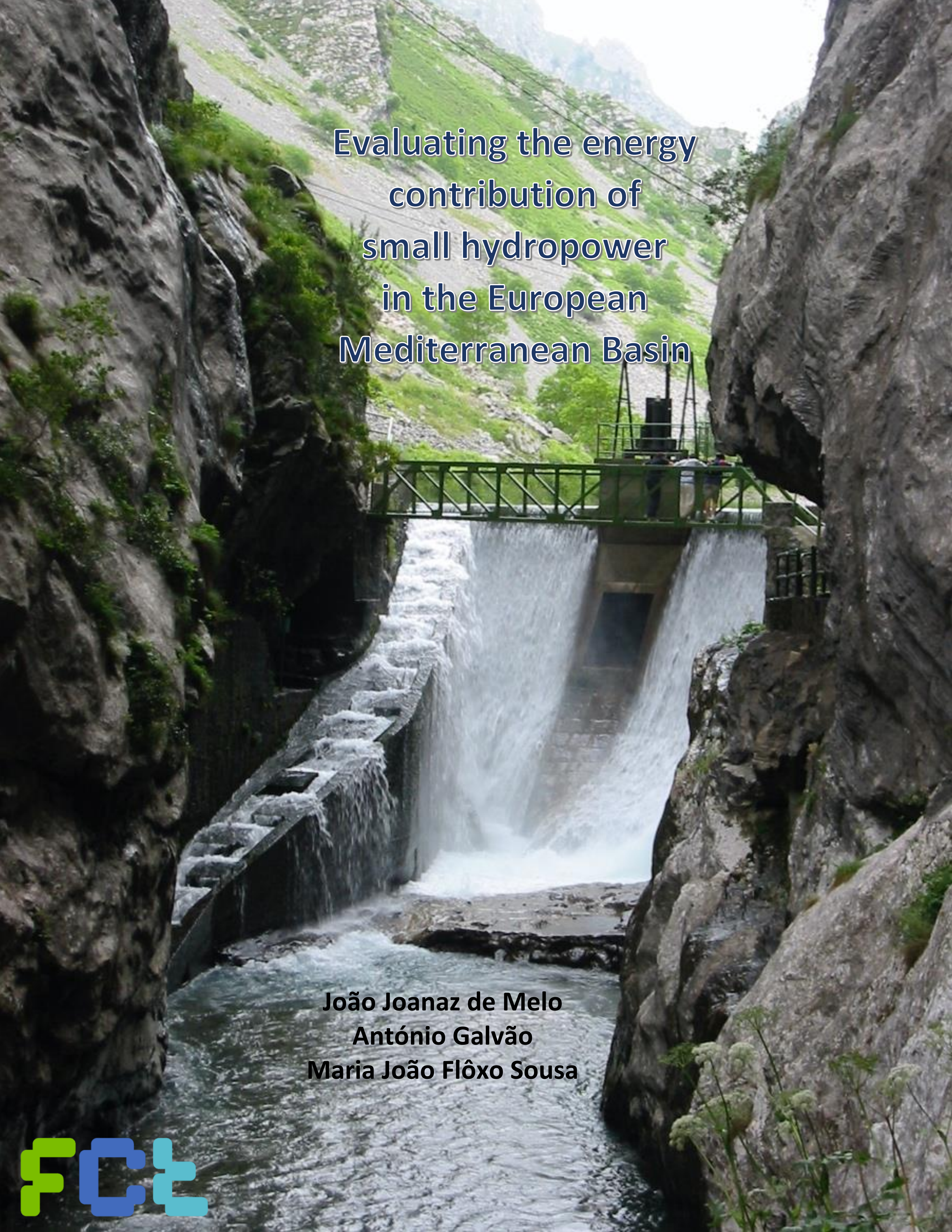

Evaluating the energy contribution of small hydropower in the European Mediterranean Basin

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The authors declare no competing interests, and that the results presented herein represent an objective assessment of the available data.

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Cover photo: Small dam in the river Cares, Picos de Europa, Spain © João Joanaz de Melo

Back cover photo: Rio Teixeira, Portugal © Ricardo Oliveira

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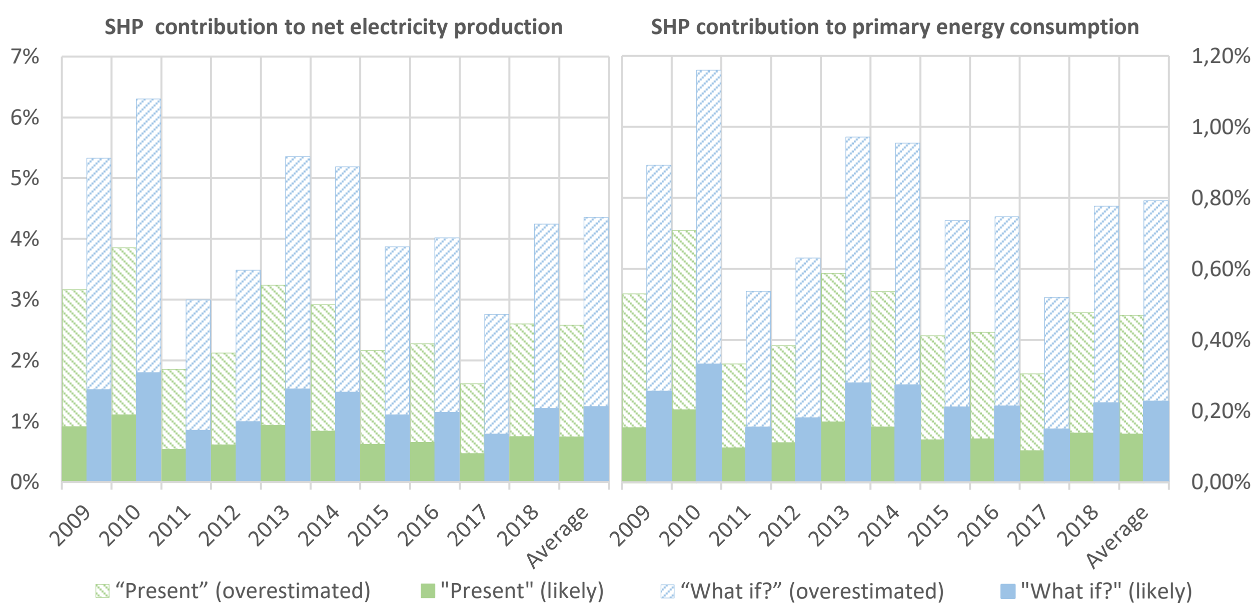
Executive summary

At a time when climate change effects are already noticeable, many governments are looking for solutions such as small hydropower (SHP) to decarbonize their economies. SHP, usually defined by installed capacity of up to 10 MW, is often believed to be a clean source of electricity supply without the negative environmental impacts associated with large dams. In this context, European policy has allowed the expansion of hydroelectricity and the promotion of SHP as part of its strategy to meet the defined renewable energy and greenhouse gas reduction targets. However, SHP is not free from harmful impacts and can have significant negative environmental effects, at times comparable to those of large dams.

The goal of this study is to evaluate the potential output of small hydropower in the European Mediterranean region and to assess its importance as an energy supplier. The study is based on a pre-existing inventory of current and projected SHP sites. For each site, theoretical hydropower potential was computed, based on climatological, hydrological and elevation open-source data, and on common SHP plant design criteria.

Results for 14 countries under two different modelling scenarios – (1) **"Present":** operating SHP sites (4 177 sites); and (2) **"What if?"**: operating, under construction and projected SHP sites (9 925 sites) – were first compared to national gross electricity consumption and primary energy consumption. Estimated potential was then compared with real SHP plant data and a likely overestimation factor was extrapolated: existing projects have a productivity, on average, around 3.5 times smaller than the theoretical (overestimated) potential. A literature review and discussion were also performed on the economics of SHP and on the viability of SHP in a climate change context.

The graphics below show the identified SHP potential and likely contributions to gross electricity consumption and primary energy consumption.



Key conclusions:

- **The potential (overestimated) contribution to the energy mix of existing SHP sites in the European Mediterranean basin is low** – on average, around 2.6% of gross electricity consumption and 0.47% of primary energy consumption. **The real contribution is likely some 3.5 times lower** – falling to around 0.74% of gross electricity consumption and 0.12% of primary energy consumption.
- **Building 5 748 new plants and more than doubling the existing number of SHP plants does not greatly increase the energy contribution of SHP.** Potential (overestimated) contribution rises from 2.6% to 4.4% of gross electricity consumption and from 0.47% to 0.79% of primary energy consumption.
- **SHP production is highly dependent on meteorological conditions**, varying by more than 50% from the best to the worse years. Results are quite variable by country and year: years of drought in some regions show high productivity in other regions. SHP potential is higher and more stable in mountain regions (due to the combined effect of elevation and orography-induced rainfall). However, **the countries with higher number of SHP installations (Italy, France, Spain, Greece) are not those with the higher productivity by plant nor the most resilient to dry years**.
- **Mediterranean SHP production will be greatly affected by climate change.** In a world 2 °C warmer, stream flow in the Mediterranean region is expected to fall significantly (by 10%-30%). Reduction in hydropower productivity will be even worse with water scarcity prompting higher competition for this resource and rain pattern modifications further decreasing productivity.
- **Investing in (i) energy efficiency and (ii) emerging technologies, such as photovoltaic, is more cost effective than SHP to achieve steady and secure electric systems**. The cost of electricity from SHP, measured as the levelized Cost of Energy (LCOE) ranges from 40 to over 300 €/MWh. This is expensive, when compared to the wholesale market price of electricity production in Europe (about 40 to 60 €/MWh), the costs of energy efficiency investments (typically 10 to 40 €/MWh), and the cost of emerging technologies such as photovoltaic (about 50 €/MWh, with a downward trend). While some low-investment, low-impact SHP projects such as refitting existing SHP sites or setting up SHP in waterworks (e.g. irrigation, water supply and wastewater systems) can be economically interesting and environmentally more acceptable, **in most cases, SHP is neither a cost-effective way to ensure a reliable electric system, nor to perform the needed energy transition or to reduce carbon emissions.**

Introduction

Bemposta dam, river Douro, Portugal,: photo by João Joanaz de Melo

To tackle climate change, the European Union has taken ambitious climate action measures, committing to achieve carbon neutrality by 2050. This will require a concerted effort across all economic sectors, and particularly in the energy sector. Europe has a long history of hydropower, and in some countries, it represents an important contributor to the renewable energy share. Much of the available potential for large hydropower projects has been exploited, with few spots available for additional projects to be implemented (Venus et al., 2020). Furthermore, the negative social and environmental impacts of large dams are well-known (WCD, 2000).

Small hydropower, on the other hand, is often believed to be a clean source of electricity supply, supposedly without the negative environmental impacts associated with large dams (ESHA, 2012). This notion has led to a policy focus on the expansion of hydroelectricity in Europe and the promotion of SHP as playing a key role in meeting Europe's renewable energy and greenhouse gas reduction targets. However, SHP does not come without negative impacts: river barriers are responsible for biodiversity loss, river fragmentation, water quality degradation, sediment retention and erosion phenomena (WWF, 2018). Also, when assessing the environmental impacts of hydropower per MW of installed power, SHP can have negative environmental effects comparable to those of large dams (Abbasi and Abbasi, 2011).

The effectiveness of SHP as a meaningful contributor to meeting energy demand in Europe, and as a tool for climate change mitigation has not yet been analysed, particularly in the Mediterranean basin, one of the world's most vulnerable regions to climate change impacts (IPCC, 2014).

The aim of our work is therefore to: (1) evaluate the potential output of existing and expected SHP plants in the Northern Mediterranean basin, using remote sensing and other open data; and (2) to assess the relevance of SHP production in meeting the region's energy demand.

Starting from an inventory of current and projected SHP sites by Schwarz (2020), a theoretical overestimated hydropower potential was computed for each site, based on climatological, hydrological and elevation open-source data, and common SHP project criteria. The results were validated by two methods: (i) comparing theoretical estimates with the power classes declared in the SHP inventory, and (ii) comparing both estimates and inventory data with real project data as available. Additionally, a literature review and discussion were performed on the economics of SHP and on the viability of SHP in a climate change context.

Rio Teixeira, Portugal: photo by Ricardo Oliveira

Small hydropower: investing in sustainability?

Small hydropower and climate change in the Mediterranean region

Petra Döll et al. (2018) assessed freshwater-related hazards and risks on an Earth approximately 1.5 °C and 2 °C warmer than during the pre-industrial era and evaluated the changes in mean annual streamflow. Figures 1 and 2 show the expected reduction in mean annual streamflow for the Mediterranean region, in an environment 1.5 °C and 2 °C warmer, respectively. The stronger colours are the areas where the eight different model combinations (MC) have a high level of agreement.

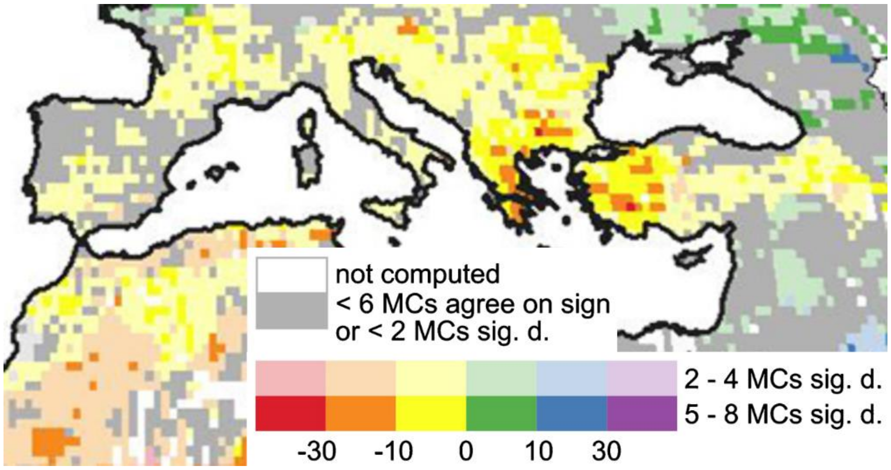


Figure 1: Expected reduction in mean annual streamflow in a world 1.5 °C warmer (adapted from Döll et al., 2018)

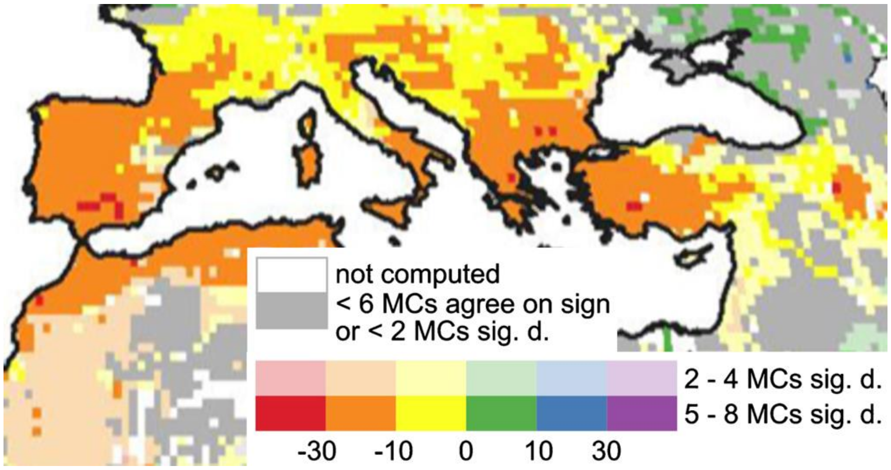


Figure 1: Expected reduction in mean annual streamflow in a world 2 °C warmer (adapted from Döll et al., 2018)

In a world 2 °C warmer most model combinations agree that there would be a significant reduction in stream flow in the Mediterranean region (figure 1). This would imply an even higher decrease in hydropower electricity production, as water scarcity would prompt higher competition for this resource – and the priority should be availability of water for human consumption, ecosystems and agriculture. Also, the change in precipitation patterns induced by climate change in the Mediterranean region is expected to exacerbate a pattern already observed today: high levels of precipitation followed by long dry periods (Giannakopoulos et al., 2005; IPCC, 2014).

Consequently, more of the stream flow will exceed the turbine design capacity and will not be utilized for power production and long periods of low flow will produce little electricity. These two combined effects will greatly decrease Mediterranean hydropower production, including small hydropower, and may render many SHP sites unexploitable.

Even under current hydrological conditions, the benefits of SHP in terms of CO_2 reduction are small, as expressed in the small SHP contribution to the energy mix, as this study goes on to show. As climate change progresses SHP contribution will fall even shorter, making the strategic investment in SHP a bad tool for a reliable electric system and for the much-needed energy transition. The exceptions are remote places where impacts of grid connection are higher than the impacts of installing SHP plants, and the equipping of SHP in ubiquitous systems, such as irrigation, water supply or wastewater systems. These latter are mainly in sites where the environmental damage is already done, which are closer to electricity use (representing less grid losses and lesser impacts from power lines), and which will still exist even in warmer scenarios, in order to sustain human populations.


Image by Josep Monter Martinez from Pixabay

The economics of small hydropower

Foz Tua dam, Portugal: photo by João Joanaz de Melo

The economic equation of small hydropower is extremely variable. There is a wide range of technical solutions for hydropower, the choice depending heavily on local conditions (climate, geology, physiography, road accessibility, single or multiple use of the waterworks, distance to the electric grid, local energy markets, among others) and on specific project targets (to satisfy local demand, or optimize peak load, or optimize electricity generation). There is also a wide range of ecological and social impacts, depending on the ecological sensitivity of the area, its population density, the types of water use, the technical solutions (e.g. size of dam or weir, fraction of natural flow diverted, effectiveness of fish ladders) and the mitigation measures adopted. Usually, larger dams cause larger negative impacts, but this is by no means a universal rule (WCD, 2000). Local conditions, careful impact assessment and proper regional water management (often absent) are critical factors to determine both project economics and environmental impacts.

It is out of the scope of this study to examine the economics of specific SHP sites. However, a brief review of available information for the sector was performed.

Ecofys et al. (2011) conducted a comprehensive study on the financing of renewable energy, which indicates levelized costs of energy (LCOE) for hydropower in Europe of between 40 and more than 200 €/MWh. Although small hydro may have higher unitary costs, the range of LCOE does not differ much between large and small hydropower: local conditions are clearly the most influential factors.

The studies carried out by the International Renewable Energy Agency (IRENA 2012, 2019) have similar results regarding the large range of unitary costs, expressed as LCOE or other indicators, corroborating the idea that local conditions are of paramount importance. These studies also indicate a global trend for an increase in maximum and average costs in the past two decades. LCOE of small hydropower projects in Europe commissioned in 2010-2018 range between 40 and 360 €/MWh, the 2014-2018 projects with an average LCOE double the 2010-2013 projects. In other regions the trend is the same, although not as marked as in Europe. The increase in costs over time may be explained by the fact that better sites (with higher energy potential, better economic indicators and fewer social conflicts) are sought and used first, so later projects often have poorer indicators. This is sometimes described as the decreasing marginal profits effect. Most of those projects have likely benefitted from significant state subsidies.

Those studies also indicate differences between regions of the world. The highest costs of hydropower are found in Europe, Oceania, North and Central America. The lowest costs are found in Brazil, China and other Asian countries. Those differences may be explained by a combination of factors: saturation of available sites, hence the onset of the decreasing profits effect; higher labour costs; more stringent regulations combined with more independent oversight by institutions and the public, leading to higher demands for impact mitigation. All these features tend to increase costs.

To understand the intrinsic economic viability (or not) of SHP, we can compare production costs with the wholesale market price. This is well established in many European countries. In the past few years, the wholesale market price of electricity production in Europe has typically oscillated between 40 and 60 €/MWh, although there are major variations between countries (AleaSoft, 2020). In many cases, the market price benefited from subsidies conferred on the utility companies in the past, as the energy sector has always been highly subsidized. In any case, we can observe that the costs of SHP vary from close or slightly under wholesale market price to four or five times more.

According to Ecofys et al. (2011), most EU countries support financially the creation of small hydropower, with subsidy levels from 70 to 200 €/MWh (on top of market price). There are different support mechanisms, the most common being the Feed-in-Tariff (FiT). The overall conclusion is that, although some SHP projects are economically viable on their own merit, the majority is not, and will only be built helped by state subsidies.

Empirical evidence suggests that SHP is more often economically interesting in one of three situations: (i) large drops in small-flow mountain rivers, (ii) small drops in medium-flow plains rivers, or (iii) installation of hydropower on dams and waterworks primarily designed for other purposes (public water supply, agriculture, sanitation). In those cases, economic viability of SHP is often contingent upon relatively small and inexpensive hydraulic works. Typically, SHP is not economically interesting (unless heavily subsidized) if requiring new large dams and waterworks. In fact, hydropower is generally becoming less and less interesting for investors, especially compared to investments in energy efficiency, solar power and other renewables (Melo et al., 2019; IRENA, 2019; Bloomberg 2020).

Portugal is a case in point: the few hydropower projects built in the past decade show very large negative impacts and average production costs close to 120 €/MWh, that is 2.5 times wholesale market average (Melo and Brazão, 2016).

The Large Hydropower Dam Program launched in 2007 was terminated in 2019, with less than half of the foreseen projects approved, and all of those suffering severe social conflicts. On the other hand, the refitting of old dams and waterworks with modern hydropower has been a successful program.

In short, economic feasibility of SHP is very contingent upon local conditions, and often uninteresting, even with public subsidies. Another relevant issue is that, comparing estimates of theoretical potential with existing projects (see Annex I – Data analysis and result validation), usually the real project has much lower installed power, and productivity, than the physical theoretical potential. This is most often due to purely technical and economic reasons. This leads us to conclude that the practical feasibility of SHP will be much lower than the theoretical potential found, firstly due to a combination of technical and economic conditions, and secondly, in a significant number of cases, also due to conflicts arising from social and economic impacts.

Methodology

White water kayaking in the river Tua, Portugal (now flooded by a reservoir): photo by João Joanaz de Melo

The goal of this work was to evaluate the potential productivity of existing and expected SHP plants in the Northern Mediterranean basin and to study its relevance in European energy systems.

Hydropower productivity depends upon the availability of water (given by stream flow, variable across seasons and years) and hydraulic head (the vertical distance between water levels at the intake and the outlet of the turbine circuit). The basic formula is $\mathbf{E_g = M.g.h}$, $\mathbf{E_g}$ being the potential gravitational energy, **M** the mass of turbined water, **g** the gravitational acceleration, and **h** the hydraulic head. This is the basis for all hydropower design criteria.

For each of the 10 360 SHP sites presented in figure 2, which were selected from the inventory by Schwarz (2020), an annual streamflow was estimated and the hydraulic head difference was calculated.

This study aims at establishing a maximum theoretical ceiling for SHP production in the European Mediterranean region. Therefore, stream flow arriving at a given SHP site was proxied by the runoff occurring in all sub-basins draining into that site. Apart from a 30% stream flow turbine design capacity exceedance (Zhou et al., 2015), no other parameters influencing water flow were considered, such as catchments, water abstraction, or evaporation along the river network. Hydraulic head was estimated as the elevation difference between the stream entry point and the stream exit point at each SHP sub-basin.

Potential installed power was estimated for each SHP site and compared to the power class declared in the SHP inventory (SHP sites where potential installed power diverged from the inventoried power class were estimated with adjusted hydraulic heads and forced to produce within the expected class). This approach generated the potential (theoretical overestimated) scenarios.

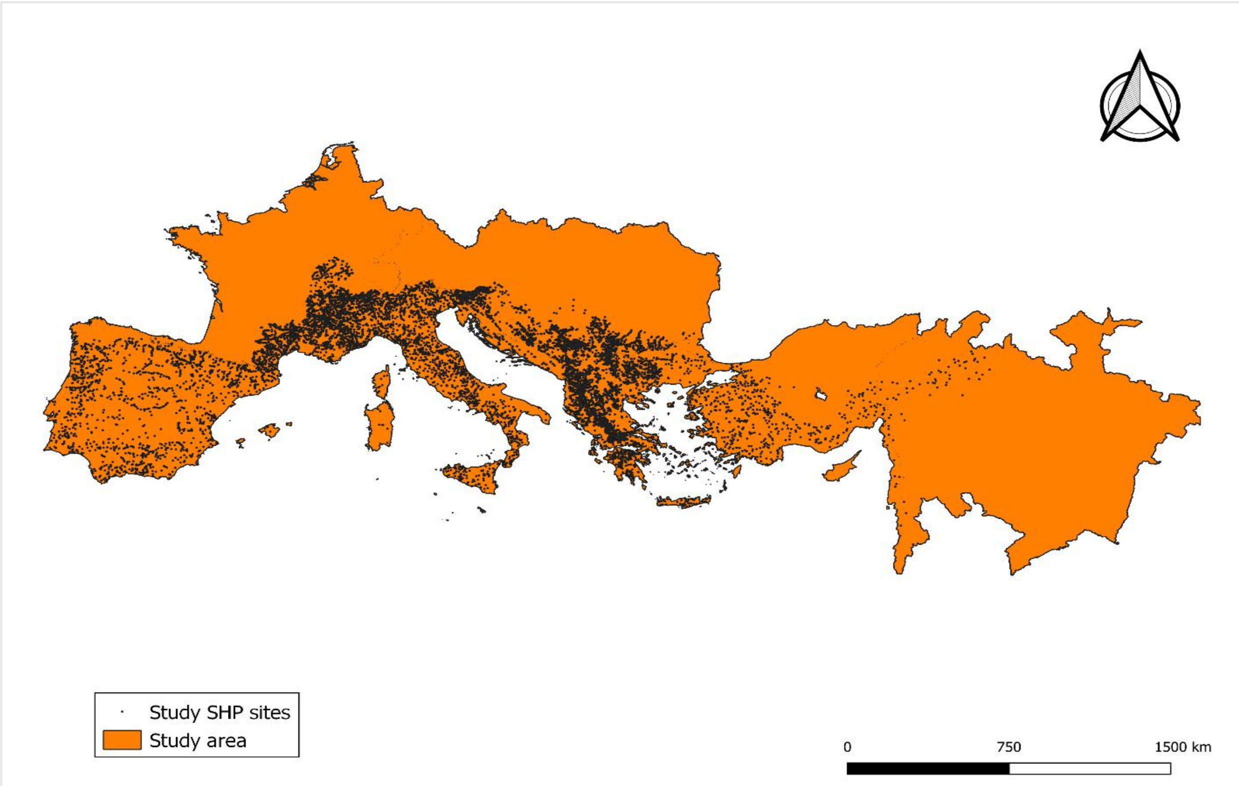


Figure 2: Study area and SHP sites (adapted from Schwarz, 2020)

SHP projects do not always exploit, by design, the site's maximum hydrologically achievable power output. To identify the unexplored potential of Mediterranean SHP plants, a **"FullPower"** variation was developed where all overestimated SHP sites could produce above the expected power class, given each site's hydrological conditions.

To understand the importance of SHP in European energy systems, estimated SHP productivity in those countries for which data was available was compared to gross electricity consumption (net production plus net imports) and to primary energy consumption (the total energy needs of a country, excluding all non-energy use of energy carriers). Two "political" scenarios were studied:

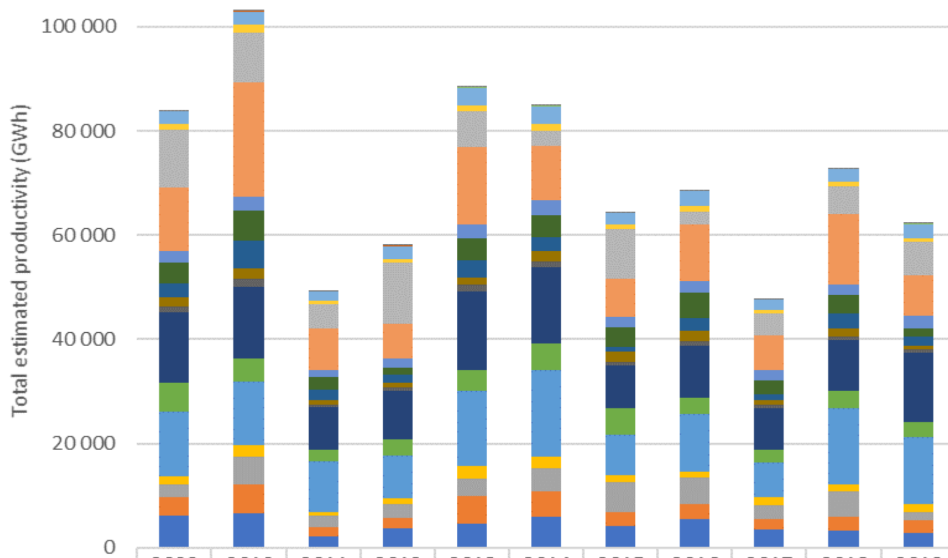
- **"Present"** contribution, i.e. the contribution of already existing SHP to meeting energy demand (only operational SHP plants were considered);
- **"What if?"** contribution, i.e. the contribution that building new SHP would bring to meeting energy demand in conditions similar to the 2009-2019 period (operational, under construction and projected SHP plants were considered).

SHP productivity estimations were then compared to available electricity generation data from real SHP sites. Productivity estimations proved to be a solid overestimation of SHP plant production, around 3 to 4 times higher. Methodological steps and validation results are addressed in more detail in Annex I.

Results and discussion

Productivity estimates

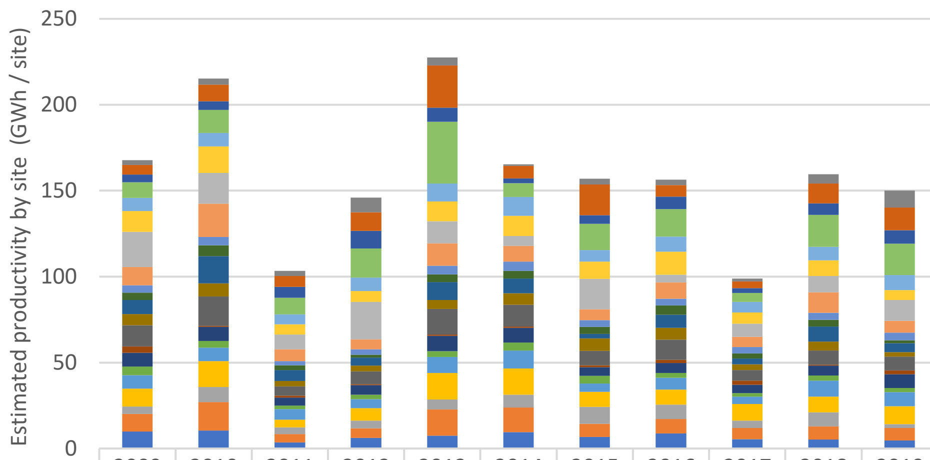
Figure 3 shows the potential (overestimated) productivity for all SHP projects – planned, under construction and operating (**"What if?"** scenario). It reveals the high variability of hydropower, dependent on meteorological conditions, with productivities varying more than 50% from the best to the worst years.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Syria	25	30	26	77	42	8	30	29	15	48	89
Palestine	6	10	6	11	25	7	18	7	4	12	13
Lebanon	18	20	26	41	33	11	20	29	11	27	31
Jordan	18	27	19	34	72	16	31	32	11	37	37
Switzerland	2 433	2 493	1 838	2 494	3 395	3 541	2 117	2 809	1 986	2 485	2 801
Kosovo	1 167	1 489	573	608	1 105	1 130	970	1 282	631	872	562
Turkey	11 084	9 688	4 648	11 807	6 935	3 074	9 545	2 444	4 106	5 181	6 552
Spain	12 152	21 937	7 935	6 561	14 728	10 350	7 155	10 829	6 814	13 493	7 815
Slovenia	2 211	2 536	1 278	1 741	2 731	2 957	2 084	2 047	1 981	2 162	2 423
Serbia	3 992	5 821	2 553	1 459	4 111	4 015	3 784	4 978	2 655	3 556	1 414
Portugal	2 681	5 222	2 047	1 546	3 420	2 847	863	2 491	1 084	2 895	1 743
North Macedonia	1 756	2 064	861	894	1 402	1 794	1 942	1 877	918	1 417	708
Montenegro	1 089	1 523	483	657	1 328	1 125	750	1 044	546	730	710
Malta	3.8	0.6	1.1	0.7	0.7	0.7	1.2	1.7	2.4	0.6	2.3
Italy	13 525	13 851	8 016	9 329	15 074	14 626	8 286	9 926	8 150	9 707	13 262
Greece	5 599	4 325	2 276	3 036	3 903	5 252	5 026	3 127	2 304	3 328	2 820
France	12 330	12 307	9 764	8 227	14 533	16 506	7 650	10 945	6 787	14 709	13 041
Croatia	1 573	2 266	659	1 070	2 298	2 274	1 315	1 287	1 457	1 354	1 538
Bulgaria	2 554	5 167	2 305	2 708	3 478	4 483	5 918	5 101	2 546	4 857	1 370
Bosnia and Herzegovina	3 459	5 607	1 628	1 895	5 207	4 839	2 579	2 827	2 200	2 601	2 455
Albania	6 213	6 611	2 289	3 838	4 638	5 959	4 218	5 479	3 424	3 319	2 947
Total	83 889	102 99	49 232	58 034	88 457	84 816	64 305	68 592	47 631	72 790	62 333

Figure 3: Total estimated productivity (GWh/year) by country; the stacked column colours follow the order of the table below: the first country in the table is the top of the stacked column, the second country is the second from the top and so on.

As the country contributions in figure 3 are influenced by the number of installed SHP plants, figure 4 shows the average productivity by plant and year. In both figures it is also possible to identify climate-induced variability on a country basis. Different climatic regions are observable, with dry years in some regions proving to be high productivity years in others, and with some countries maintaining steadier productivities than others. It is also clear that the countries with most SHP installations (Italy, France, Spain, Greece) are not those with the higher productivity by plant nor the most resilient to dry years.

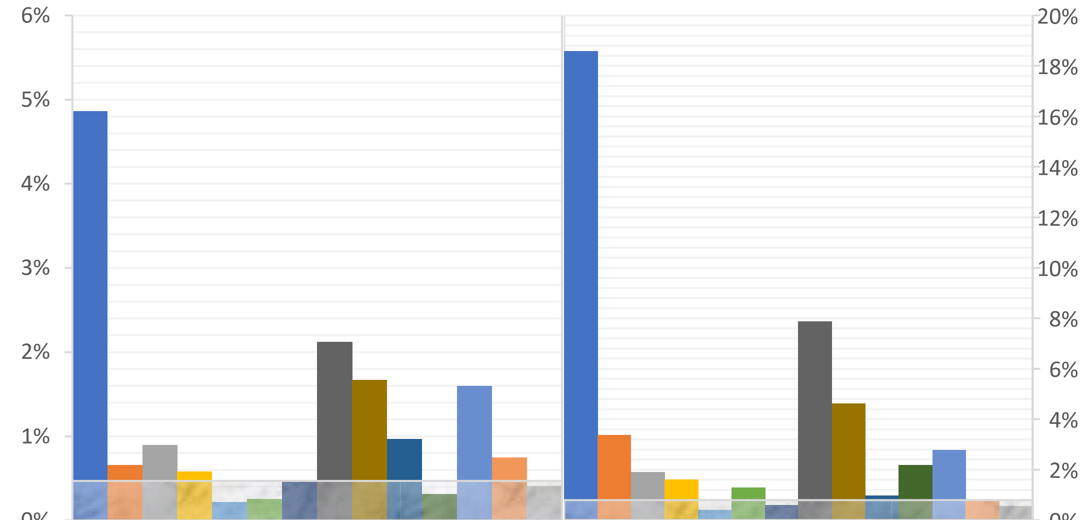


	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Syria	2,8	3,4	2,9	8,5	4,7	0,9	3,3	3,3	1,6	5,3	9,9
Palestine	5,6	9,8	6,3	10,7	24,6	7,2	17,9	6,6	3,8	11,5	13,3
Lebanon	4,4	5,1	6,4	10,3	8,2	2,7	4,9	7,3	2,8	6,8	7,7
Jordan	9,1	13,4	9,6	17,0	35,9	8,0	15,4	16,0	5,3	18,6	18,3
Switzerland	7,6	7,7	5,7	7,7	10,5	11,0	6,6	8,7	6,2	7,7	8,7
Kosovo	12,2	15,5	6,0	6,3	11,5	11,8	10,1	13,4	6,6	9,1	5,9
Turkey	20,5	17,9	8,6	21,8	12,8	5,7	17,6	4,5	7,6	9,6	12,1
Spain	10,7	19,3	7,0	5,8	13,0	9,1	6,3	9,5	6,0	11,9	6,9
Slovenia	4,1	4,8	2,4	3,3	5,1	5,5	3,9	3,8	3,7	4,1	4,5
Serbia	4,4	6,4	2,8	1,6	4,5	4,4	4,2	5,5	2,9	3,9	1,6
Portugal	8,1	15,8	6,2	4,7	10,4	8,6	2,6	7,5	3,3	8,8	5,3
North Macedonia	6,5	7,7	3,2	3,3	5,2	6,7	7,2	7,0	3,4	5,3	2,6
Montenegro	12,2	17,1	5,4	7,4	14,9	12,6	8,4	11,7	6,1	8,2	8,0
Malta	3,8	0,6	1,1	0,7	0,7	0,7	1,2	1,7	2,4	0,6	2,3
Italy	8,0	8,2	4,7	5,5	8,9	8,6	4,9	5,9	4,8	5,7	7,8
Greece	5,0	3,8	2,0	2,7	3,5	4,7	4,5	2,8	2,0	2,9	2,5
France	7,8	7,8	6,2	5,2	9,2	10,4	4,8	6,9	4,3	9,3	8,3
Croatia	10,6	15,2	4,4	7,2	15,4	15,3	8,8	8,6	9,8	9,1	10,3
Bulgaria	4,3	8,6	3,9	4,5	5,8	7,5	9,9	8,5	4,3	8,1	2,3
Bosnia and Herzegovina	10,2	16,5	4,8	5,6	15,4	14,3	7,6	8,3	6,5	7,7	7,2
Albania	9,9	10,5	3,6	6,1	7,4	9,5	6,7	8,7	5,5	5,3	4,7
Average	8,0	10,2	4,9	6,9	10,8	7,9	7,5	7,5	4,7	7,6	7,1

Figure 4: Estimated average productivity by site, by country (GWh/year/site)

Small hydropower energy contribution

In this section, the analysis of SHP contribution to meeting energy demand is presented for both scenarios: **"Present"** (where only operating SHP sites are studied) and **"What if?"** (where all SHP sites – operating, under construction and planned – are studied). The indicators used were the ratio of SHP productivity to (i) gross electricity consumption (net production plus net imports), and (ii) primary energy consumption.

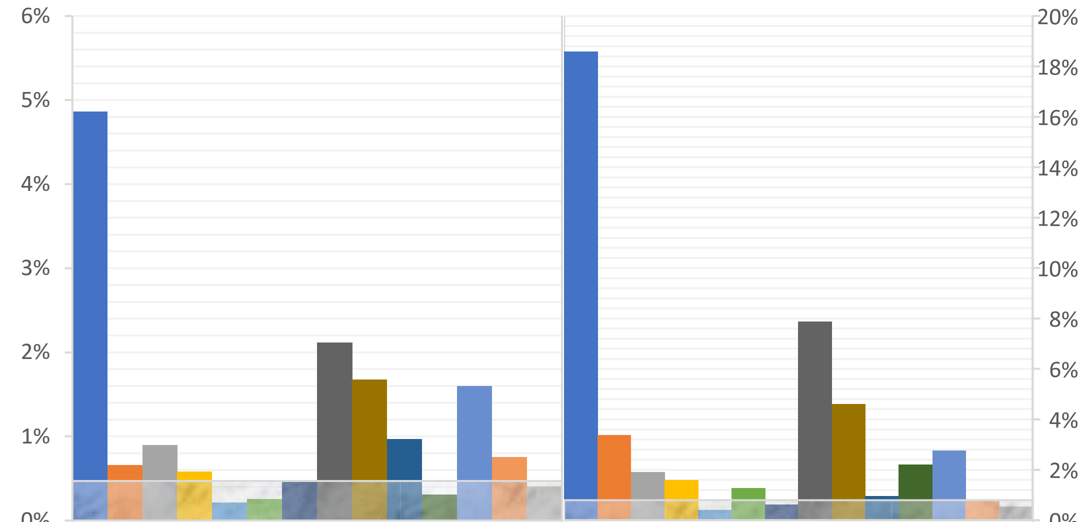


	"Present" contribution to primary energy consumption (%) - average 2009-2018	"What if?" contribution to primary energy consumption (%) - average 2009-2018
Albania	5%	19%
Bosnia and Herzegovina	0,7%	3%
Bulgaria	0,9%	2%
Croatia	0,6%	2%
France	0,2%	0,4%
Greece	0,3%	1%
Italy	0,5%	0,6%
Montenegro	2%	8%
North Macedonia	2%	5%
Portugal	1%	1%
Serbia	0,3%	2%
Slovenia	2%	3%
Spain	0,7%	0,8%
Turkey	0,4%	0,5%
Global	0,47%	0,79%

Figure 5: Average potential SHP contribution to gross electricity consumption

While SHP sites in Kosovo, Switzerland, Jordan, Lebanon, Palestine, and Syria were modelled, their contributions to the energy mix were not computed, due to insufficiency of comparable statistics. Contributions for year 2019 were not estimated due to unavailability of Eurostat data. Malta was excluded from the analysis as there are no operating SHP plants in the inventory, only one planned plant. Detailed analysis (yearly and by country) of contributions to gross electricity consumption and to primary energy consumption are presented in Annex II and Annex III, respectively.

In figure 5, the country-wise analysis of the contribution of the theoretical (overestimated) **"Present"** scenario SHP plants to gross electricity consumption shows high variability, with the majority of countries falling below a 5% contribution, even in rainy years. Contributions for the study region average at 2.6% per year, with a maximum of 3.8% in 2010 and a minimum of 1.6 % in 2017 (Annex II, Figure II-1).



	"Present" contribution to primary energy consumption (%) - average 2009-2018	**"What if?"** contribution to primary energy consumption (%) - average 2009-2018
Albania	5%	19%
Bosnia and Herzegovina	0,7%	3%
Bulgaria	0,9%	2%
Croatia	0,6%	2%
France	0,2%	0,4%
Greece	0,3%	1%
Italy	0,5%	0,6%
Montenegro	2%	8%
North Macedonia	2%	5%
Portugal	1%	1%
Serbia	0,3%	2%
Slovenia	2%	3%
Spain	0,7%	0,8%
Turkey	0,4%	0,5%
Global	0,47%	0,79%

Figure 6: Average potential SHP contribution to primary energy consumption

Contributions to primary energy consumption (figure 6) have a similar pattern in variation between and within countries. Most of the countries' contributions are below or around 1%, with a yearly average of 0.47%, a maximum of 0.71% in 2010 and a minimum of 0.3% in 2017 (Annex III, Figure III-1).

Percentage contribution for both gross electricity consumption and primary energy consumption shows high scores in Albania, Montenegro, North Macedonia and Slovenia. However, these high percentage scores in some countries may not reflect higher hydropower production potential. The countries in which

SHP makes higher possible contributions also have a lower gross electricity consumption (see Annex I Table I-6) and a lower primary energy consumption (Annex I Table I-7). These lower energy indicators could be caused by several factors such as lower population densities or higher energy poverty, among others, but precise reasons can only be understood through a case-by-case analysis.

Hence, importantly, investing in new SHP plants does not significantly improve the relevance of SHP in the energy context. Building an extra 5 748 SHP facilities and having 2.4 times more operational SHP plants results in a small increase of SHP contribution: from 2.6% to 4.4% of gross electricity consumption (see figure 5) and from 0.47% to 0.79% of primary energy consumption (see figure 6).

Figures 7 and 8 compare the theoretical yearly contribution to gross electricity consumption and to primary energy consumption, respectively, for two variants of the **"Present"** scenario: "InstalledPower" is based on the inventory power class, while "FullPower" represent an upgrade to the maximum power theoretically available on site. The chess pattern interval represents the productivity with a 10 to 30% reduction in flow (Q), expected to happen in a world 2°C warmer. Note that climate change induced reductions will probably be even higher (see section SHP: investing in sustainability? – Small hydropower and climate change in the Mediterranean region).

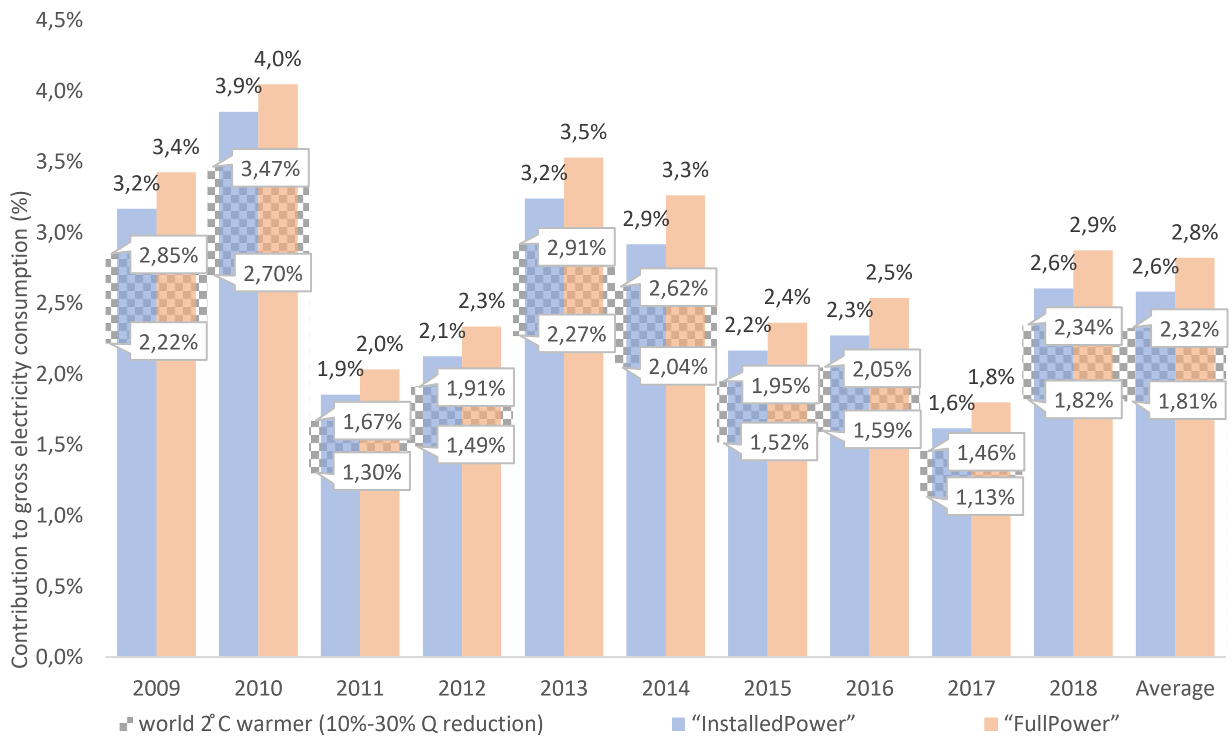


*Figure 7: Theoretical contribution of SHP to gross electricity consumption – **"Present"** scenario comparisons*

Figures 7 and 8 show that exploiting the remaining available potential "FullPower" would not significantly improve SHP contribution to energy demand: the latter would grow on average from 2.6% to 2.8% of gross electricity consumption and from 0.47% to 0.51% of primary energy consumption.

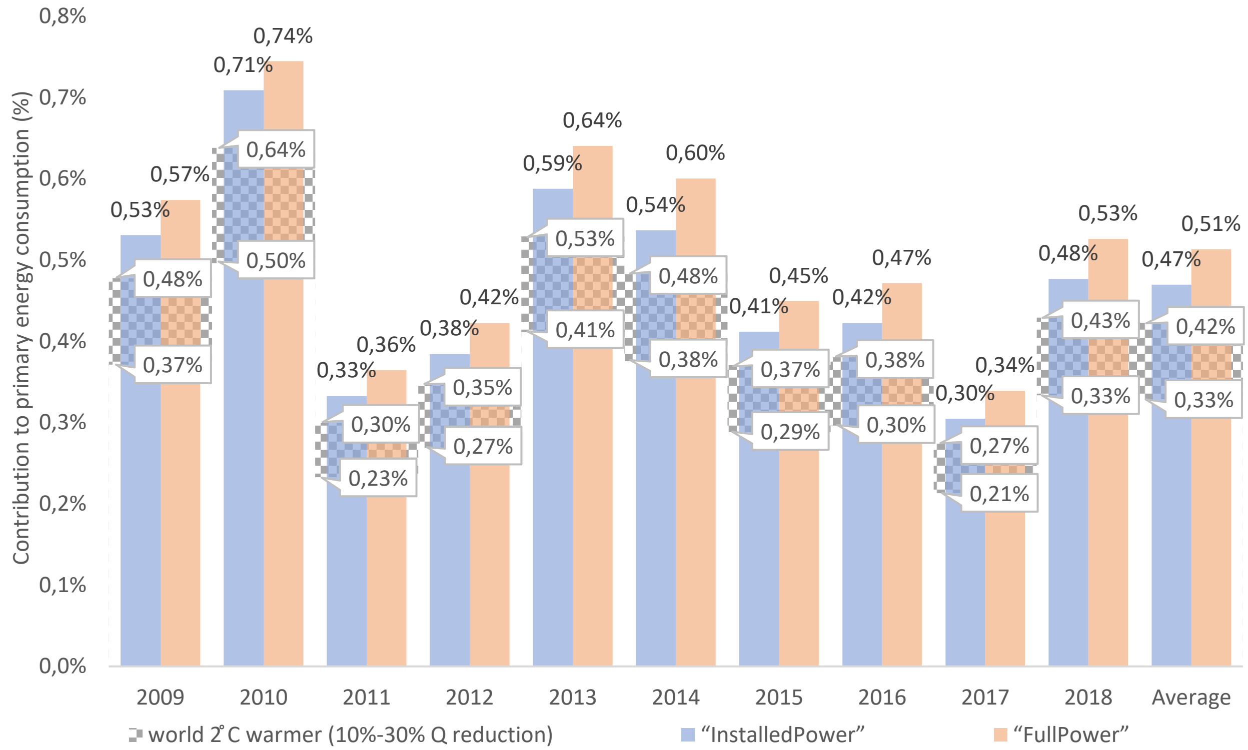
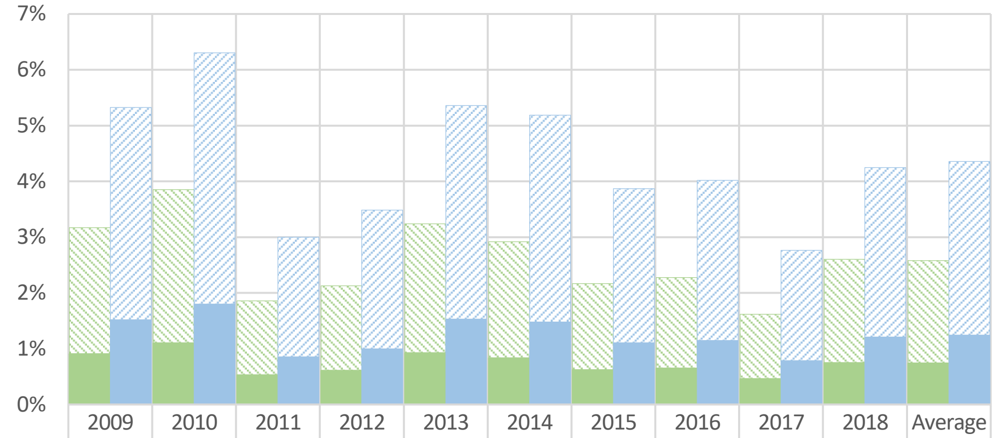


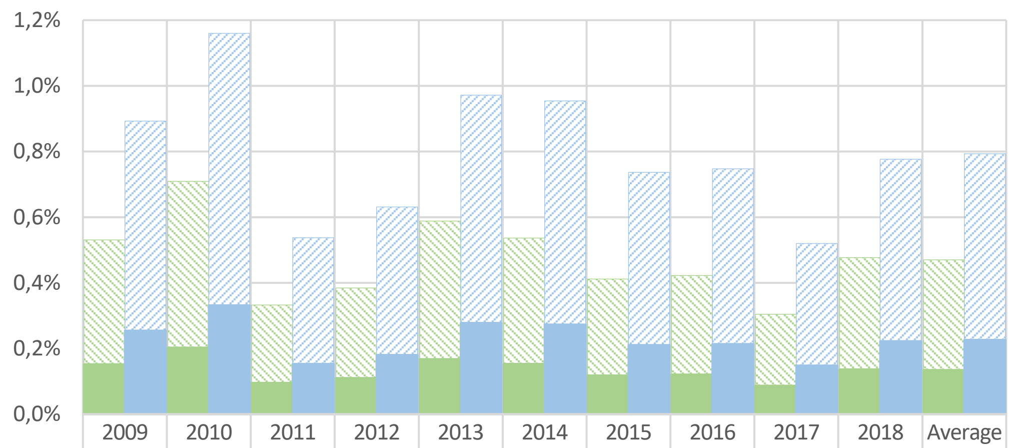
*Figure 8:1 Theoretical contribution of SHP to primary energy consumption – **"Present"** scenario comparisons*

Estimated SHP productivities, and consequently their contribution to meeting energy demand, are by design an overestimation. Comparison with real SHP production data revealed that SHP productivity is overestimated, on average, around 3 to 4 times (see Annex I – Data analysis and result validation). Figures 9 and 10 compare the theoretical contributions (overestimated) to gross electricity consumption and primary energy consumption with the likely contributions (3.5 x lower). Likely contributions are expected to be significantly lower than theoretical estimates: on average, around 0.74% of the theoretical contribution to gross electricity consumption and 0.13% of the contribution to primary energy consumption for the **"Present"** scenario; and about 1.2% of the contribution to gross electricity consumption and 0.23% of the contribution to primary energy consumption for the **"What if?"** scenario.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
"Present" (overestimated)	3,2%	3,9%	1,9%	2,1%	3,2%	2,9%	2,2%	2,3%	1,6%	2,6%	2,6%
"What if?" (overestimated)	5,3%	6,3%	3,0%	3,5%	5,4%	5,2%	3,9%	4,0%	2,8%	4,2%	4,4%
"Present" (3.5 x lower)	0,90%	1,1%	0,53%	0,61%	0,93%	0,83%	0,62%	0,65%	0,46%	0,74%	0,74%
"What if?" (3.5 x lower)	1,5%	1,8%	0,86%	1,0%	1,5%	1,5%	1,1%	1,1%	0,79%	1,2%	1,2%

Figure 9: Contribution of SHP to gross electricity consumption - comparing different scenarios



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
"Present" (overestimated)	0,53%	0,71%	0,33%	0,38%	0,59%	0,54%	0,41%	0,42%	0,30%	0,48%	0,47%
"What if?" (overestimated)	0,89%	1,2%	0,54%	0,63%	1,0%	1,0%	0,74%	0,75%	0,52%	0,78%	0,79%
"Present" (3.5 x lower)	0,15%	0,20%	0,10%	0,11%	0,17%	0,15%	0,12%	0,12%	0,087%	0,14%	0,13%
"What if?" (3.5 x lower)	0,25%	0,33%	0,15%	0,18%	0,28%	0,27%	0,21%	0,21%	0,15%	0,22%	0,23%

Figure 10: Contribution of SHP to primary energy consumption - comparing different scenarios

Conclusions


Rio Teixeira, Portugal: photo by Ricardo Oliveira

The goal of this study was to develop research to evaluate the potential output of SHP in the European Mediterranean basin and assess its potential contribution to the region's energy mix. Two different modelling scenarios were assessed: the **"Present" scenario**, which depicts an overestimation of the contribution of currently operating SHP plants in the European Mediterranean region, and the **"What if?" scenario**, which depicts the contributions of existing plus projected SHP plants, for external conditions similar to the 2009-2019 period. Our research came to the following conclusions:

- **The potential (overestimated) contribution of existing SHP sites to the energy mix is low**: Yearly overestimated productivity for currently operating SHP sites varies between 1.6% and 3.9% of the region's gross electricity consumption, with an average of 2.6%. Contribution to primary energy consumption ranges from 0.3% to 0.7%, with an average of 0.5%. The real SHP contribution is likely some 3.5 times lower – falling to around 0.74% of gross electricity consumption and 0.12% of primary energy consumption on a yearly average.

- **Building 5 748 new plants and more than doubling the existing number of SHP plants does not greatly increase the energy contribution of SHP**: Yearly overestimated productivity, considering operating, under construction and planned SHP plants, varies between 2.8% and 6.3% of the gross electricity consumption, with a yearly average of 4.4%, and between 0.5% and 1.2% of primary energy consumption, with a yearly average of 0.8%. The real yearly average contribution is probably only around 1.2% of gross electricity consumption and 0.23% of primary energy consumption.

  Exploring the remaining hydrological potential of the inventoried sites ("FullPower" scenario variant) would not significantly improve SHP energy contribution. The operating SHP plants yearly average contribution to gross electricity consumption would only increase from 2.6% to 2.8% and grow from 0.47% to 0.51% for primary energy consumption.

- **SHP productivity, and consequently its contribution to meeting energy demand, is by design overestimated:** Since we considered all runoff as stream flow, and considered neither local technical constraints, nor economic criteria, nor social or ecological impacts and conflicts, a realistic estimate of viable potential will be significantly lower. Moreover, comparison of theoretical estimations with real SHP production data revealed that SHP productivity is overestimated on average around 3.5 times.
- **Productivity estimates are quite variable from country to country, with a great climate-induced variability:** Dry years in some regions prove to be high productivity years in other regions. Hydropower potential is higher in mountain regions (due to the combined effect of elevation and rainfall) and these are also the regions with a more stable productivity. The countries with a higher number of SHP installations (Italy, France, Spain, Greece) are not those with higher productivity by plant nor the most resilient to droughts.
- **Climate change effects will greatly decrease Mediterranean hydropower production, including small hydropower, and may render many SHP sites unexploitable:** Considering climate change reveals that a sustained 2 °C increase in global temperature, compared to pre-industrial era, would significantly reduce (10%-30%) stream flow in the Mediterranean region. This reduction would represent an even higher decrease in hydropower production as water scarcity would prompt higher competition for this resource – and the priority should be availability of water for human consumption, ecosystems and agriculture. Also, changes in precipitation patterns in the Mediterranean region tend to produce, even today, high levels of precipitation followed by long dry periods, meaning that in flood periods not all flow will be used, while long periods of low flow will limit electricity generation.
- **Investing in energy efficiency and in emerging technologies like photovoltaic is a more cost-effective way to achieve steady and secure electric systems, than installing SHP plants:** The economic parameters of SHP vary significantly with local conditions (climate, geology, physiography, road accessibility, single or multiple use of the waterworks, distance to the electric grid, local energy markets, among others) and specific project targets (to satisfy local demand, or optimize peak load, or optimize electricity production). Similarly, the social and ecological impacts vary significantly, depending on water management practice and project impact assessment. The cost of electricity from SHP, measured as the levelized Cost of Energy (LCOE) ranges from 40 to over 300 €/MWh, depending mostly on local factors. This range of values can be compared to the wholesale market price of electricity production in Europe (about 40 to 60 €/MWh in the past few years, although it varies much from country to country), to the costs of energy efficiency investments (typically 10 to 40 €/MWh), and to the cost of emerging technologies such as photovoltaic (with reported costs of about 50 €/MWh, with a downward trend).

  Some low-investment, low-impact SHP projects, such as the refitting of existing SHP plants and the installation of SHP in other purpose waterworks (including irrigation, water supply and wastewater systems) can be economically interesting and have lower ecological impacts. Nevertheless, a case-by-case economic analysis and impact assessment is always necessary. And even then, the odds are that most planned SHP plants in Europe are not interesting, either economically or ecologically. In most cases, SHP is not a cost-effective way to ensure a reliable electric system, to perform the needed energy transition nor to reduce carbon emissions.

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Annex I: Detailed methodology

The estimation of SHP electricity production and its contribution to meeting energy demand in the European Mediterranean basin included the following steps:

- Selection of data and equations for installed power and productivity assessment
- Preliminary estimation of stream flow and hydraulic head for each SHP site
- Data analysis and result validation
- Computation of SHP contribution to meeting energy demand by country

Equations for installed power and productivity

The potential installed power is calculated according to

$$P_i = \rho * Q_{max} * g * \Delta H_i * \eta$$

Equation I-1

Where:

- P_i is the hydropower potential installed power (watt) for installation i;
- ρ is the density of water (kg m^{-3}), assumed constant at 1 000 kg m^{-3};
- Q_{max} is the maximum stream flow (m^3 s^{-1}) for installation i occurring on year series ranging from 2009 to 2019;
- g is the gravitational acceleration, 9.80665 m s^{-2};
- ΔH_i is the hydraulic head (m) for installation i, calculated as the elevation difference between the stream entry point in sub-basin i and the stream exit point at sub-basin i;
- η is the net generation efficiency (dimensionless), considered constant (at 0.80) across and within all small hydropower installations.

The potential electricity production can then be calculated by multiplying power with operation time (equation I-2). Estimations were computed on a yearly basis.

$$P_{i,y}{}^{out} = \rho * Q_{i,y} * g * \Delta H_i * \eta * T_y$$

Equation I-2

Where:

- $P_{i,y}{}^{out}$ is the hydropower output (watt hour) for installation i at year y;
- ρ is the density of water (kg m^{-3}), assumed constant at 1 000 kg m^{-3};
- $Q_{i,y}$ is the yearly average stream flow (m^3 s^{-1}) for installation i at year y;
- g is the gravitational acceleration, 9.80665 m s^{-2};
- ΔH_i is the hydraulic head (m) for installation i, calculated as the elevation difference between the stream entry point in sub-basin i and the stream exit point at sub-basin i;
- η is the net generation efficiency (dimensionless), considered constant (at 0.80) across and within all small hydropower installations;
- T is the number of hours in year y.

Equations I-1 and I-2 have been widely used for the estimation of small hydropower potential (Zhou et al., 2015; Cyr et al., 2011; Kaunda et al., 2012) and have also been used for other applications, such as irrigation systems (Nicotra et al., 2018), water supply lines (Kucukali, 2011) or even in hydro turbine selection (Williamson et al., 2011). The proposed estimation does not consider artificial constraints to Q and ΔH, such as those resulting from storage hydropower projects and/or hydraulic head maximization, as these project characteristics are difficult to inventory and analyze at the proposed scale. Nevertheless, as the availability of water and the maximum available hydraulic drops are the main constraints to hydroelectricity production, such projects would always be limited by these physical properties. Thus, even when storing water for electricity production, or when artificially increasing stream flow, such flows can never be maintained for indefinite periods of time, and thus total energy output should be comparable to the estimations resulting from the proposed methodology. Similarly, even if hydraulic drops are maximized, maximum gross ΔH_i is always limited by the existing terrain elevation and constrained by technical and financial boundaries (Cyr et al., 2011). The proposed methodology estimates the highest possible streamflow to establish an upper bound for the electricity production of SHP projects in the study region. All the runoff occurring in the basins draining to each SHP project is accounted for at the sub-basin exit point; all SHP generators are considered to be installed at their sub-basin exit point.

Stream flow and hydraulic head estimation

The 11 864 sites inventoried by Schwarz (2020) were cross-checked with the river network. 21 sites were relocated to fall within active streams and 1 504 were excluded for being outside the study area and/or exceeding the SHP criteria, resulting in a total of 10 360 SHP sites analysed in this study (table I-1).

Table I-1 SHP sites by region

Region	Number of SHP sites			
	Planned	In construction	Operating	Total
Albania	417	52	159	628
Bosnia and Herzegovina	242	11	86	339
Bulgaria	332	5	261	598
Croatia	109	2	38	149
France	1 106	0	474	1 580
Greece	1 042	8	79	1 129
Italy	834	3	858	1 695
Malta	1	0	0	1
Montenegro	70	3	16	89
North Macedonia	170	14	85	269
Portugal	1	0	329	330
Serbia	805	30	75	910
Slovenia	210	5	318	533
Spain	137	0	997	1 134
Turkey	138	2	402	542
Kosovo	70	16	10	96
Switzerland	148	1	173	322
Jordan	0	0	2	2
Lebanon	1	0	3	4
Palestine	0	0	1	1
Syria	4	0	5	9
Total	**5 837**	**152**	**4 371**	**10 360**

The information used in the present study from Schwarz (2020) inventory was, for each SHP site: country, status, location, class of installed power (0-1 MW, 1-10 MW). The inventory does not contain actual installed power, productivity, technical, economic nor environmental information.

For each SHP site, the total drained basin was determined using the Pfafstetter hydrological feature codes present in the CCM2 database. The Pfafstetter Coding System is a hierarchical method of hydrologically coding river basins, designed in a way that water drainage topology is directly described by the code, making it possible therefore to compare different points in the water system and to determine whether they are located upstream or downstream (Jager and Vogt, 2010). Figure I-1 shows an example of a drainage basin of a SHP site.

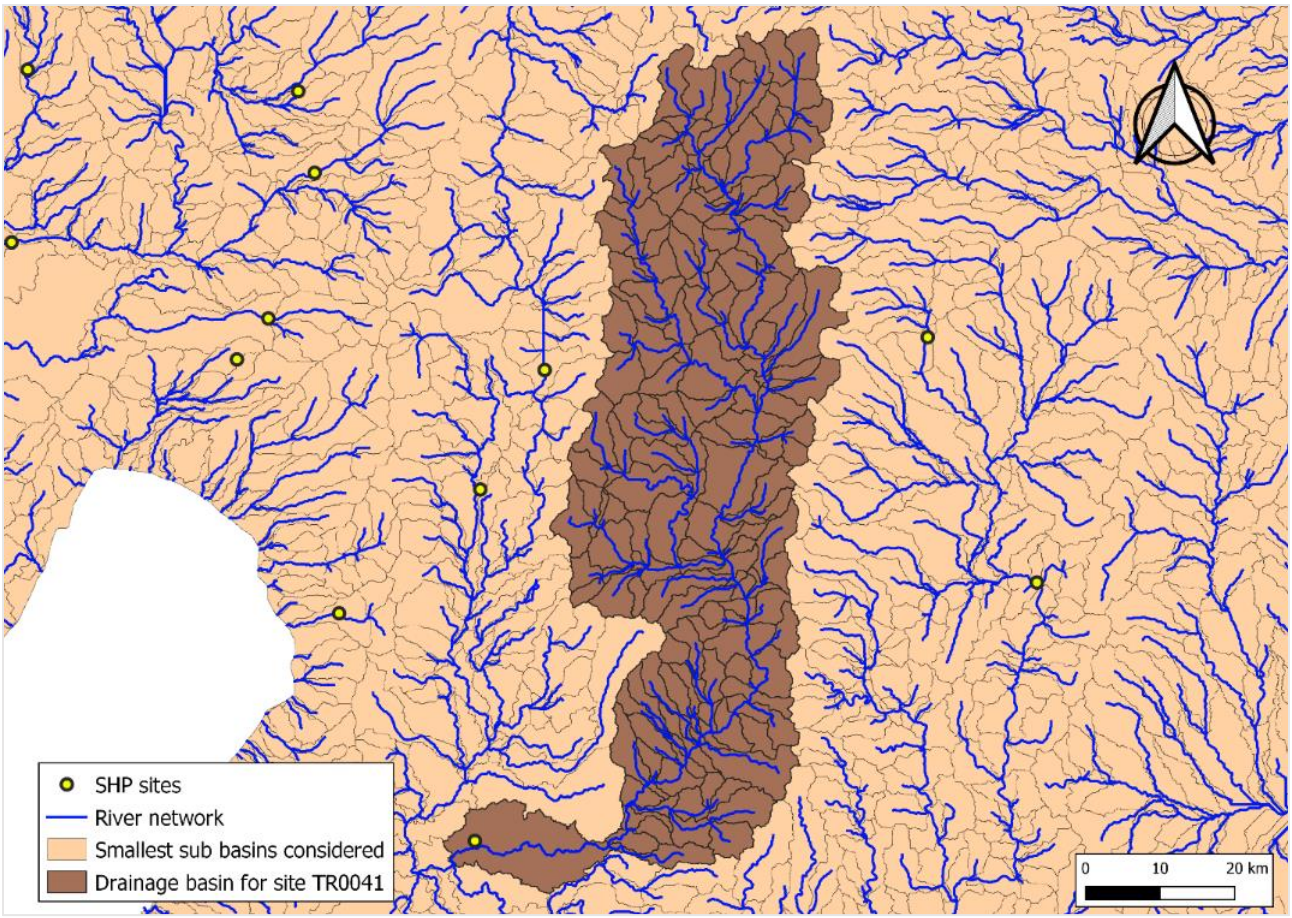


Figure I-1 Drainage basin for SHP site TR0041

The flow arriving at every SHP site was estimated by aggregating monthly runoff values taken from the TerraClimate dataset (Abatzoglou et al., 2018) for a series of 11 years (2009 to 2019). All runoff computations and data downloads were made within the Google Earth Engine code editor (available at https://code.earthengine.google.com/). Figure I-2 illustrates 2009 runoff values in the study region.

By averaging the pixel count of each runoff pixel within each SHP site drainage basin, we derived the average runoff for each SHP site, which in turn was multiplied by the drainage basin area to get the theoretical maximum flow for the SHP project.

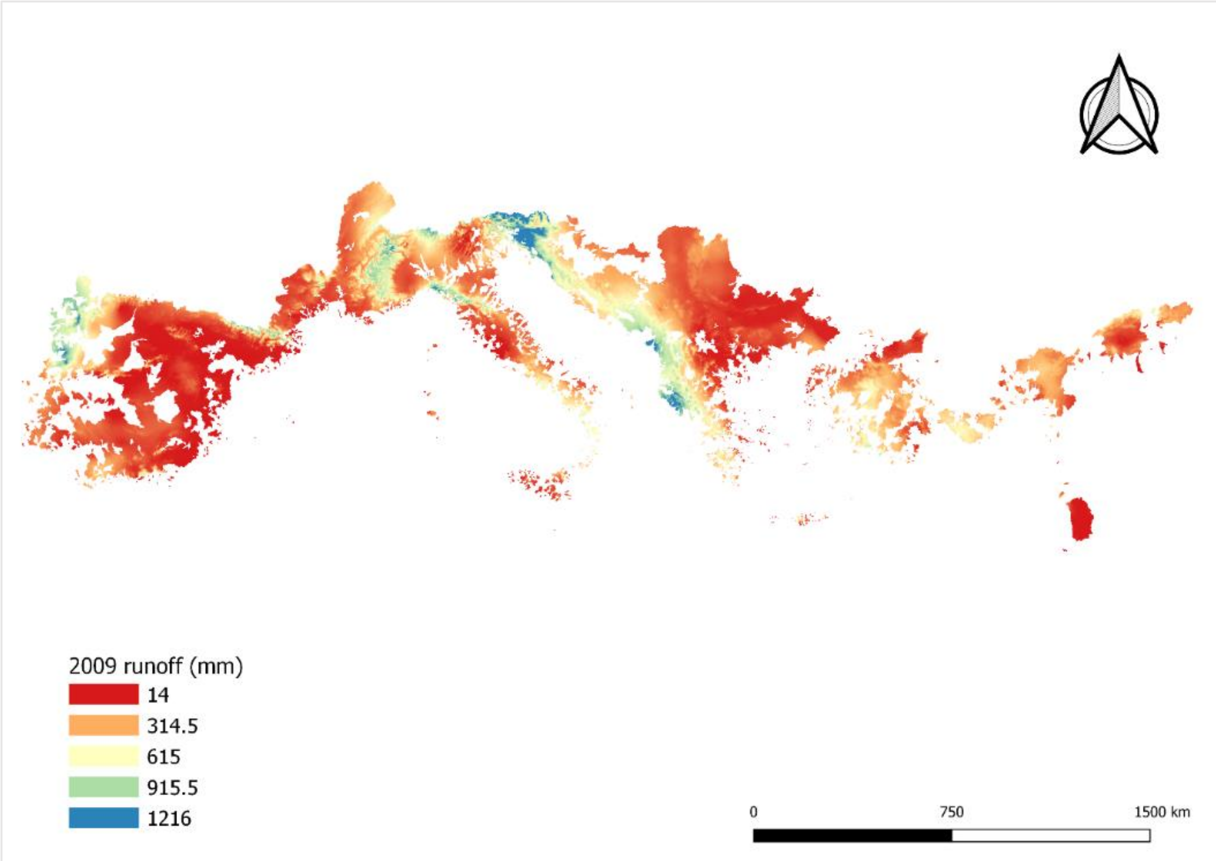


Figure I-2 Runoff in year 2009 in the study region (adapted from Abatzoglou et al., 2018)

Given the high variability of stream flow either within or across years, hydropower facilities will convert much but not all potential power. In this study we assume a 30% stream flow exceedance (Zhou et al., 2015), i.e. there is a 30% chance that monthly stream flow will exceed the turbine design capacity and will not be utilized for power production, hence we consider that up to 70% of the natural flow may be used.

Apart from the flow exceedance, no other parameters influencing water flow, such as catchments, water abstraction, or evaporation along the river network, are considered in the study.

Gross hydraulic head (ΔH) was estimated as the elevation difference between the stream entry point and the stream exit point at each SHP sub-basin.

With the flow arriving at each SHP and the correspondent hydraulic head, the potential installed power was estimated with Equation I-1 and compared with the correspondent power class present in the SHP inventory. Table I-2 synthesizes the results of the comparison.

Results deviating from expected classes are explained by a number of reasons, such as (i) deviations between the river network model and the real river system; (ii) misplaced or misclassified SHP sites on the SHP database; (iii) inconsistencies in runoff and altitude estimations; (iv) overpowered or underpowered SHP sites; or (v) technical characteristics (like catchments) not considered in the study. Differences due to the unknown technical characteristics of each project should not greatly influence the results since potential hydropower is always limited by available Q and ΔH. Deviations between the river model and real rivers and inconsistencies in the SHP database are expected and difficult to address.

Further investigation revealed that the two main contributors to result deviations were (i) runoff underestimations derived from errors in the Pfafstetter codes in the river database; (ii) and/or misplaced/misclassified SHP sites in the Schwarz (2020) database.

Table I-2 Comparison between estimated installed power and SHP inventory power classes

Criteria	Inventory power classes	Number of SHP
Estimated installed power within expected inventory class	[0.1, 1] MW	2 988
	]1, 10] MW	1 351
Estimated installed power below expected inventory class	[0.1, 1] MW	1 555
	]1, 10] MW	3 324
Estimated installed power above expected inventory class	[0.1, 1] MW	1001
	]1, 10] MW	141
Total SHP projects		10 360

To account for the deviations between estimated power output and inventoried power classes, the theoretical overestimated results in this study were computed considering the following procedure:

- SHP plants within expected inventory class were modelled with the hydrological and topographical conditions estimated for the study;
- SHP plants above expected inventory class were forced to produce at the upper limit of its expected class (1 MW for the [0.1, 1] MW class and 10 MW for the]1, 10] MW) by adjusting the hydraulic head and maintaining flow data;
- SHP plants below expected inventory class were forced to produce at the average potential power of their expected classes (0.235 MW for the [0.1, 1] MW class and 1.739 MW for the]1, 10] MW), estimated from the SHP sites within expected inventory class, by adjusting the hydraulic head and maintaining flow data;

As several SHP projects do not exploit, by design, the hydrologically maximum achievable power output, the maximum potential productivity was estimated, by allowing all overestimated SHP sites to produce above the expected power class, given each site's hydrological conditions – the "FullPower" scenario variation.

Data analysis and result validation

To verify the validity of the proposed estimations two comparisons with electricity generation data from real SHP sites were made:

- Portuguese SHP site specific comparison: comparison with a set of 80 known Portuguese sites (2016 and 2017 data);
- 2010 country comparison: an overall comparison with 2010 SHP generation data from 7 countries: Bulgaria, France, Greece, Italy, Portugal, Slovenia, Spain.

The main results and conclusions are presented below.

Portuguese SHP site specific comparison

Starting from a set of 80 known Portuguese SHP sites (APREN, 2018), with information on installed power and electricity generation for the years 2016 and 2017, a validation of Schwarz (2020) data was performed. All valid data was analysed against comparable study results.

Schwarz (2020) data validation

The comparison focused on two aspects: accuracy of Schwarz (2020) SHP georeferentiation; and SHP power classification.

The analysis of the georeferentiation of the Schwarz (2020) base data is shown in figure I-3. Figure I-4 evaluates the expected power classification from the Schwarz (2020) database against the installed power in the 58 matched Portuguese SHP plants.

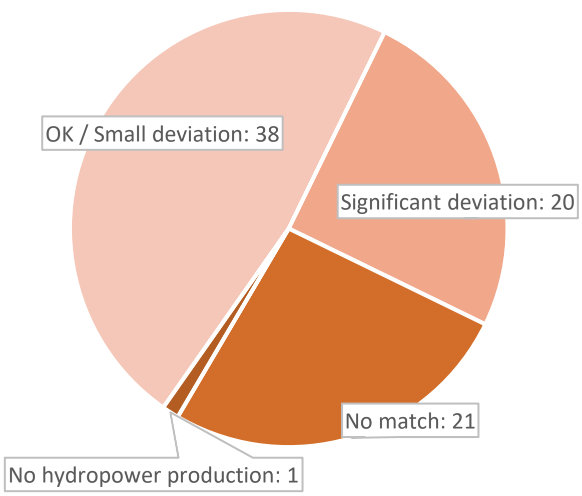


Figure I-3 Georeferentiation: Schwarz (2020) vs SHP Portuguese subset (nr of sites)

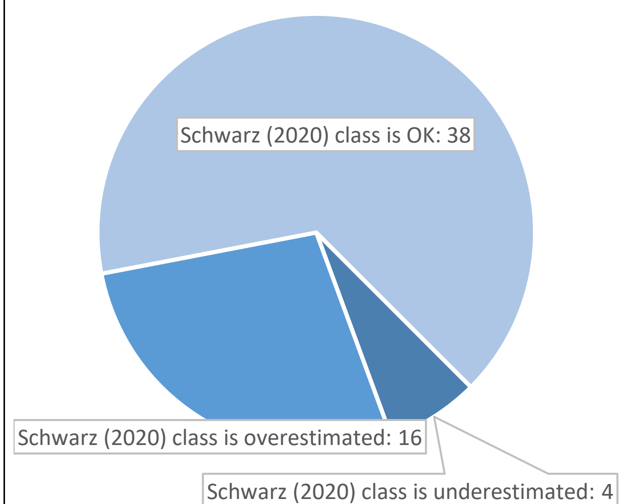


Figure I-4 Power class: Schwarz (2020) vs 58 SHP Portuguese subset (nr of sites)

Regarding georeferencing, 22 of 80 Portuguese SHP real sites had no match in the Schwarz (2020) database. The analyses of the matched Schwarz (2020) data shows that 38 of the 58 matched sites correspond to expected location. The “OK / small deviation” class includes locations with georeferencing deviations up to 1 km and/or plants where there are several kilometres of channels or pipelines between water abstraction and the power plant. 20 of 58 matched sites were georeferenced at distances of several kilometres of real location. One dam was mentioned in a site where no electricity production exists and no plans for the construction of a power plant could be found.

The deviations found in the comparisons shown above contribute to the deviations found between the study’s expected power and Schwarz (2020) power classes. The other main contributor is the underestimation of drainage areas in some sites due to errors in the Pfafstetter classification.

Estimated productivity vs Portuguese site data

Tables I-3 and I-4 present a comparison between real plant data and the theoretical results of this study for the subset of matching sites with available electricity generation data.

Table I-3 Electricity generation (GWh): study overestimated results vs Portuguese SHP real plant data

Electricity generation (GWh/year)	2016	2017
Portuguese SHP real plant data	656	289
Study overestimated results	730	331

Table I-4 Under- and over-estimation: study overestimated results vs Portuguese SHP real plant data

Comparison between estimated and real electricity generation		2016	2017
estimated >= real	No. SHP plants with data	33 (62%)	37 (65%)
	Average ratio Estimated generation/Real generation	3.3	2.5
estimated < real	No. SHP plants with data	20 (38%)	20 (35%)
	Average ratio Estimated generation/Real generation	0.58	0.55

Table I-3 shows that overall electricity generation was, in line with the study objectives, overestimated. Most SHP plants (63%) are overestimated (table I-4). The average deviation between estimated power and real power shows that electricity production for overestimated sites is greatly overestimated – about 3 times more. The underestimated sites were underestimated by a smaller factor, about 0.6. This analysis indicates that the results from the study should provide a solid overestimation of SHP plant production.

Country comparison

The country analysis consists of a comparison of the estimated electricity generation for each country against declared electricity generation data from the European Small Hydropower Association (ESHA, 2012), for the year 2010. In this section no site-specific comparison is performed because the ESHA data does not provide site-specific information, only bulk data. Table I-5 shows the comparison results.

Table I-5 Comparison: study estimated central results vs real data (ESHA 2010)

Country	Study results for operating plants in 2010			ESHA data (2010)		
	No. operating plants	Estimated generation (GWh)	Average generation (GWh/plant)	No. plants	Declared generation (GWh)	Average generation (GWh/plant)
Bulgaria	261	2 403	9	136	630	5
France	474	6 720	14	1 935	6 920	4
Greece	79	743	9	96	753	8
Italy	858	10 752	13	2 427	10 958	5
Portugal	329	5 190	16	155	1 370	9
Slovenia	318	1 447	5	535	465	1
Spain	997	20 361	20	1 047	4 719	5
Total	3 316	47 617	14	6 331	25 815	4

The number of operating plants indicated by Schwarz (2020) database differs significantly from ESHA data in all 7 countries. Overall, the number of existing plants declared by ESHA is almost twice the number of operating plants identified in the Schwarz (2020) database. Despite that, the estimated theoretical productivity of the sites identified as currently operating is about twice actual production in the year.

Country by country analysis reveals that estimated generation in some regions is slightly underestimated, but in these countries the number of operating plants considered in the study is significantly lower than those declared by ESHA as operating in 2010.

Analysis of average generation by plant reveals that theoretical productivity in all countries is greatly overestimated, 3.5 times higher than generation in the real sites (operating in 2010), indicating that study results are a robust overestimation of Mediterranean European SHP generation.

Small hydropower energy contribution

To understand the relevance of the contribution that SHP makes to meeting energy demand, estimated electricity productivity for the SHP inventory sites was compared to the gross electricity consumption (net production plus net imports) (Table I-6) and to the primary energy consumption (Table I-7) for the European countries where data was available. Two situations were analysed:

- "**Present**" contribution: Where only the already operational SHP plants are considered in the contribution assessment;
- **"What if?"**: Where all SHP sites (operating, under construction and planned) are considered in the contribution assessment.

The "**Present**" contribution analysis should represent an overestimation of current SHP contribution in the European Mediterranean region, whilst **"What if?"** should depict the contributions of existing and expected SHP in energy demand conditions similar to the 2009-2019 period.

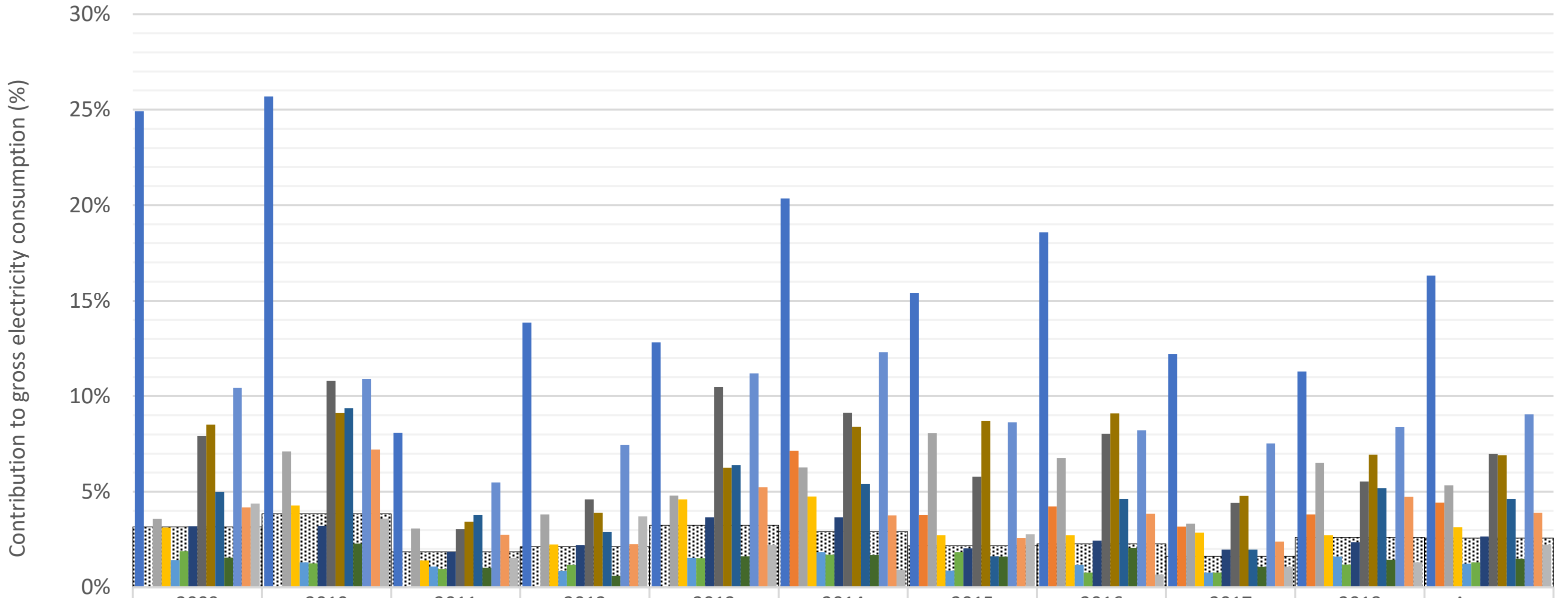
Table I-6 Gross electricity consumption by country in the study region (adapted from Eurostat, 2020)

Gross electricity consumption (TWh)										
Country\Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Albania	7	7	7	7	9	8	7	8	7	8
Bosnia and Herzegovina						13	13	13	13	13
Bulgaria	34	34	35	35	34	34	34	35	36	35
Croatia	18	18	18	18	18	17	18	18	18	19
France	486	514	492	503	509	481	491	499	498	495
Greece	60	59	57	55	54	56	57	59	57	56
Italy	326	335	337	331	321	313	319	317	323	324
Malta	2	2	2	2	2	2	2	2	2	3
Montenegro	4	4	4	4	3	3	3	3	3	3
North Macedonia	8	8	9	8	8	8	8	7	7	7
Portugal	53	55	54	53	53	52	53	54	55	56
Serbia	34	35	36	35	35	33	35	35	35	35
Slovenia	12	13	14	14	14	14	14	14	15	15
Spain	275	283	277	275	269	265	270	272	274	275
Turkey	186	202	218	231	235	245	254	267	284	290

Table I-7 Primary energy consumption by country in the study region (adapted from Eurostat, 2020)

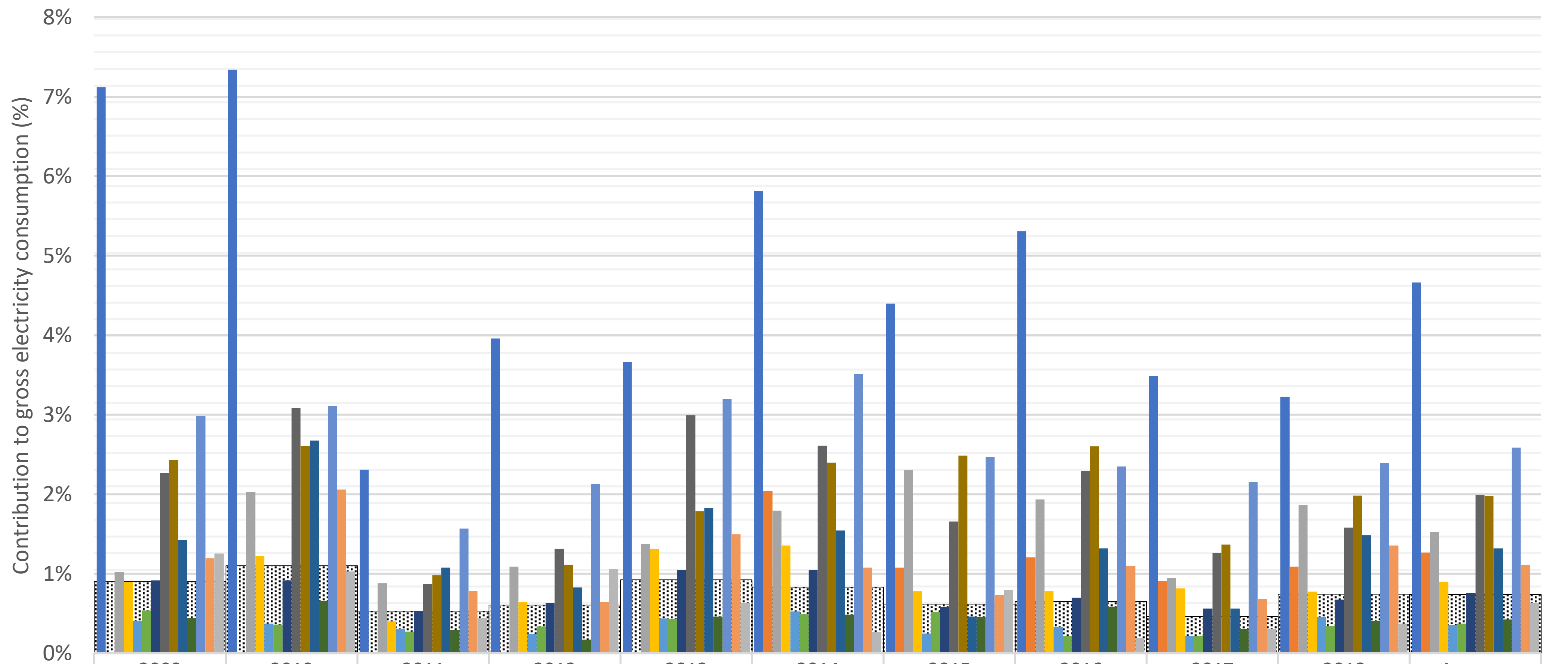
Primary energy consumption (TWh)										
Country\Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Albania	24	23	23	26	23	26	27	24	26	27
Bosnia and Herzegovina							69	71	78	78
Bulgaria	221	197	202	216	207	192	201	209	206	213
Croatia	107	105	104	101	95	93	88	93	94	97
France	2 970	2 864	2 960	2 898	2 898	2 912	2 789	2 842	2 792	2 782
Greece	354	341	315	309	307	271	269	270	266	269
Italy	2 048	1 908	1 946	1 884	1 821	1 769	1 660	1 734	1 721	1 733
Malta	12	10	10	10	12	10	10	9	8	9
Montenegro	14	10	13	13	12	12	12	12	12	12
North Macedonia	35	33	34	36	35	31	31	30	30	31
Portugal	274	274	263	256	244	244	241	251	254	265
Serbia	185	170	172	180	166	167	149	165	170	173
Slovenia	87	79	81	83	79	77	74	73	76	78
Spain	1 563	1 435	1 434	1 430	1 435	1 350	1 328	1 379	1 387	1 463
Turkey	1 096	1 082	1 143	1 241	1 286	1 241	1 356	1 457	1 529	1 692
Kosovo	26	29	29	29	27	27	26	29	31	29

Annex II: Small hydropower contribution to gross electricity consumption



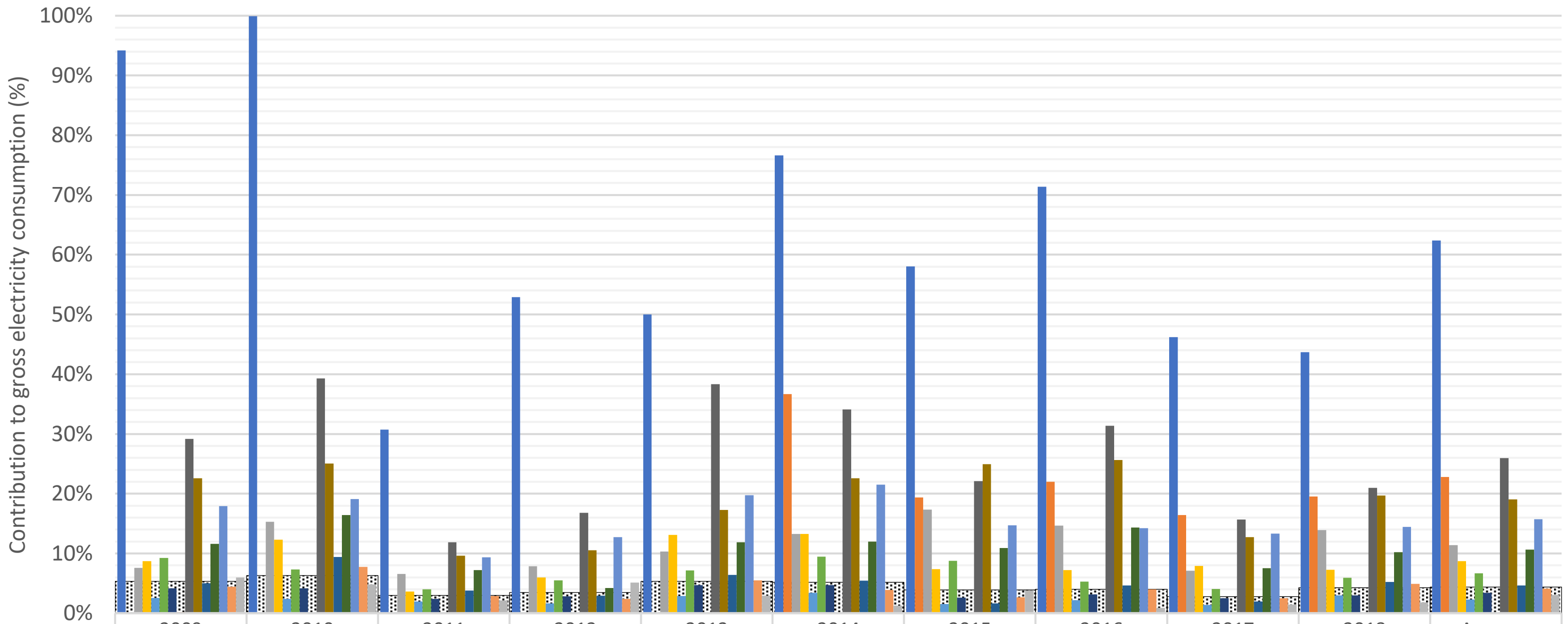
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Global	3,17%	3,85%	1,86%	2,12%	3,24%	2,92%	2,17%	2,27%	1,62%	2,60%	2,58%
Albania	25%	26%	8%	14%	13%	20%	15%	19%	12%	11%	16%
Bosnia and Herzegovina						7%	4%	4%	3%	4%	4%
Bulgaria	4%	7%	3%	4%	5%	6%	8%	7%	3%	7%	5%
Croatia	3%	4%	1,4%	2%	5%	5%	3%	3%	3%	3%	3%
France	1%	1%	1%	0,9%	2%	2%	0,9%	1%	0,8%	2%	1%
Greece	2%	1%	1%	1%	2%	2%	2%	0,8%	0,8%	1%	1%
Italy	3%	3%	2%	2%	4%	4%	2%	2%	2%	2%	3%
Montenegro	8%	11%	3%	5%	10%	9%	6%	8%	4%	6%	7%
North Macedonia	9%	9%	3%	4%	6%	8%	9%	9%	5%	7%	7%
Portugal	5%	9%	4%	3%	6%	5%	2%	5%	2%	5%	5%
Serbia	2%	2%	1%	0,6%	2%	2%	2%	2%	1%	1%	1%
Slovenia	10%	11%	5%	7%	11%	12%	9%	8%	8%	8%	9%
Spain	4%	7%	3%	2%	5%	4%	3%	4%	2%	5%	4%
Turkey	4%	4%	2%	4%	2%	0,9%	3%	0,7%	1%	1,3%	2%

*Figure II-1 Overestimated contribution to gross electricity consumption (**"Present"**)*



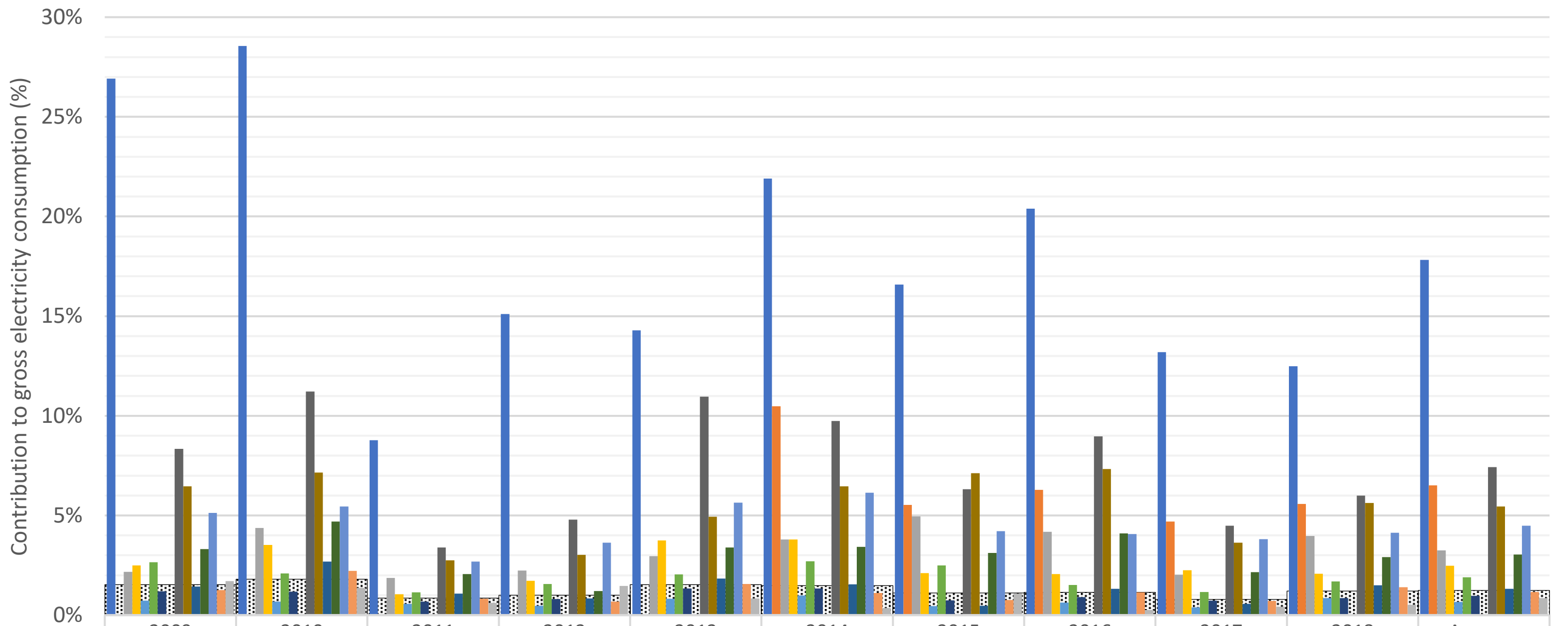
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Global	0,90%	1,10%	0,53%	0,61%	0,93%	0,83%	0,62%	0,65%	0,46%	0,74%	0,74%
Albania	7%	7%	2%	4%	4%	6%	4%	5%	3%	3%	5%
Bosnia and Herzegovina						2%	1%	1%	1%	1%	1%
Bulgaria	1%	2%	1%	1%	1%	2%	2%	2%	1%	2%	2%
Croatia	1%	1%	0,4%	1%	1%	1%	1%	1%	1%	1%	0,9%
France	0%	0%	0%	0,2%	0%	1%	0,2%	0%	0,2%	0%	0,4%
Greece	1%	0%	0%	0%	0%	0%	1%	0,2%	0,2%	0%	0,4%
Italy	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0,8%
Montenegro	2%	3%	1%	1%	3%	3%	2%	2%	1%	2%	2%
North Macedonia	2%	3%	1%	1%	2%	2%	2%	3%	1%	2%	2%
Portugal	1%	3%	1%	1%	2%	2%	0%	1%	1%	1%	1%
Serbia	0%	1%	0%	0,2%	0%	0%	0%	1%	0%	0%	0,4%
Slovenia	3%	3%	2%	2%	3%	4%	2%	2%	2%	2%	3%
Spain	1%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1,1%
Turkey	1%	1%	0%	1%	1%	0,3%	1%	0,2%	0%	0,4%	0,6%

*Figure II-2 Probable real contribution to gross electricity consumption (**"Present"**)*



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Global	5,33%	6,30%	2,99%	3,49%	5,36%	5,19%	3,87%	4,02%	2,76%	4,24%	4,35%
Albania	94%	100%	31%	53%	50%	77%	58%	71%	46%	44%	62%
Bosnia and Herzegovina						37%	19%	22%	16%	20%	23%
Bulgaria	8%	15%	7%	8%	10%	13%	17%	15%	7%	14%	11%
Croatia	9%	12%	4%	6%	13%	13%	7%	7%	8%	7%	9%
France	3%	2%	2%	2%	3%	3%	2%	2%	1%	3%	2%
Greece	9%	7%	4%	5%	7%	9%	9%	5%	4%	6%	7%
Italy	4%	4%	2%	3%	5%	5%	3%	3%	3%	3%	3%
Malta	0,19%	0,03%	0,05%	0,03%	0,03%	0,03%	0,05%	0,07%	0,10%	0,03%	0,1%
Montenegro	29%	39%	12%	17%	38%	34%	22%	31%	16%	21%	26%
North Macedonia	23%	25%	10%	11%	17%	23%	25%	26%	13%	20%	19%
Portugal	5%	9%	4%	3%	6%	5%	2%	5%	2%	5%	5%
Serbia	12%	16%	7%	4%	12%	12%	11%	14%	8%	10%	11%
Slovenia	18%	19%	9%	13%	20%	22%	15%	14%	13%	14%	16%
Spain	4%	8%	3%	2%	5%	4%	3%	4%	2%	5%	4%
Turkey	6%	5%	2%	5%	3%	1%	4%	1%	1%	2%	3%

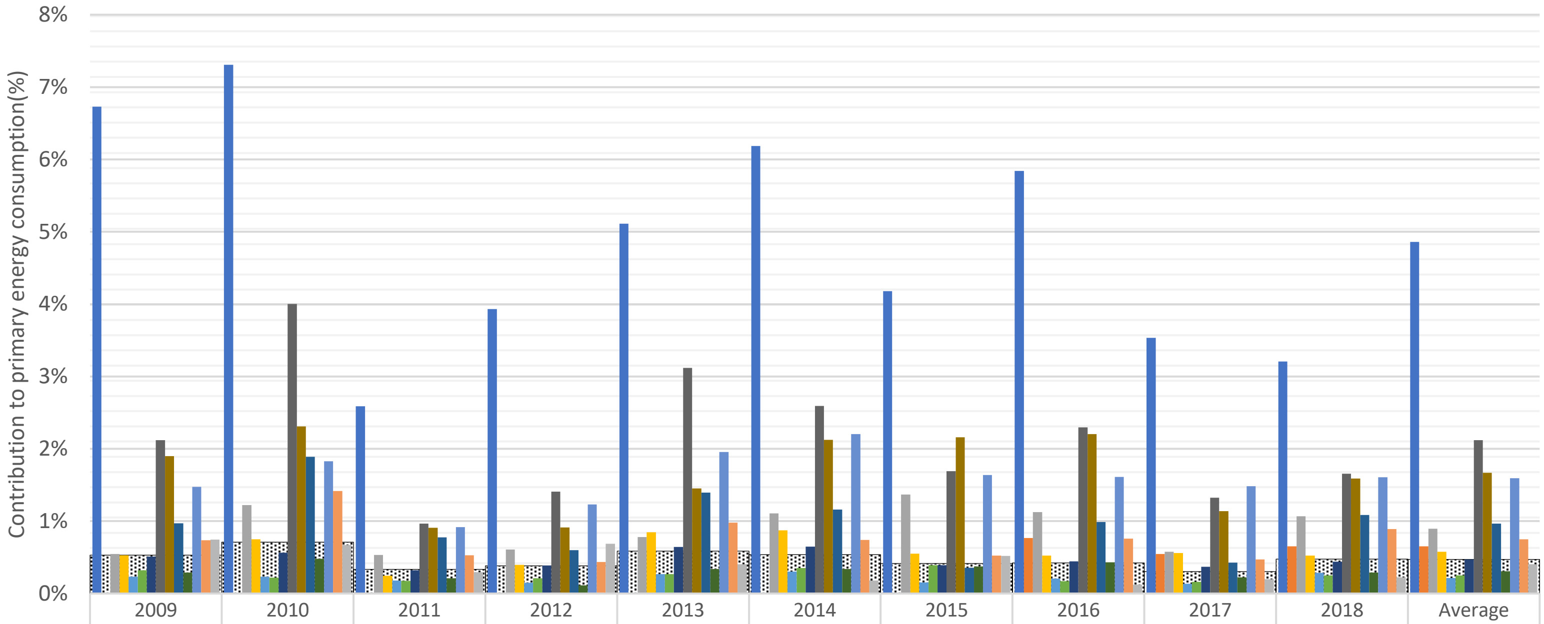
*Figure II-3 Overestimated contribution to gross electricity consumption (**“What if?”**)*



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Total	1,52%	1,80%	0,86%	1,00%	1,53%	1,48%	1,11%	1,15%	0,79%	1,21%	1,24%
Albania	27%	29%	9%	15%	14%	22%	17%	20%	13%	12%	18%
Bosnia and Herzegovina						10%	6%	6%	5%	6%	7%
Bulgaria	2%	4%	2%	2%	3%	4%	5%	4%	2%	4%	3%
Croatia	2%	4%	1%	2%	4%	4%	2%	2%	2%	2%	2%
France	1%	1%	1%	0%	1%	1%	0%	1%	0%	1%	0,7%
Greece	3%	2%	1%	2%	2%	3%	3%	2%	1%	2%	2%
Italy	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Malta	0,05%	0,01%	0,02%	0,01%	0,01%	0,01%	0,02%	0,02%	0,03%	0,01%	0,02%
Montenegro	8%	11%	3%	5%	11%	10%	6%	9%	4%	6%	7%
North Macedonia	6%	7%	3%	3%	5%	6%	7%	7%	4%	6%	5%
Portugal	1%	3%	1%	1%	2%	2%	0%	1%	1%	1%	1%
Serbia	3%	5%	2%	1%	3%	3%	3%	4%	2%	3%	3%
Slovenia	5%	5%	3%	4%	6%	6%	4%	4%	4%	4%	4%
Spain	1%	2%	1%	1%	2%	1%	1%	1%	1%	1%	1%
Turkey	2%	1%	1%	1%	1%	0%	1%	0%	0%	1%	0,9%

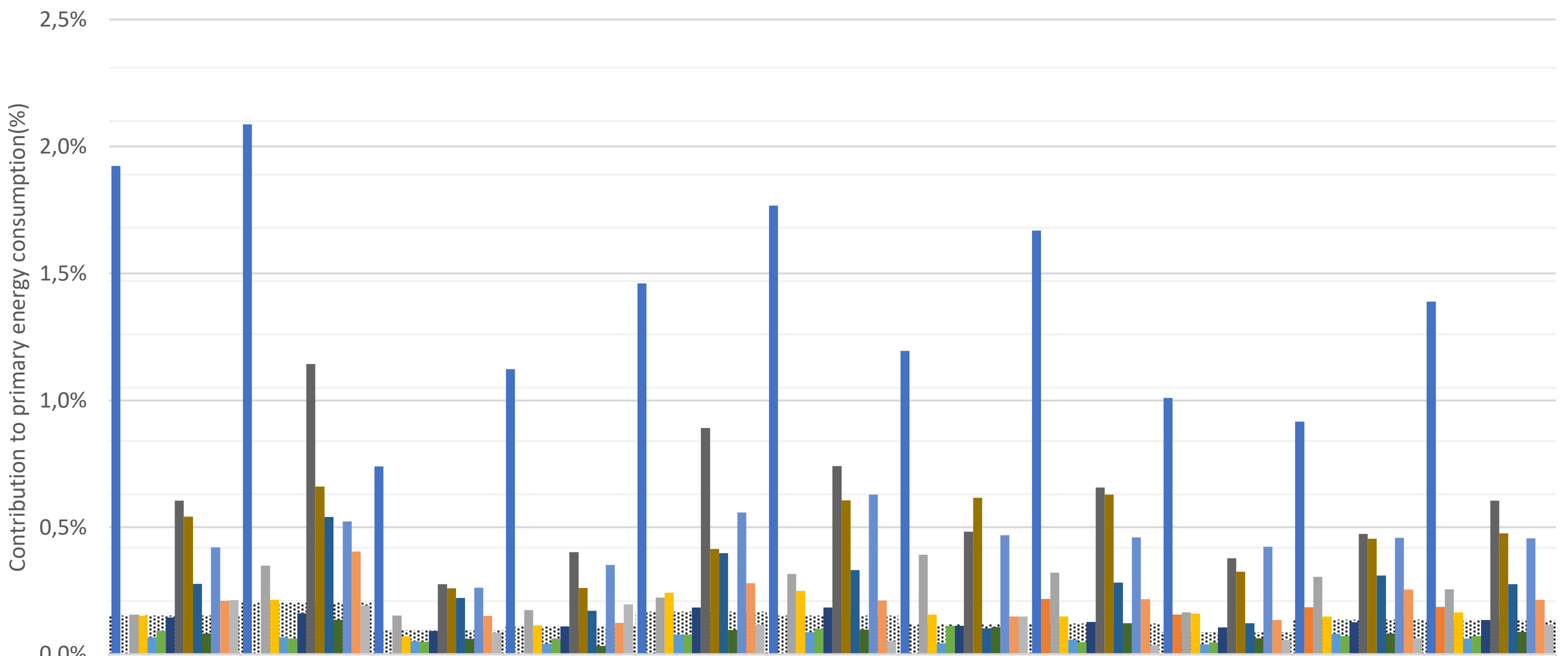
*Figure II-4 Probable real contribution to gross electricity consumption (**"What if?"**)*

Annex III: Small hydropower contribution to primary energy consumption



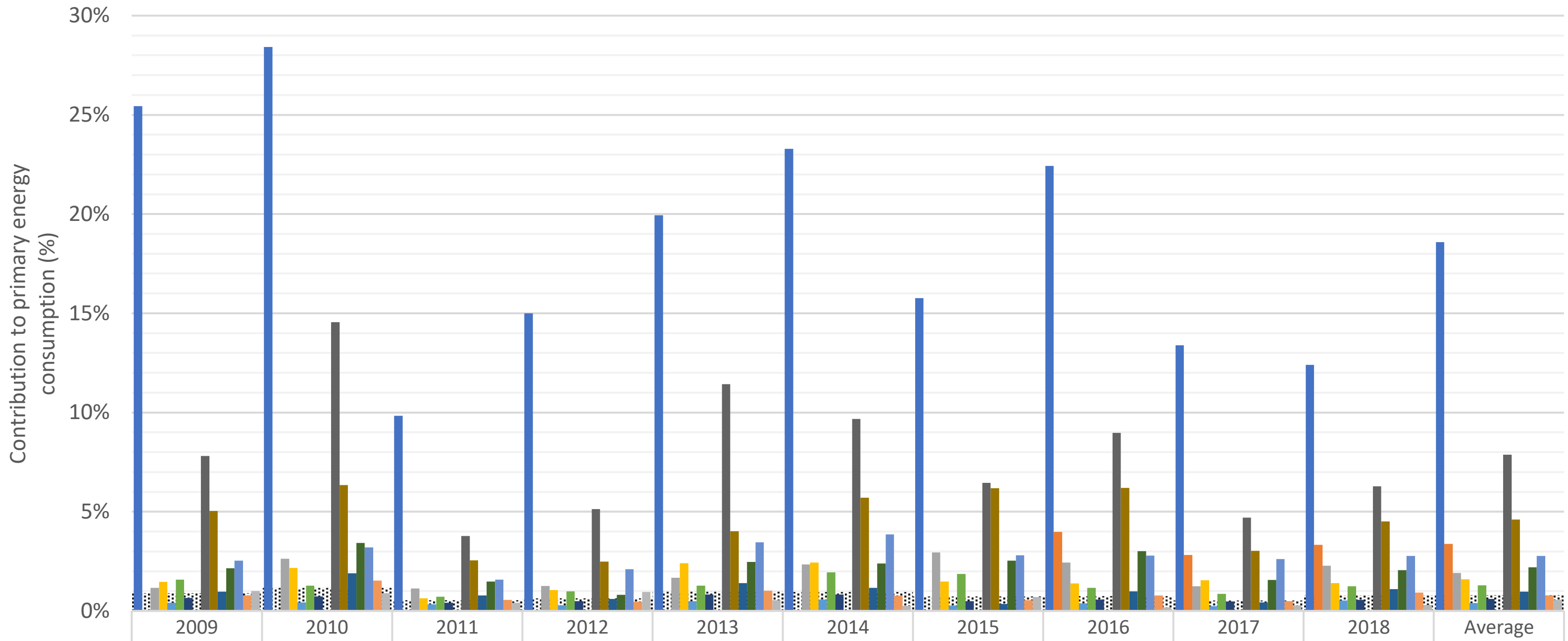
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Global	0,53%	0,71%	0,33%	0,38%	0,59%	0,54%	0,41%	0,42%	0,30%	0,48%	0,47%
Albania	7%	7%	3%	4%	5%	6%	4%	6%	4%	3%	5%
Bosnia and Herzegovina								0,8%	0,5%	0,7%	0,7%
Bulgaria	0,5%	1%	0,5%	0,6%	0,8%	1%	1%	1%	0,6%	1%	0,9%
Croatia	0,5%	0,8%	0,2%	0,4%	0,8%	0,9%	0,5%	0,5%	0,6%	0,5%	0,6%
France	0,2%	0,2%	0,2%	0,1%	0,3%	0,3%	0,2%	0,2%	0,1%	0,3%	0,2%
Greece	0,3%	0,2%	0,2%	0,2%	0,3%	0,4%	0,4%	0,2%	0,2%	0,3%	0,3%
Italy	0,5%	0,6%	0,3%	0,4%	0,6%	0,6%	0,4%	0,4%	0,4%	0,4%	0,5%
Montenegro	2%	4%	1%	1%	3%	3%	2%	2%	1%	2%	2%
North Macedonia	2%	2%	0,9%	0,9%	1%	2%	2%	2%	1%	2%	2%
Portugal	1%	2%	0,8%	0,6%	1%	1%	0,4%	1%	0,4%	1%	1%
Serbia	0,3%	0,5%	0,2%	0,1%	0,3%	0,3%	0,4%	0,4%	0,2%	0,3%	0,3%
Slovenia	1%	2%	0,9%	1%	2%	2%	2%	2%	1%	2%	2%
Spain	1%	1%	0,5%	0,4%	1%	0,7%	0,5%	0,8%	0,5%	0,9%	0,7%
Turkey	1%	0,7%	0,3%	0,7%	0,4%	0,2%	0,5%	0,1%	0,2%	0,2%	0,4%

*Figure III-1 Overestimated contribution to primary energy consumption (**"Present"**)*



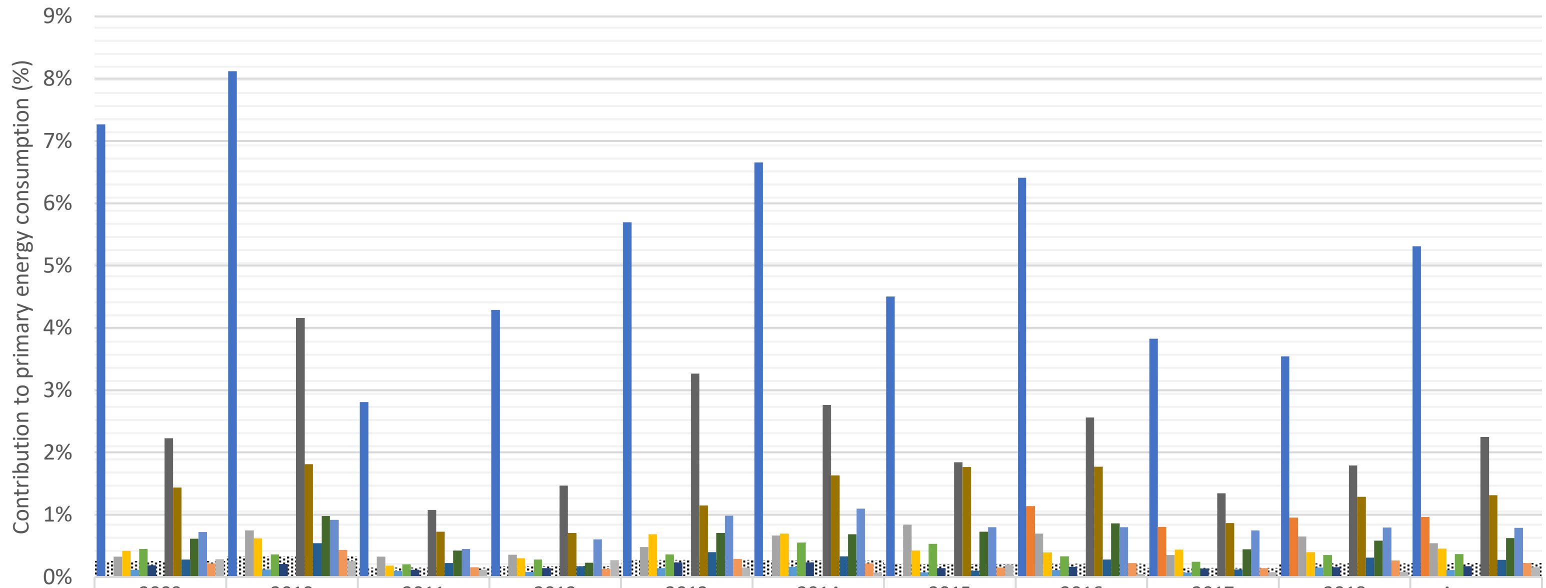
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Global	0,15%	0,20%	0,10%	0,11%	0,17%	0,15%	0,12%	0,12%	0,09%	0,14%	0,13%
Albania	2%	2%	1%	1%	1%	2%	1%	2%	1%	1%	1%
Bosnia and Herzegovina								0%	0%	0%	0,2%
Bulgaria	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0,3%
Croatia	0,2%	0,2%	0,1%	0,1%	0%	0%	0,2%	0,1%	0,2%	0,1%	0,2%
France	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%	0,0%	0,1%	0,0%	0,1%	0,1%
Greece	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%	0,1%	0,0%	0,0%	0,1%	0,1%
Italy	0%	0%	0,1%	0,1%	0,2%	0,2%	0,1%	0,1%	0,1%	0,1%	0,1%
Montenegro	1%	1%	0%	0%	1%	1%	0%	1%	0%	0%	0,6%
North Macedonia	1%	1%	0%	0%	0%	1%	1%	1%	0%	0%	0,5%
Portugal	0%	1%	0%	0,2%	0%	0%	0,1%	0%	0,1%	0%	0,3%
Serbia	0,1%	0%	0,1%	0,0%	0%	0%	0%	0%	0,1%	0%	0,1%
Slovenia	0%	1%	0%	0%	1%	1%	0%	0%	0%	0%	0,5%
Spain	0%	0%	0,2%	0,1%	0%	0%	0,1%	0%	0,1%	0%	0,2%
Turkey	0%	0,2%	0,1%	0%	0%	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%

*Figure III-2 Probable real contribution to primary energy consumption (**"Present"**)*



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Total	0,89%	1,16%	0,54%	0,63%	0,97%	0,95%	0,74%	0,75%	0,52%	0,78%	1%
Albania	25%	28%	10%	15%	20%	23%	16%	22%	13%	12%	19%
Bosnia and Herzegovina								4%	3%	3%	3%
Bulgaria	1%	3%	1%	1%	2%	2%	3%	2%	1%	2%	2%
Croatia	1%	2%	1%	1%	2%	2%	1%	1%	2%	1%	2%
France	0%	0%	0%	0%	1%	1%	0%	0%	0%	1%	0%
Greece	2%	1%	1%	1%	1%	2%	2%	1%	1%	1%	1%
Italy	1%	1%	0%	0%	1%	1%	0%	1%	0%	1%	1%
Malta	0,03%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,02%	0,03%	0,01%	0%
Montenegro	8%	15%	4%	5%	11%	10%	6%	9%	5%	6%	8%
North Macedonia	5%	6%	3%	2%	4%	6%	6%	6%	3%	5%	5%
Portugal	1%	2%	1%	1%	1%	1%	0%	1%	0%	1%	1%
Serbia	2%	3%	1%	1%	2%	2%	3%	3%	2%	2%	2%
Slovenia	3%	3%	2%	2%	3%	4%	3%	3%	3%	3%	3%
Spain	1%	2%	1%	0%	1%	1%	1%	1%	0%	1%	1%
Turkey	1%	1%	0%	1%	1%	0%	1%	0%	0%	0%	1%

*Figure III-3 Overestimated contribution to primary energy consumption (**“What if?”**)*



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Total	0,25%	0,33%	0,15%	0,18%	0,28%	0,27%	0,21%	0,21%	0,15%	0,22%	0,23%
Albania	7%	8%	3%	4%	6%	7%	5%	6%	4%	4%	5%
Bosnia and Herzegovina								1%	1%	1%	1%
Bulgaria	0%	1%	0%	0%	0%	1%	1%	1%	0%	1%	0,5%
Croatia	0%	1%	0%	0%	1%	1%	0%	0%	0%	0%	0,5%
France	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0,1%
Greece	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0,4%
Italy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0,2%
Malta	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%	0,00%	0,004%
Montenegro	2%	4%	1%	1%	3%	3%	2%	3%	1%	2%	2%
North Macedonia	1%	2%	1%	1%	1%	2%	2%	2%	1%	1%	1%
Portugal	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0,3%
Serbia	1%	1%	0%	0%	1%	1%	1%	1%	0%	1%	1%
Slovenia	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%
Spain	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0,2%
Turkey	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0,2%

*Figure III-4 Probable real contribution to primary energy consumption (**“What if?”**)*