plant. The combination of the two factors determines the relative importance of a specific type of plant to the total water consumption of the Italian electricity mix.

Although the hydropower contributes 18.5% (reservoir hydropower 10%) of the national electricity, it dominates the overall consumption of the mix (about 67%) as it presents a specific consumption (16 m^3/MWh) due to the evaporation from the reservoir, which is much higher than the other sources. On the other hand, natural gas plants with a contribution to the mix of 28% are responsible for less than 4%, because of low specific consumption (0.6 m^3/MWh). Low specific water consumption depends on high electricity efficiency and on high percentage of electricity produced by natural gas power plants that use sea water or air system for cooling. With a share of around 7% in the mix, photovoltaic contribution is 3.5% of the consumption, while with a share in the mix equal to 14%, imported electricity accounts for 17% of consumption (Figure 3).

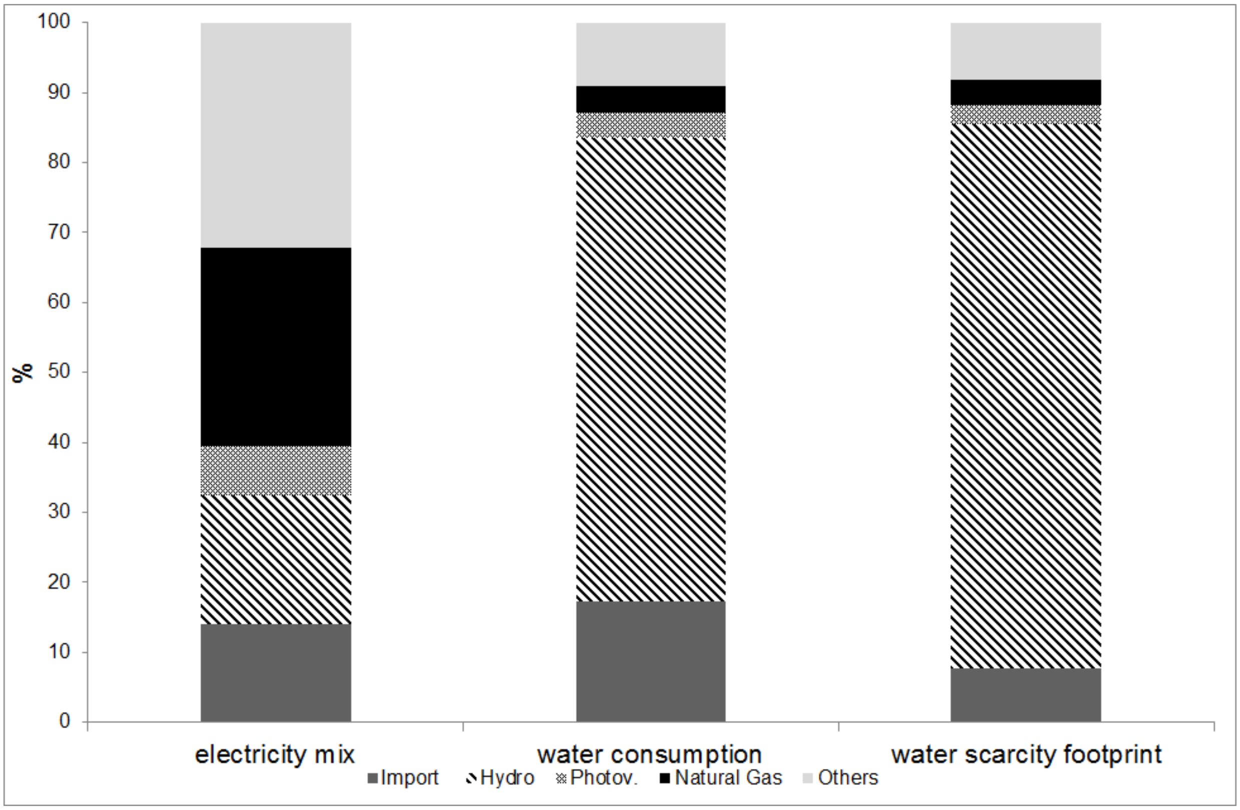

Figure 3. Italian electricity mix, water consumption of electricity and water footprint of electricity by energy source

In analogy with water consumptions, the results of AWARE method shows (Figure 3) the predominance of hydropower contribution on the overall water scarcity footprint. On a total water scarcity impact of 175 $m^3_{world\ eq}$/MWh, 78% comes from hydropower, about 8% is attributable to imported electricity and only residual contributions are attributable to natural gas (about 3.5%) and photovoltaic (about 3%) power plants. Then, moving from water consumption to water footprint assessment the relative contribution of hydropower increases, while imported electricity with a share of 17% in overall consumption, becomes much less significant in terms of water footprint (about 7%). This is because of different geographic areas involved in electricity produced by hydropower (Italy) and imported electricity (mix of several European countries). The above described results bring to the conclusion that the overall impact on water scarcity of the Italian electricity mix is attributable, mainly, to the hydroelectric power plants. However a clarification is needed, concerning the allocation of impacts between the various purposes of the reservoir.

Since a reservoir can have multiple purpose (e.g, electricity production, irrigation, drinking-water supply, mitigation of floods), the water consumption should be allocated at the various functions performed by the reservoirs and not only to the electricity production. Alpine Reservoirs, in fact, keep a resource when it is overabundant (winter/summer) and realise it when it is lacking, also for other uses. This question has been debated in the literature and some studies, for example Mekonnen et al. (2016) proposed simplified hypotheses to allocate the water consumption to the different uses of a reservoir. The issue require, undoubtedly, a deepening, but in the absence of structured information on the multiple uses of the Italian reservoirs and since an harmonized and internationally shared approach is still lacking, it was considered more appropriate, in the present study, to allocate the water consumption entirely to electricity production. Moreover in consideration of temporal variability of consumption and availability of water resource for hydropower a monthly assessment should be implemented. Data improvement in order to produce a monthly assessment for water footprint of hydropower is a topic of main concern for future researches.

Comparison between technologies

Even if the goal of the present work is to assess water footprint of Italian electricity mix, a comparison between the different types of plants was carried out for a better comprehension of results. For each type of power plant and net import, water consumption and water footprint per unit

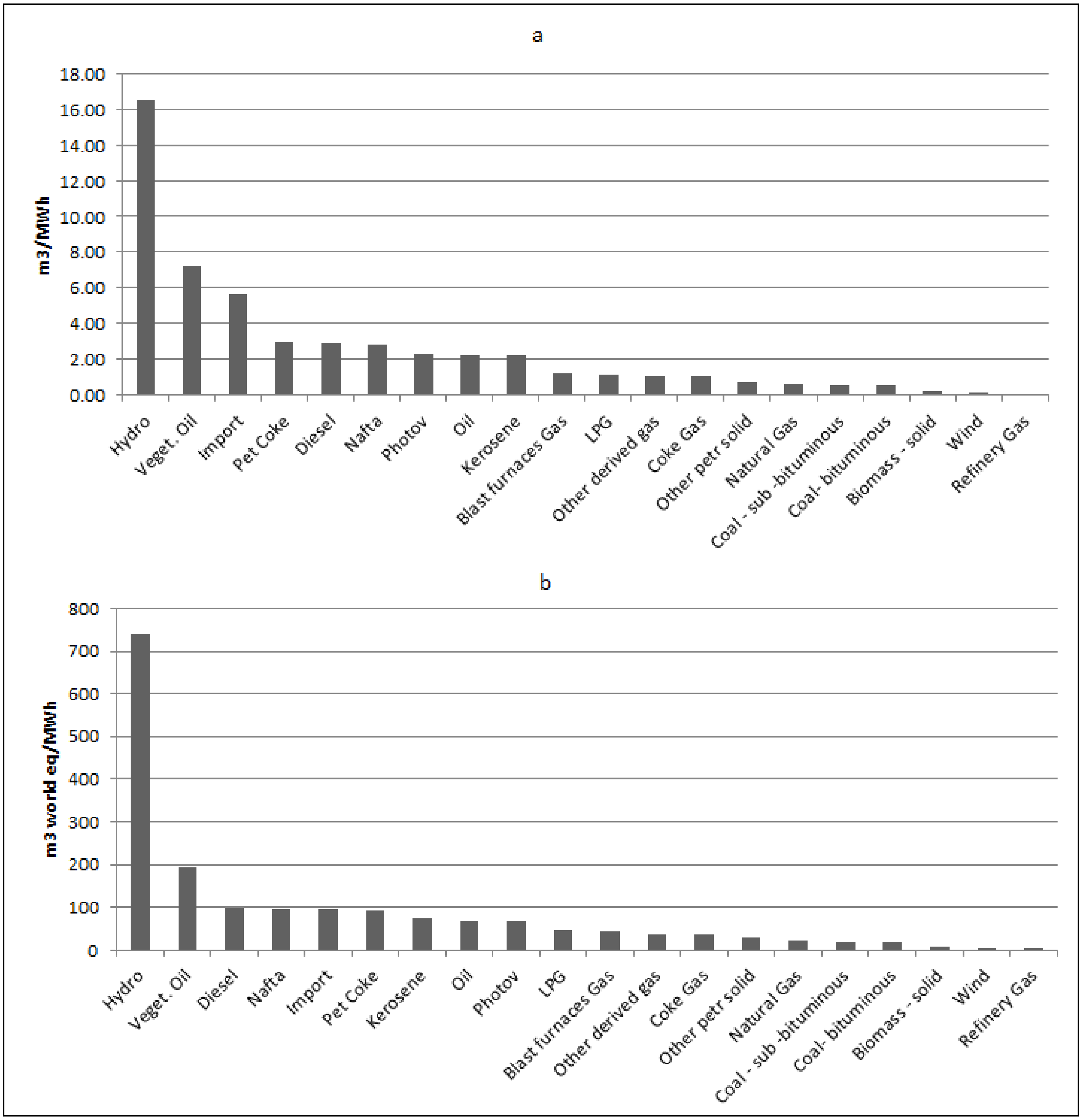

Figure 4. Comparison between types of plant: water consumption (a) and water footprint per unit of electricity (b)

of electricity were calculated.

In Figure 4, the different types of power plant are ordered by water consumption (a) and by water footprint (b)[3]. Concerning life cycle water consumption per unit of electricity fed into national grid, the maximum value is associated to hydropower, followed by vegetal oil power plants and imported electricity. Among thermoelectric, it is interesting to note that the specific consumption of the natural gas plants is almost equal to that of coal plants. Even if gas power plants have better yields and, specific water consumptions lower than coal power plants, the average consumption of Italian coal power plants is influenced by the very high percentage, among them, using sea water for cooling.

Electricity produced by hydropower has a far greater

[3] Biogas and Geothermal plants are excluded from the analysis due to the low reliability of the relating data for the Italian context. In consideration of the very low contribution to the Italian mix, results in terms of electricity mix are not affected. However, in studies aimed at comparing different electricity production technologies an improvement in this data can be essential.

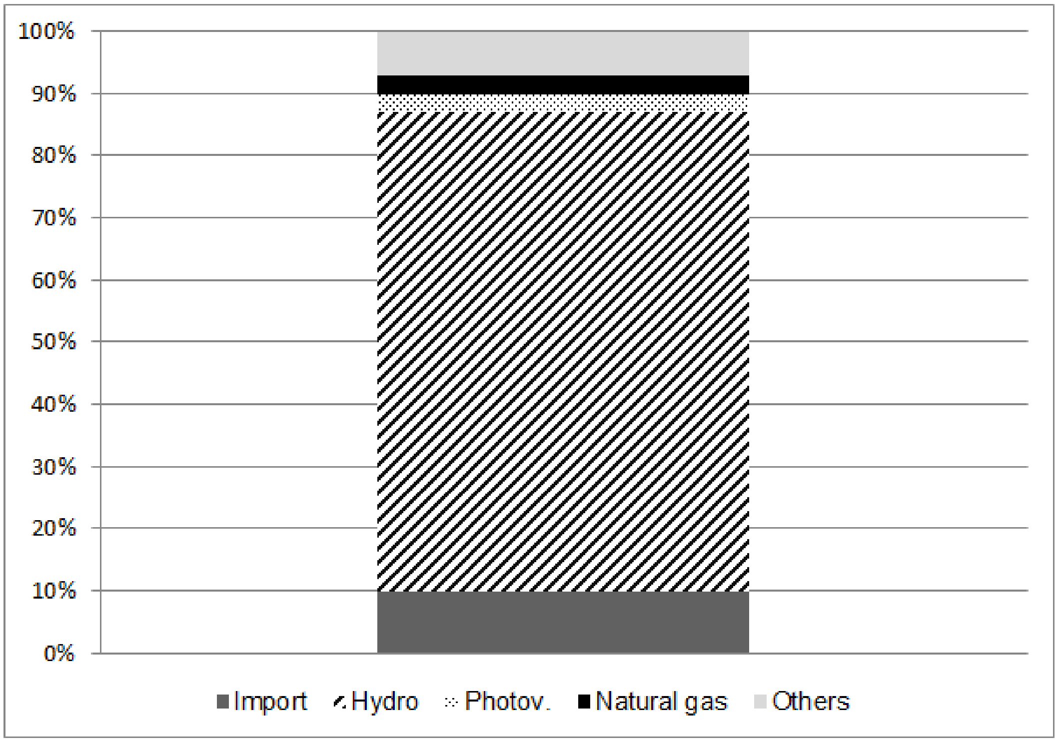

Figure 5. Water scarcity footprint of Italian electricity mix by sources. Results of WAVE method application

impact on water scarcity than the other types of power plants. The impact of electricity produced by vegetable oil amounts to only 25% of that of hydropower. All the other types of power plant (import included) show values under 15% of water scarcity footprint of the hydroelectric. Regarding life cycle phases, except for vegetable oils power plants, all the thermoelectric power plants present the larger part of both water consumption and water scarcity footprint during the operation phase, for cooling processes. For vegetable oils power plants the main consumption occurs for the fuel supply and it is related to the irrigation for the growth of the energy crops. Operation phase is the most important also for hydropower since the consumption is associated to evaporation from reservoir. The construction phase is mainly responsible for both the overall water consumption and water scarcity footprint only in the case of electricity produced by photovoltaic due to the production of silicon for photovoltaic modules.

DISCUSSION

Since the above results are among the first obtained through the new ISO approach and the AWARE method, we focused the discussion on three aspects particularly significant in view of future studies or methodological deepening: the robustness of the conclusions, the relevance of primary data and the needs for data improvement relating to processes localization (instead of using global datasets).

Robustness of conclusions

As stressed by the authors, the maturity of the AWARE method is still limited as it has only been applied in a limited number of case studies. The authors recommend that a sensitivity analysis must be performed with a different method. Therefore, in order to test robustness of conclusions, the results of AWARE method have been compared with those of WAVE method application (Berger et al., 2014). The WAVE method results (Figure 5) lead to the same conclusions in terms of contributions of the different types of plants to the water footprint of Italian electricity mix. As a matter of fact, 77% of the overall impact is attributable to hydropower, about 10% to imported electricity and few percentage points are attributed to photovoltaic and natural gas power plants. However, more caution should be given when the goal is to compare different technologies. Looking at the specific water footprints (per unit of electricity) of the different types of power plants, the use of one method in place of the other can lead in some cases to appreciable, even if still slight, differences.

This is the case of imported electricity and electricity from vegetable oils as shown in Table 2, where both AWARE and WAVE results are reported (in percentage respect to those of hydropower).

Table 1. AWARE and WAVE results for import and vegetable oils power plants. Percentage results respect to Hydropower results.

	Imported electricity	Electricity from vegetable oils	Hydropower
AWARE	13%	26%	100%
WAVE	18%	35%	100%

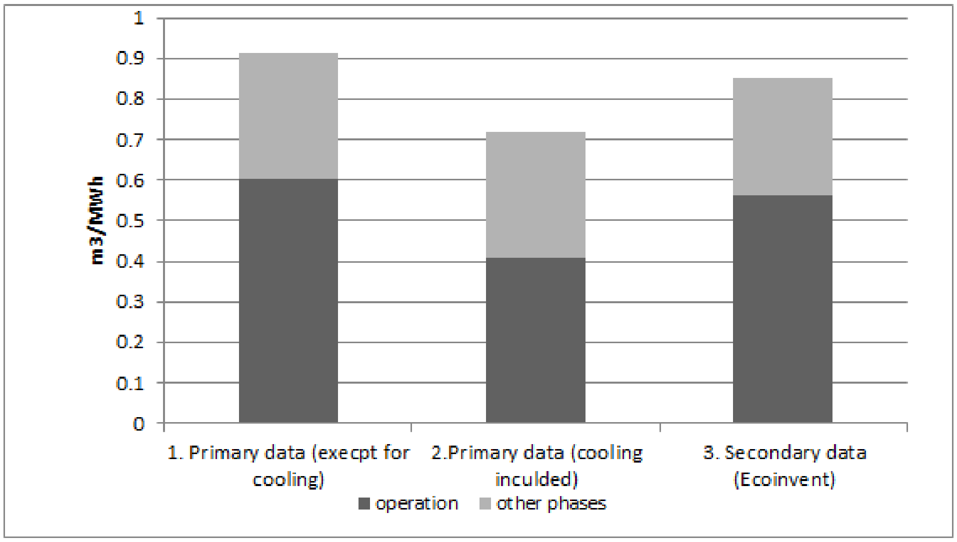

Figure 6. Natural gas combined cycle water consumption in case 1, case 2 and case 3

The role of primary data: sensitivity analysis on natural gas power plants

As already reported, in this study, primary data are used which specifically concerns thermoelectric plants such as efficiency, import mix of natural gas, net calorific value of natural gas, import mix of oil products, net calorific value of oil products and type of system and type of water resource (fresh water, sea water) used for cooling. In order to highlight the importance of primary data, an in-depth analysis on natural gas combined cycle plants was carried out. Among thermoelectric plants, the analysis concentrated on natural gas combined cycle plants because of their high contribution to the overall electricity. The life cycle consumption (Figure 6) and the water footprint (Figure 7) were assessed in the following three cases:

1. Using primary data for plant efficiency, natural gas net calorific value, natural gas import mix and secondary data (Ecoinvent) for cooling system;
2. Using primary data for plant efficiency, natural gas net calorific value, natural gas import mix and cooling system;
3. Using only secondary data (Ecoinvent)

In Case 1, an overall consumption slightly higher (10% higher) than the one derived from the use of secondary data (Case 3) was calculated. When primary data for cooling systems are also used (Case 2), the overall consumption drop to 85% of that calculated with secondary data (Case 3). Water footprint assessment leads to slightly different results. The water footprint calculated with primary data (Case 2) amounts to 80% of water footprint calculated using secondary data (Case 3). That is, a consumption 15% lower than Case 3 corresponds to water scarcity footprint that is 20% lower than Case 3, due to different import markets of natural gas taken into consideration in the two cases which entails, also, differences in the geographic regions taken into consideration.

To put in evidence only the effect of using primary data for cooling system, Case 1 and 2 must be compared. Obviously the differences in results concerns only the operation phase, since the other life cycle stages share the same data in both calculations. The use of the percentages of different cooling systems derived from the environmental declarations of Italian power plants registered to EMAS in place of that from literature (reported in Table 1), led to remarkable differences in terms of both total water consumption (20% lower) and water scarcity impact (25% lower).

Localization of processes and needs for data improvements

Figure 8 shows water consumption of Italian electricity mix

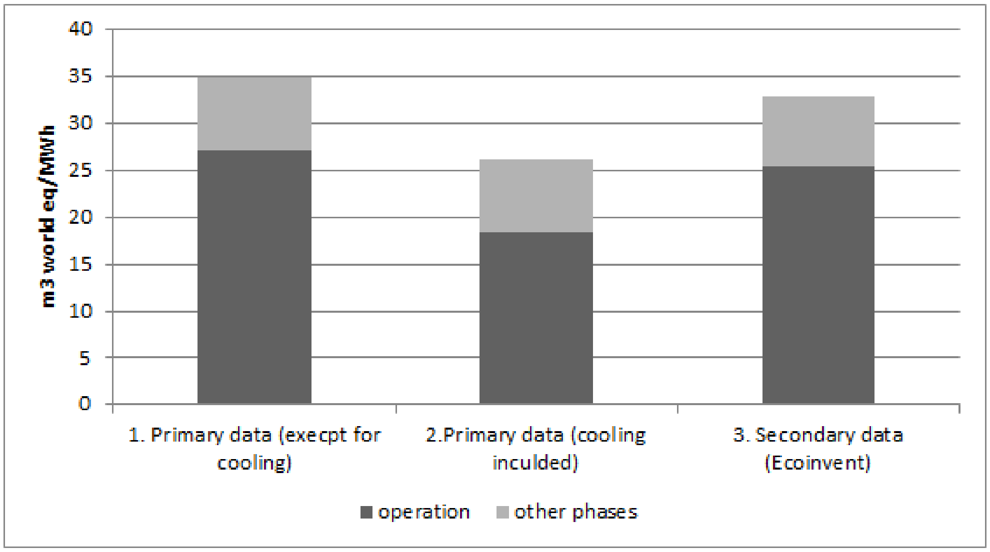

Figure 7. Natural gas combined cycle water footprint with AWARE method in case 1, case 2 and case 3

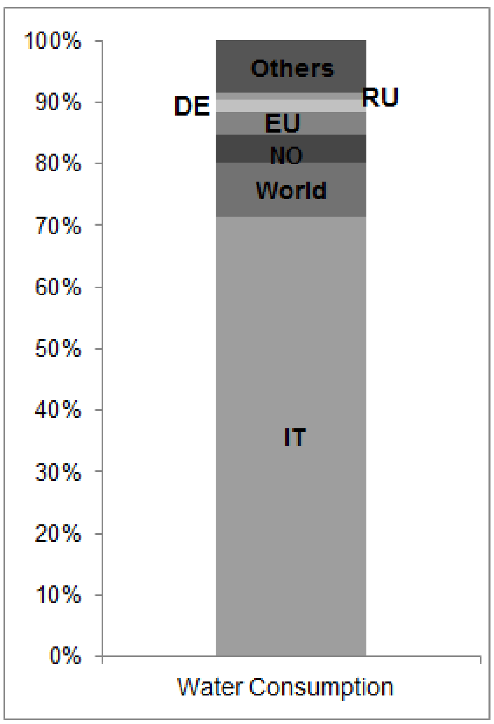

Figure 8. Water consumption of Italian electricity mix by geographic area

by geographic area. The main contribution (about 70%) to the overall consumption is located in Italy and is mainly due to the hydropower and, only for a few percentage points, to the cooling of thermoelectric plants. Other specific locations which are involved with an appreciable contribution are related to the import of electricity, while only 1 to 2% of the overall consumption is located in Russia (supply of natural gas) and Germany (construction of photovoltaic panels). Each one of the remaining geographic areas presents a contribution lower than 1%.

For imported electricity, different locations are involved. In particular, an appreciable share of water consumption (about 5% of the overall consumption of Italian electricity mix) is localized in Norway, due to the high share of hydropower in the Norwegian electricity mix. It must be underlined that to model the electricity imported in Italy we chose to make reference to an average European mix (ENTSO-e), instead of considering the actual nodes of import (Austria, Switzerland, etc.). The reason is that the European electricity market is a single, integrated and interconnected system in which each node influences and is influenced by the others. The impacts connected to the import of electricity in Italy have been, therefore, modelled using the ENTSO-e electricity mix. A not negligible share (around 15%) of water consumption is associated with the generic locations “Europe” and “World”, which refer to many processes modelled with European or world average markets. An example is the silicon market for photovoltaic for which specific information of the actual production countries is only partially available in Ecoinvent 3.3 and consequently more than 65% of water consumption per unit of electricity produced by photovoltaic is associated to “Europe” and “World” (Figure 9).

Trying to improve these data, at least for the most meaningful processes (e.g, market of silicon in consideration of the foreseeable growth of photovoltaic in the future), would be a task for future studies. A deepening on data related to the localization of processes can be essential when the focus is a comparative LCA or to assess different fuel supply chains. For example, for electricity produced by bio-

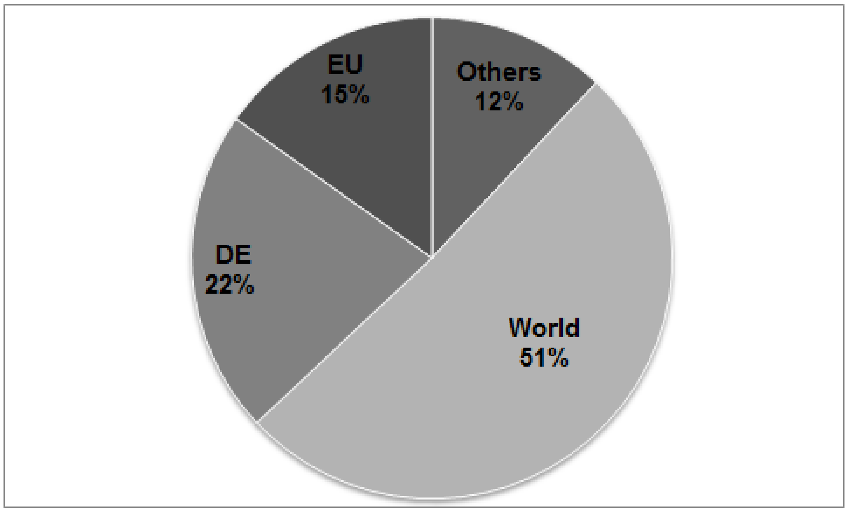

Figure 9. Water consumption of electricity from photovoltaic, by geographic area

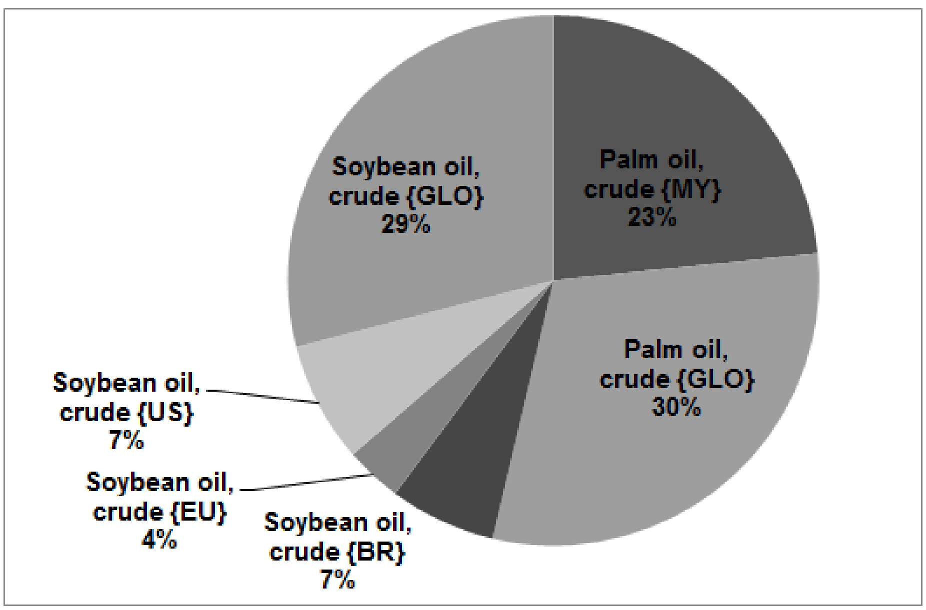

Figure 10. Vegetable oils market for electricity production in Italy

liquids (vegetable oils), for which most of water consumption occurs in the upstream phase, a different origin of energy crops could imply different water consumptions (due to differences in water flow for irrigation) and, above all, a different water scarcity footprint. An example is given as follows.

Figure 10 shows vegetable oils market for electricity production in Italy according to Ecoinvent (geographic origin of vegetable oils) and primary data (types of vegetable oils). It should be underlined that in Ecoinvent the main lack of data is related to agricultural processes (Pfister et al., 2016). Therefore, in addition to the information about type of oil utilized, also primary data on location of the irrigation activity and on the irrigation water amount would be preferable. About 60% of vegetable oil (29% soybean and 30% palm oil) comes from an average world market, 23% from Malaysia (Palm oil), 7% from United States (soybean oil), 7% from Brazil (soybean oil) and only 4% from Europe (soybean oil).

In the hypothesis ("Hp1") of eliminating the share from Malaysia (which goes from 23% to 0%) and referring all the palm oil to the world average market (which goes from 30% to 53%), the water footprint per unit of electricity produced by vegetable oil in Italy will become 25% lower (Figure 11).

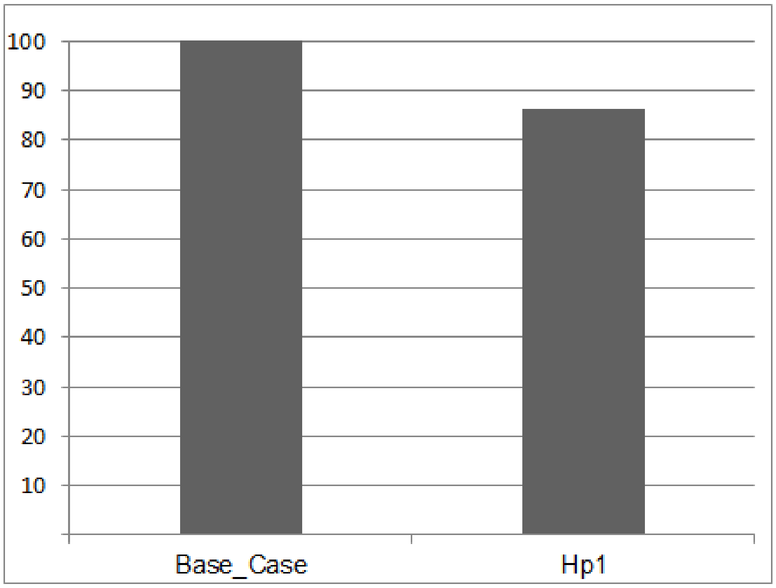

Figure 11. Water footprint per unit of electricity produced by vegetable oil in Italy, according to the present work (Base case) and in the hypothesis of no vegetable oils from Malaysia (Hp1)

This reported hypothesis is to be intended as a simplified example to explain how important an improvement of data could be for future studies on water scarcity footprint of different bio-liquid supply chains, also, in the framework of encouraging bio-liquids sustainability.

Conclusions

The study provided first results of water footprint assessment of Italian electricity mix according to ISO 14046 application and can support water footprint assessment in a wide field of LCA applications, since electricity is often the most water intensive process in the life cycle of industrial products. A great effort was dedicated to the inventory phase (collection of data on flows exchange, in input and output, between processes and environment) since a detailed electricity mix was considered which consists of more than one hundred types of power plants, from conventional and alternative energy sources. As regards data, results showed that for cooling systems of power plants primary data are recommendable, especially in case of coastal regions, such as Italy, with a great share of power plants using sea water.

The analysis of water consumption by geographic location helped to identify which data require improvements and in-depth analysis. Even if these data (e.g, silicon market for photovoltaic panels, vegetable oils market) do not significantly influence the results in terms of electricity mix (because of low share of photovoltaic or bio-liquids electricity in the Italian mix), they can be essential for studies aimed at comparing different electricity production solutions. Furthermore, an improvement of data concerning location of processes can be important to understand how different supply chains or markets affect the overall impact, since water consumption determines a more or less important impact on the availability of water resource, depending on the geographic location. If it is true that the localization of the processes plays an important role also in the "classical" LCA (e.g, impacts of transport, impacts of energy mix of production locations), then it becomes determinant in the water footprint assessment, due to the relevance of the geographical dimension inherent in the methodology.

AWARE results indicate that the overall impact on water scarcity of the Italian electricity mix is attributable, mainly, to the hydroelectric power plants, but the allocation of water scarcity impact of hydropower to multiple uses and the temporal scale of the assessment are topics to be further investigated.

AKNOWLEDGEMENT

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development - General Directorate for the Electricity Market, Renewable Energy and Energy Efficiency, Nuclear Energy in compliance with the Decree of March 8th, 2006.

Conflicts of interest

The authors declare that they have no conflict of interest.

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Cite this article as:

Gargiulo A, Carvalho ML, Girardi P (2018). Water scarcity footprint: The case study of the Italian electricity mix. Acad. J. Environ. Sci. 6(11): 288-300.

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