A review of hydropower dams in Southeast Europe – distribution, trends and availability of monitoring data using the example of a multinational Danube catchment subarea

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ABSTRACT

Currently, Southeast Europe (SEE) is witnessing a boom in hydropower plant (HPP) construction, which has not even spared protected areas. As SEE includes global hotspots of aquatic biodiversity, it is expected that this boom will result in a more severe impact on biodiversity than that of other regions. A more detailed assessment of the environmental risks resulting from HPP construction would have to rely on the existence of nearby hydrological and biological monitoring stations.

For this reason, we review the distribution and trends of HPPs in the area, as well as the availability of hydrological and biological monitoring data from national institutions usable for environmental impact assessment. Our analysis samples tributary rivers of the Danube in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Montenegro, referred to hereafter as TRD rivers.

Currently, 636 HPPs are operating along the course of TRD rivers, most of which are small (<1 MW). An additional 1315 HPPs are currently planned to be built, mostly in Serbia and in Bosnia and Herzegovina. As official monitoring stations near HPPs are rare, the impact of those HPPs on river flow, fish and macroinvertebrates is difficult to assess.

This manuscript represents the first regional review of hydropower use and of available data sources on its environmental impact for an area outside of the Alps. We conclude that current hydrological and biological monitoring in TRD rivers is insufficient for an assessment of the ecological impacts of HPPs. This data gap also prevents an adequate assessment of the ecological impacts of planned HP projects, as well as the identification of appropriate measures to mitigate the environmental effects of existing HPPs.

1. Introduction

The European Union (EU) has committed to goals for the reduction of Europe’s greenhouse gas emissions; these goals are implemented through the EU Renewable Energy Directive (RES) [1]. The development of hydropower represents one of the options to mitigate climate change [2]. Hence, all EU countries as well as some non-EU states have established national plans aiming to reduce greenhouse gas emissions that include financial subsidies for renewable energy production. These in turn, have triggered a revival in the construction of hydropower plants (HPPs) [3,4].

To date, hydropower contributes 41.7% of the EU’s renewable electricity, and thus 11.4% of electricity generation in the EU in total [5]. Like in many other regions of the world, Southeast Europe (SEE) is currently planning to develop significantly more HPPs, which means a boom in HPP construction on many rivers that have so far mostly remained undammed [6].

Although hydropower is considered a renewable energy source,
greenhouse gas emissions from reservoirs appear to present a significant problem [7,8]. Therefore, HPPs do not always contribute to the mitigation of global climate change. Furthermore, hydropower plants may also cause significant environmental impacts at local and regional levels, such as: (a) river fragmentation, which prevents natural migrations of aquatic biota [9]; (b) severe modification of river flow and temperature regimes [10–12]; (c) dramatic reductions in sediment transport [13,14]; and (d) hydro-morphological degradation of downstream river sections [15]. These multiple impacts of HPPs usually result in damage to the ecological integrity of ecosystems, which is reflected in the disappearance of aquatic key species and by the loss of ecological functions [16, 17].

In Europe, hydro-morphological degradation is among the primary factors that prevent rivers from obtaining good ecological status according to the EU Water Framework Directive (WFD) [18]. The severe hydrological and ecological effects of hydropower have been reported repeatedly in other regions [e.g. 15–17], but there are few studies available relating to Southeast Europe [e.g. 10,12-26]. Existing studies demonstrate: (a) alterations of flow regime due to large [10,12, 22,24,25] and small [26] HPPs; (b) alterations of the macroinvertebrate community downstream of large HPPs [23,27]; (c) alterations of the fish community due to water abstraction to feed small [28] and large HPPs [29]; (d) and finally alterations of the fish community due to the transformation of river channels into storage reservoirs HPPs [e.g. 30–34]. These studies are mostly snap-shot studies, except the mentioned studies on flow regime. Among mentioned studies, most ecological studies (except [23,33]) are based on data from the post-impact period only, while studies on flow regime mostly analyse data from pre- and post-impact periods [12,22,24,25]. Furthermore, most of the studies just investigate the impacts of only a single HP dam.

Until recently, SEE’s rivers were mostly undammed [3,35]. In 2012, the morphology of ~80% of rivers, of a total of 35,000 km of rivers in SEE, had still been assessed as having a good condition; this was by far the highest percentage in Europe, where 80% of rivers have been found to be in poor hydromorphological condition [35]. Most European rivers have been heavily modified by human activities in order to serve human demands for power generation, water supply, flood control, navigation and other uses [36].

For biogeographical reasons, the river systems of SEE are home to very diverse and highly endemic freshwater fauna [37–40], and therefore have been identified by the WWF as one of the key places (Global 200 ecoregions) for biodiversity conservation on a global scale. Among all European threatened species, 52% of mollusc species (151) and 28% of freshwater fish species (52) occur in the Balkan region, making the Balkan Peninsula the most important “hotspot” for threatened biodiversity in Europe. About 75% of threatened fish species and 70% of threatened mollusc species in SEE are highly vulnerable to the construction of dams and other habitat alterations that accompany the construction of reservoirs [38]. Nevertheless, SEE is currently experiencing a boom in planned HPP construction even in national parks and other protected areas (e.g. EU Natura 2000 sites, regional parks) [6,41], which would have a massive impact on river ecosystems.

Aquatic biodiversity is protected by the International Convention of Biological Diversity (CBD), as well as by the associated EU Biodiversity Strategy in EU Member States, the goal of which is to halt biodiversity loss [42,43]. Moreover, the goal of the Natura 2000 network [44] is to protect target species and habitats. Due to the obvious conflict of interest between EU regulations for the development of renewable energy (EU RES) and for the protection of biodiversity [45,46], the International Commission for the Protection of the Danube River (ICPDR) published an guiding principles on sustainable hydropower development in the Danube Basin [47]. A more comprehensive report on the impact of hydropower on rivers in Natura 2000 areas was published by the European Commission [48]. This report described the various impacts of hydropower on freshwater biodiversity and included some best-practice examples, but did not offer any comprehensive approach to reconciling the conservation targets of Natura 2000 sites with hydropower generation. Apart from this weakness of the report, the mitigation measures recommended in it, have barely been implemented in SEE so far.

For these reasons, there is a need for the harmonization of EU and national policies on the development of renewable energy sources, on water management and on nature conservation in rivers and floodplains [49]. However, a more integrative approach to river management will clearly need to be based on detailed knowledge of the current ecological status of a given river section, especially on river sections subject to intense human use, as provided by hydrological and biological monitoring data. An adequate impact assessment of existing HPPs would require a) hydrological data recorded both upstream and downstream of HPPs (or before and after HPP construction) on a sub-daily basis, and b) biological data collected at least once per year both from reference stations and downstream of the HPP. In contrast, currently the most common practice consists of regular measurements of basic phys-chemical parameters of river water. If biological and hydrological data are captured at all, they only are recorded for a subset of rivers, and often not publicly accessible. In addition, currently there is no scientific overview of the number of existing and planned HPPs publicly available, and no overview of the ecological impacts of altered flow regimes.

In order to partially fill these knowledge gaps in SEE, we collected available data on the number and geographical distribution of existing HPPs and some key features of them for all tributary rivers to the Danube in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Montenegro. Based on this dataset, we then analysed whether available environmental monitoring data would allow an assessment of the ecological impacts of HPPs.

2. Materials and methods

The study area covers the river basins of tributary rivers to the middle and lower Danube (TRD) within the countries of Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro (Fig. 1). The total catchment area under analysis was 248,025 km². The area contains three major river basins, (the Sava, the Velika Morava and the Timok), several smaller river basins (the Mlava, the Pek, the Porečka Reka, and the Zamna) and parts of the Drava, Mura, Tisza and Tamiš river basins (Fig. 2).

For those rivers, we collected metadata on HPPs, as well as from biological monitoring stations (fish, macroinvertebrates) and hydrological monitoring stations (water level, discharge). Most metadata were obtained from national environmental agencies, with some even accessible online on their websites (Appendix A). Metadata on existing HPPs were extracted from various data sources, such as from national institutions and a large number of publicly available data sources, as published or unpublished literature and websites. The metadata of most HPPs include the following information: (a) country; (b) river; (c) name; (d) type of HPP (storage, pumped storage, run-of-the-river); (e) power capacity (MW; expected annual production in GWh); (f) year of completion; (g) dam height; (h) reservoir volume; (i) reservoir length; and (j) location of dams and each HPP. HPPs were categorised into three capacity groups: small (<1 MW), medium (1–10 MW) and large (<10 MW). Nevertheless, the HPP inventory remained incomplete in regards to existing small HPPs with an installed capacity less than 0.1 MW (N = 174) and existing medium HPPs (N = 2). For these HPPs, only information about location and installed capacity are available.

For each HPP, we selected nearby biological monitoring stations that could be used to assess the impacts of HPP generation based on the following criteria: (1) downstream altered stations located within an 8 km distance downstream of storage and run-of-the-river HPPs; and/or (2) downstream altered stations located downstream of dams/weirs for HPPs with water diversion; (3) for macroinvertebrates, we searched for upstream unaltered reference stations without impacts resulting from hydropower operations, while for fish we searched for data before an
HPP was built. Similarly, we searched for hydrological monitoring stations (with discharge or water level data) located in the vicinity (10 km) upstream and downstream of an HPP in order to detect flow regime changes caused by HPPs. Alternatively, we selected individual downstream gauging stations in cases where data were available for the period before and after the construction of an upstream HPP.

First, we identified altered biological and hydrological monitoring stations, followed by a search for their unaltered pair. This selection of biological and hydrological monitoring stations was performed by a proximity analysis in QGIS (v. 2.18.1). The results were subsequently checked visually in order to ensure that the HPP and monitoring station were in fact located on the same river.

3. Results

3.1. Distribution of hydropower plants

In the tributary rivers of the Danube in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Montenegro (TRD) under study, 636 operating HPPs were recorded, 42 of which were large (>10 MW), 72 medium (1–10 MW) and 522 small (≤1 MW) sized. The largest number of operating HPPs was located in Slovenia (N = 394), with numerous small HPPs (Fig. 2a). A large number of HPPs, 1315, are in the planning phase as well.

Most HPPs are located in the Sava River Basin (N = 438), followed by the Drava (N = 110), the Velika Morava (N = 74), the Banat-East Serbia (N = 12) and the Mura (N = 2) river basins. No HPP has been built in the Tisza and Central Danube Basins (Fig. 2A). The main stems of the Sava and the Drava rivers are heavily exploited for hydropower production. Both rivers together host a total of 17 large, 1 medium and 6 small sized HPPs in the countries under study, while the Drava River is used by 23 large HPPs along its whole course and several small sized HPPs.

In terms of operation mode, run-of-river HPPs dominate numbers-wise in the study area (598 grid-connected facilities) compared to storage and pumped-storage plants (35 and 3 grid-connected facilities, respectively) (Fig. 2B). Storage HPPs (35) predominantly operate in peak mode (with hydropneaking), and also dominate in installed power capacity (69% of total installed capacity) (Table 1).

In terms of dam size, the study area hosts 51 HPPs with dams above 10 m height, with the highest dam measuring a height of 220 m (the Mratinje HPP, Piva River, Montenegro). Furthermore, information on 59 impoundments for 41 large, 10 medium and 4 small HP facilities were identified. These reservoirs can retain up to 7.2 km$^3$ of water and a river length of 1015 km has been transformed into reservoirs. Assuming that each small and medium HPP is associated with a small impoundment of at least 0.2 km in length, total river length transformed into reservoirs increases to 1127.2 km.

Analysis of available data on dam age revealed that most of the existing large hydropower plants were built between 1950 and 1990 (Fig. 3). In these decades, more than five large HPPs were constructed per decade. After 2000, the number of newly constructed small hydropower plants increased sharply, which was followed by a boom in medium-sized hydropower plants (Fig. 3).

3.2. Installed hydropower per country and facility size

Among the 636 operating HPPs in the study area, Slovenia hosts by far the most small HPPs (394 HPPs), followed by Serbia (73), Bosnia and Herzegovina (37), Croatia (12) and Montenegro (7).

Large HP facilities comprise an overwhelming share (94%) of total installed capacity in the rivers under analysis, which equates to 5137 MW. This capacity is generated by only 6% of the total number of HPPs. Small HPPs represent 82% of the total number, yet only provide 2% of total installed capacity.

In contrast to Slovenia, the TRD rivers in Croatia are only used by 23 HPPs. Total installed capacity of all HPPs is 452 MW, 438 MW of which is produced by large, 11 MW by medium and only 3 MW by the 12 small
Fig. 2. Distribution of hydropower plants in river basins (indicated by shading) of the study area, and (A) size classes and (B) operation modes and size classes indicated by respective symbols; data sources: Hydropower plants in Slovenia [50]; QGIS 2017 (v. 2.18.1).
HPPs there. This equates to 97% of the total installed capacity provided by the six large HPPs.

On TRD rivers in Bosnia and Herzegovina, it is mostly small (37 HPPs) and medium (27 HPPs) HPPs that are installed, and only four large HPPs. The latter, however, produce 83% of the total installed capacity (515 MW), with 14% from medium and 3% from small HPPs.

The TRD rivers in Serbia host in total 115 HPPs in total, among which 14 large HPPs provide 97% of installed capacity (Fig. 4). Serbia’s small HPPs (≤1 MW) currently contribute 1% to the total installed capacity, while medium HP plants (1–10 MW) contribute 2%. However, small and medium HP facilities represent about 88% of all HPPs in Serbia numbers-wise. In total, Serbia has the greatest installed capacity (3060 MW) among the countries under review.

The TRD rivers of Montenegro host the fewest HPPs (11 HPPs) in the study area. Similarly to other countries, one large HPP in Montenegro contributes the most to total installed capacity (96%), while small and medium HPPs numerically represent 91% of all HPPs.

Table 1

<table>
<thead>
<tr>
<th>Hydropower plant type/capacity class</th>
<th>Installed capacity [MW]</th>
<th>Number of hydropower plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run-of-river plants (total)</td>
<td>954</td>
<td>598</td>
</tr>
<tr>
<td>Small (≤1 MW)</td>
<td>113</td>
<td>517</td>
</tr>
<tr>
<td>Medium (1–10 MW)</td>
<td>168</td>
<td>66</td>
</tr>
<tr>
<td>Large (&gt;10 MW)</td>
<td>673</td>
<td>15</td>
</tr>
<tr>
<td>Storage power plants (total)</td>
<td>3753</td>
<td>35</td>
</tr>
<tr>
<td>Small (≤1 MW)</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Medium (1–10 MW)</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Large (&gt;10 MW)</td>
<td>3733</td>
<td>24</td>
</tr>
<tr>
<td>Pumped storage plants (total)</td>
<td>743</td>
<td>3</td>
</tr>
<tr>
<td>Small (≤1 MW)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Medium (1–10 MW)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large (&gt;10 MW)</td>
<td>743</td>
<td>3</td>
</tr>
</tbody>
</table>

Fig. 3. Historical dynamics of hydropower plant construction (total number per decade – left vertical axis and bars) and cumulative installed power capacity of hydropower plants (MW – right vertical axis and lines) in the study area of TRD; for the current decade only hydropower plants that were finished by October 2017 are included; 173 micro (<0.1 MW) and 2 medium-sized HPPs were excluded from the analyses due to the unknown date of their completion.

Fig. 4. Hydropower size classes as percentages of total numbers of hydropower plants (left bar for each country in the study area), and as percentages of total installed electricity generation capacity (MW) (right bar) for 2017. The numbers represent the respective numbers of total installed capacity (MW) for the respective HP size class.
3.3. Availability of monitoring data

Among the total of 636 HPPs in the study area, only 14 HPPs were found with hydrological monitoring stations (gauging stations) in their proximity either upstream and/or downstream of the dam, only 6 of them with fish monitoring stations, and only 4 of them near macroinvertebrate monitoring stations for both the unaltered and altered situations (Fig. 5).

Hence, only 2.2% of HPPs could be surveyed using hydrological monitoring stations, 0.9% by fish monitoring stations, and 0.6% by macroinvertebrates monitoring stations. None of the HPPs have been equipped with suitable adjacent monitoring sites capturing both altered and unaltered states for all three parameters. Four HPPs in Slovenia, five in Croatia, and two in Serbia were outfitted with hydrological monitoring stations that record sub-daily discharge data. Therefore, only 1.7% of existing HPPs have capacities for conducting analyses of potential sub-daily flow alteration due to sudden and artificial water level changes (hydropoeaking). Breaking it down by countries, Slovenia and Croatia show the best availability of monitoring stations suitable for the assessment of HPP impacts. Available monitoring sites were mostly located near larger HPPs (twelve on hydrology, six on fish, two on macroinvertebrates), while there are hardly any monitoring stations near small HPPs (2 on hydrology, 2 on macroinvertebrates). In Serbia, no fish monitoring had been conducted until end of 2017 according to Ref. [51,112]. In the legal entity of the Republika Srpska in Bosnia and Herzegovina, fish monitoring has only been conducted since 2016, while in the legal entity of the Federation of Bosnia and Herzegovina, fish monitoring has been performed since 2011. In Montenegro surface water monitoring is performed in a traditional way, observing only physico-chemical parameters, which does not fully follow monitoring standards of the WFD. Monitoring parameters and frequencies are focused mostly on the protection of drinking water. Hence, fish and macroinvertebrate monitoring programmes have not been established yet [113].

3.4. Expected future development of hydropower by country

According to the National Renewable Energy Action Plans (NREAP) of the selected SEE countries, the planned increase in renewable energy production is expected to be predominantly provided by hydropower (Table 2). According to the NREAPs, these countries will provide state financial subsidies (e.g. fixed feed-in tariffs, feed-in premiums) to hydropower operators if the installed capacity of the HPP is lower than 5 MW in Slovenia, lower than 30 MW in Serbia (where the tariff decreases with lower power capacity, with the highest tariff for HPPs of 0.2–0.5 MW), and lower than 10 MW in Croatia as well as in Bosnia and Herzegovina.

This means that Slovenia and Croatia do not plan to add more small HPPs, while both Bosnia and Herzegovina and Serbia plan major increases in the current installed capacity of small HPPs (Table 2).

A total of 1315 HP projects are planned to be built on TRD rivers in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Montenegro, most of them small ones (N = 883), though 294 are medium-sized and 138 are large. The geographical distribution of planned HPPs is as follows: 150 in Slovenia, 106 in Croatia, 266 in Bosnia and Herzegovina, 780 in Serbia and 53 in Montenegro. Moreover, current plans call for further exploitation of the large Drava and Sava rivers by the construction of large HPPs. Besides that, the expected geographical distribution of future small HP projects aims to use currently undammed rivers.

255 of the 1315 HP projects (19.4%) are planned in Natura 2000 and other protected areas (Fig. 6). Among those, 67 are planned in protected areas in Slovenia (45% of all those planned in Slovenia), 57 in Croatia (54% of all those planned in Croatia), 18 in Bosnia and Herzegovina (7% of all those planned in Bosnia and Herzegovina), 109 in Serbia (14% of all those planned in Serbia) and 4 in Montenegro (8% of all those planned in Montenegro).

4. Discussion

4.1. Distribution of hydropower plant size

Several studies have already investigated the global distribution of HPPs [4,9,61,62], among them the Global Reservoir and Dam (GranD) database [61], but without considering small HPPs.
Fig. 6. Distribution of planned hydropower power plants in the Danube river basin of Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro; data source: Natura 2000 [57]; protected areas of Bosnia and Herzegovina [58]; protected areas of Serbia [59], protected areas of Montenegro [60]; planned hydropower plant projects [6]; QGIS 2017 (v. 2.18.1).

For Europe, several subsequent inventories of HPPs have been published as well, including the following: (a) incomplete dataset focusing on large HP dams for Romania [63]; and (b) for Greece [114]; (c) a very detailed inventory of hydropower plants for Austria [64]; and (d) Poland [65]; and finally there is (e) an outdated inventory on small HPPs in Serbia [66].

This manuscript represents the first regional review of hydropower use and on available data sources to assess hydropower plant’s environmental impact for an area outside of the Alps. Furthermore, our dataset of existing HPPs for TRD rivers in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Montenegro also includes small and medium-sized HPP, excluding dams and reservoirs that are not used for HP.

The situation that most HPPs are small and contribute only marginally to HP production is similar to other regions of Europe [67]; for example in Austria small HPPs represented a total of 87% of HPP facilities, but only 3% in terms of electrical generation capacity in 2014 [64]. In such countries, water had already been used for many centuries to power flour mills, sawmills or hammer mills. In the early 20th century, this early form of hydropower use was gradually upgraded by the installation of turbines for electricity production at former mill sites [68]. As a consequence, small HPPs occur in large numbers in that region, especially in Slovenia where the beginning of the construction of small HPPs was encouraged in the early 80’s by the Energy Economy Act, which allowed the construction of energy facilities outside the electricity sector. Thus, by the time of independence in 1990, most small hydropower plants had already been built [115]. In contrast, in the other countries of the study area construction activity first focused exclusively on large state-owned HPPs, while the construction of small ones has only recently been encouraged by the Renewable Energy Directive and the associated subsidy schemes. Therefore, their total environmental impact may exceed the impacts of the less numerous large HPPs [69,70]. If the environmental impacts of HPPs are assessed by considering the impact per MW of power generated, small HPPs appear to have similarly severe environmental effects as large HPPs [71]. However, there is a lack of knowledge and assessment capacity of the local and cumulative environmental impacts of small HPPs, as well as on their socioeconomic effects [72].

4.2. Factors influencing the size distribution of hydropower plant

The construction of HPPs of a certain size in recent years was likely determined by several factors, such as the availability of previously unused hydropower potential, regional electricity demand, the availability of a high-voltage electric grid, and the structure of financial subsidy programmes [73–75]. In order to achieve the objectives of the EU Renewable Energy Directive, most EU Member States established financial subsidy system for renewable electricity production, as fixed feed-in tariffs and/or feed-in premiums. These financial incentives were designed to be most beneficial for small HPPs [52–56], and seem to have been sufficiently attractive to trigger the present boom in small-sized HPP construction in the study area [76], as well as globally [77], although the study of Nielsen et al. (2019) [78] aims to deny that the hydropower boom is actually taking place. Furthermore, study of Nicolini et al. (2017) 79 has shown that there is a positive correlation between financial subsidies and the production of incentivized renewable energy. According to a 2015 study by the International Monetary Fund, Serbia and Bosnia and Herzegovina were among the world’s top ten countries in terms of energy subsidies as percentage of gross domestic product [80]. The large number of small HPPs with small electricity output raises the question whether these financial support schemes provided at the national level for small HPPs are efficient for increasing the share of renewable electricity production [71]. The efficiency concerning the use of public money to subsidise the development of renewable energy generation should perhaps therefore be assessed in terms of newly constructed renewable energy capacity per €1 million of subsidies, for instance. In addition, the environmental impact caused by the various ways of subsidising renewable energy generation could be considered, too. Efficiency could then be assessed in terms of newly constructed renewable energy capacity per €1 million of subsidies, but also in terms of environmental impact per 1 MW of newly constructed renewable capacity, for example. Most planned HPPs in the study region are small, though they may still cause significant damage since they
extend to almost every river and are unfortunately often constructed on rivers that have high ecological value [6,35]. In contrast to SEE, where many small HPPs have been planned to be built, in the USA, small HPPs are increasingly seen as prime candidates for dam removal [81].

The fact that 19.4% of all new HP projects are planned in protected areas shows that this practice contradicts guidelines for hydropower development [47] that emphasise protected sites as “no-go” areas, or that set very high thresholds in terms of impact mitigation and compensation for doing so [48]. Previous research has already shown that HPP development may represent the most important cause of protected area deterioration [82,83]. In that way, planned HP projects would probably significantly affect the hotspot of biodiversity in SEE [3, 40,41]. It is important to note that the total inland area designated as protected in Bosnia and Herzegovina and Serbia is small; indeed, the percentage of total state territory is significantly below the European average (1.4% in Bosnia and Herzegovina, 7.56% in Serbia) [84,85]. Furthermore, since they are not EU member states, there is no Natura 2000 network for them yet. This in turn means that the percentage of planned HPPs that would significantly affect species that are protected in the EU under the Natura 2000 network would be much higher than the previously mentioned 7% for Bosnia and Herzegovina and 14% for Serbia.

4.3. Availability of monitoring data

According to the EU Directive on Public Access to Environmental Information (2003/4/EC), the public authorities of EU Member States are obliged to provide access to the environmental information that they collect for everyone [86]. However, in reality official monitoring data in our study area were often rather difficult to obtain, with the best situation in Slovenia where the data are partly accessible online or easily available on request, while in Croatia some required data could not be obtained. In non-EU countries, and especially Serbia, data availability and accessibility were generally worse compared to EU countries. In multiethnic Bosnia and Herzegovina, the structural complexity of governmental institutions and the lack of coordination and communication among the various agencies and institutions represent major obstacles to access to environmental information. Since EU Member States are obliged to collect consistent and comprehensive environmental data as required by EU legislation (e.g. WFD, Natura 2000 network), Slovenia and Croatia have been implementing biological and hydrological monitoring programmes accordingly. In Serbia, as an EU candidate country, existing legislation on the monitoring and assessment of surface waters is still not fully in line with the requirements of the WFD [51]. Since 2011, in the autonomous entity of the Federation of Bosnia and Herzegovina, the implementation of the WFD has been in process, but water monitoring is not yet in accordance with the WFD requirements [87]. In Montenegro, the assessment of surface waters is mostly based on national legislation that only partially complies with the requirements of the WFD [88].

Long-term and continuous environmental monitoring is fundamental for identifying and classifying potential human pressures and for determining their impact on aquatic ecosystems [89–91]. Hydrological monitoring stations may collect data on river flow, which may be modified on an hourly, daily or seasonal basis by HPPs [10,12,92,93], or may be generally reduced by redirecting river water into canals or pipes guiding it to downstream sites, or to other river catchments [12,94]. Monitoring stations for water quality may detect changes in river water temperature, organic matter, turbidity, nutrients and dissolved oxygen content that may be caused by dam construction upstream [11,12,95, 96]. Biological monitoring stations may collect data on communities of benthic algae, invertebrates or fish that may be affected by changes in flow regime, water temperature, or dissolved nutrients, or due to the cessation of sediment supply from upstream [19,97–99].

Previous studies have documented that dams and weirs constructed for the hydropower production in SEE have already obstructed the dispersal and migration of aquatic biota. This has resulted in a significant decline in self-sustaining *Hucho hucho* and *Chondrostoma nasus* populations in some rivers of the region (e.g. Sava, Drava, Dobra) [33, 100]. Furthermore, storage HPPs that operate in hydropoeking mode cause ecological effects such as stranding and catastrophic drift of fish and macroinvertebrates downstream of the water releases from HPPs [101–103]. The structure and functions of biological communities in river sections affected by hydropoeking becomes highly altered, causing serious environmental concerns [101]. However, the ecological effects mentioned here have not been studied in SEE yet, except for the two aforementioned fish species.

In spite of the dire need for such data, our metaanalysis of national monitoring programmes showed a broad lack of consistent and comprehensive monitoring data. The number of monitoring stations located near HPPs is obviously far below acceptable levels, and the same is true for reference stations outside the affected river section as well. In addition, there is almost no recent data available from targeted monitoring programmes which assess the ecological impacts by small HPPs, and only very little data for larger ones. Therefore, a denser and strategically designed network of monitoring stations should be initiated to provide continuous information on biological and hydrological markers. Additionally, the monitoring of water bodies affected by HPPs should include assessment of mitigation measure effectiveness (e.g. effectiveness of fish passes) proposed in environmental impact assessment (EIA), but should also evaluate if the quantities and schedules of environmental flow releases are appropriate. This could be partly done through increase in number of operational and investigative monitoring stations under WFD, as similarly mentioned by Carvalho et al., 2019 [104].

No comprehensive environmental impact assessment study was ever conducted for many operating HPPs in the selected countries of SEE (see Ref. [105], as required by the Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment [109], a situation which is similar in other countries [106]. Existing EIAs are frequently biased by insufficient consideration of impacts, very limited field studies, and by the use of outdated scientific data, which partly relates to insufficient national monitoring programmes. However, EIAs and social impact assessments (SIAs) should transform the hydropower sector to help the benefits to exceed the costs and to ensure that HPPs contribute to sustainable energy systems [107]. Even if EU directives have been implemented into national legislation [e.g. 13, 72, 81], the procedures for implementation and actual practice often do not meet the objectives of EU directives [105]. Moreover, the lack of systematic and reliable field monitoring data also hampers the design of more environmentally friendly hydropower system (e.g. suitable fish passes, appropriate environmental flows).

5. Conclusions

This study is the first comprehensive and large-scale overview of existing and planned HPPs and monitoring data to examine hydropower’s effects on freshwater biodiversity (fish and macroinvertebrates) and hydrology in the selected countries of SEE. This study thus contributes to the development of a knowledge base on the environmental impact of hydropower generation, which is a prerequisite for informed decisions concerning hydropower projects among energy planners, investors, and other stakeholders. More informed decisions can facilitate the more balanced responses and the drafting of harmonised policies to meet the challenges of climate change, energy security and freshwater biodiversity loss [110] in a more integrative way, thereby avoiding severe degradation of river ecosystems. Hydropower projects can only truly generate environmentally friendly electricity when they are built in the right places and with adequate mitigation measures [111].

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Appendix A. Supplementary data

Supplementary data to this article can be found at https://doi.org/10.1016/j.rser.2019.109434.

References


[105] EIA/SEA of hydropower projects in South East Europe. WWF Adria; South East Europe Sustainable Energy Policy; 2015 (SEE-SEP).


