We are bearing witness to a boom in the construction of hydropower plants (HPPs) in South East Europe (SEE), which has not even spared the protected areas. As this region includes global freshwater biodiversity points, it is expected that this boom will result in a stronger biodiversity impact compared to other regions. A more detailed assessment of environmental risks arising from the construction of HPPs should rely on the existence of nearby hydrological and biological monitoring stations.
For this reason, this study examines the distribution and trends of HPPs in the area, as well as the availability of hydrological and biological monitoring data by national institutions, which can be used to assess environmental impacts. The analysis deals with tributaries of the Danube in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Montenegro, hereinafter referred to as the TRD river.

Introduction

Currently, 636 HPPs are operating along the TRD, most of which are small HPPs (<1 MW). An additional 1,315 HPPs are currently planned, mainly in Serbia and Bosnia and Herzegovina. Given that official monitoring stations near HPPs are scarce, it is difficult to evaluate the impact of these HPPs on river flow, fish and macro-invertebrates.
Current hydrological and biological monitoring on the TRD rivers is not sufficient to assess the environmental impacts of HPPs. This data gap also prevents adequate assessment of the environmental impacts of planned HP projects, as well as identifying appropriate measures to mitigate the environmental impact of existing HPPs.
The European Union (EU) has committed itself to the goals of reducing European greenhouse gas emissions; these targets are implemented through the Renewable Energy Directive (RES). Hydropower development is one of the options for mitigating climate change. Therefore, all EU countries, as well as some non-EU countries, have established national plans aimed at reducing greenhouse gas emissions, which include financial subsidies for generating renewable energy. They, in turn, initiated the revival of the construction of hydropower plants.
Currently, hydropower accounts for 41.7% of renewable electricity in the EU, and 11.4% of total EU electricity generation. As in many other regions of the world, SE Europe is currently planning to develop large number of HPPs, which means a boom in the construction of HPPs on many rivers that have remained largely intact so far.
Although hydropower is considered a renewable energy source, the emission of greenhouse gases from reservoirs is a significant problem. Therefore, HPPs do not always contribute to mitigating global climate change. In addition, hydropower plants can also cause significant

environmental impacts at local and regional level, such as: (a) river fragmentation, which impedes the natural migration of aquatic biota; (b) serious changes in river flow regime and temperature; (c) dramatic reductions in sediment transport; and (d) hydro-morphological degradation of downstream river sections. These multiple impacts of HPP usually result in damage to the ecological integrity of the ecosystem, which is reflected in the disappearance of key aquatic species and the loss of ecological functions.

In Europe, hydro-morphological degradation is one of the main factors preventing rivers from receiving good ecological status in accordance with the EU Water Framework Directive (VFD). Severe hydrological and environmental effects of hydropower have been reported repeatedly in other regions, but there are few studies available regarding Southeast Europe.

Existing studies show: (a) changes in flow regimes due to large and small HPPs; (b) changes in the macro-invertebrate community downstream of large HPPs; (c) changes in fish communities due to water capture to supply of small and large hydropower plants; and (d) changes in the fish community due to the transformation of river channels into hydropower plants reservoirs.

Until recently, rivers in Southeast Europe were mostly undamaged. In 2012, morphology in about 80% of rivers, out of a total of 35,000 km of regional rivers, was still in good condition; this was by far the highest percentage in Europe, where 80% of the rivers were found to be in poor hydro-morphological condition. Most European rivers are heavily modified by human activities to meet human needs for electricity generation, water supply, flood control, navigation and other uses.

For biogeographic reasons, river systems in SE Europe are home to a very diverse and endemic freshwater fauna, identified by WWF as one of the key sites (global 200 ecoregions) for biodiversity conservation globally. Among all European endangered species, 52% of molluscs and 28% of freshwater fish occur in the Balkan region, making the Balkan Peninsula the most important focal point for endangered biodiversity in Europe. About 75% of endangered fish species and 70% of endangered mollusc species in SE Europe are highly sensitive to dam construction and other habitat changes that accompany the construction of reservoirs. However, the region is currently experiencing a boom in planned hydropower construction, even in national parks and other protected areas (e.g. EU Natura 2000 sites and regional parks), which will have a huge impact on river ecosystems.

Aquatic biodiversity is protected by the International Convention on Biological Diversity (CBD), as well as by the Biodiversity Strategies in the EU Member States, aimed at halting the loss of biodiversity. Moreover, the objective of the Natura 2000 network is to protect the

target species and habitats.
Due to the apparent conflict of interest between EU renewable energy (EU RES) strategies and biodiversity protection, the International Commission for the Protection of the Danube River (ICPDR) has established guiding principles for sustainable development of hydropower in the Danube basin. The European Commission published a comprehensive report on the impact of hydropower on rivers in Natura 2000 sites. This report describes the different impacts of hydropower on freshwater biodiversity and includes some best practices, but did not offer a comprehensive approach to aligning Natura 2000 conservation objectives with hydropower generation.
Apart from this weakness of the report, the mitigation measures recommended therein have so far hardly been implemented in SE Europe. There is therefore a need to harmonize EU and national policies for renewable energy development, water management and nature conservation in rivers.
However, an integrative approach to river management must obviously be based on a detailed knowledge of the current ecological status of a particular river section, especially sections exposed to intensive human use, as provided by hydrological and biological monitoring data.
Adequate impact assessment of existing hydropower plants requires a) hydrological data recorded upstream and downstream of hydropower plants (or before and after the construction of HPPs), and b) biological data collected at least annually from reference stations and downstream from HPPs.
In contrast, currently the most common practice consists of regular measurements of basic physical and chemical river water parameters. If biological and hydrological data are recorded at all, they are recorded only for a subset of rivers, and are often not publicly available. In addition, there is currently no publicly available scientific review of existing and planned hydropower plants, nor an overview of the environmental impacts of altered flow regimes.
To partially fill these gaps, available data were collected on the number and geographical distribution of existing HPPs and some key features for all tributaries of the Danube in Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro. On the basis of this data set, it is determined whether the available environmental monitoring data allow the assessment of the environmental impacts of HPPs.

Distribution of hydropower plants

In the tributaries of the Danube in Slovenia, Croatia, Bosnia and Herzegovina, Serbia and

Montenegro (TRD), 636 operational HPPs were studied, 42 of which were large (larger than 10 MW), 72 medium (1 to 10 MW) and 522 small HPPs (1 MW). The largest number of operational HPPs is in Slovenia (394), with numerous small hydropower plants. A large number of HPPs, 1,315, are also in the planning stages.
Most of the HPPs are located in the Sava River Basin (438), followed by the Drava (110), Velika Morava (74), Serbia Banat-East (12) and the Mura River Basin (2). No HPPs were built in the Tisza River basins and the middle Danube. The main tributaries of the Sava and Drava rivers are heavily used for hydropower plant generation. The two rivers together have a total of 17 large, one medium and ten small hydropower plants in the countries under study, while the Drava River uses 23 large hydropower plants throughout and several small hydropower plants.
In terms of their operating mode, river hydropower plants dominate the study area (598 grid-connected facilities) compared to storage and pump-storage plants (35, or three grid-connected facilities). HPPs (35) operate predominantly in peak mode and also dominate in terms of their installed capacity (69% of total installed capacity).
In terms of the dam size, there are 51 HPPs in the study area with dams over 10 meters high, while the highest dam is 220 meters high (HPP Mratinje, Piva River, Montenegro). Furthermore, information was found on 59 reservoirs for 41 large, 10 medium and four small HP plants. These reservoirs can hold up to 7.2 cubic kilometres of water, while the river length of 1,015 kilometres has been converted into reservoirs. Assuming that each small and medium HPP is associated with a small reservoir of at least 0.2 kilometres in length, the total river length converted to reservoirs increases to 1,127.2 kilometres.
An analysis of available dam age data reveals that most of them were built between 1950 and 1990 for existing large hydropower plants. In these decades, more than five large HPPs have been built each decade. After 2000, the number of newly built small hydropower plants increased sharply, followed by the boom of medium hydropower plants.

Hydropower plants installed by country and size of facility

Among the 636 operating HPPs in the study area, Slovenia hosts the largest number of small hydropower plants (394 HPPs), followed by Serbia (73), Bosnia and Herzegovina (37), Croatia (12) and Montenegro (7). Large hydropower facilities have a huge share (94%) of the total installed capacity on the analysed rivers, which is 5,137 MW. This capacity generates 6% of the total number of HPPs. Small hydropower plants represent 82% of the total, but make up only 2% of the total installed capacity.
Most hydropower plants in Slovenia have a capacity of less than 0.1 MW. On the other hand,

92% of the total installed capacity is provided by large HPPs (858 MW), which represent only 4% of the total number of plants. Similarly, Slovenian medium-sized hydropower plants (1-10 MW) provide only 2% and small hydropower plants (1 MW) 6% of the total installed capacity. However, together, the number of small and medium-sized hydropower plants accounts for 96% of the 403 plants in Slovenia.
Unlike Slovenia, TRD rivers in Croatia are used only by 23 HPPs. The total installed capacity of all HPPs is 452 MW, of which 438 MW are large, 11 MW medium, while the capacity of 12 small HPPs is only 12 MW. This means that 97% of the total installed capacity is provided by six large HPPs.
The TRD rivers in Bosnia and Herzegovina contain mainly small (37) and medium HPPs (27) and only four large HPPs. The latter, however, make up 83% of the total installed capacity (515 MW), while the share of the medium and small is 14% and 3%, respectively.
There are a total of 115 HPPs on the TRD rivers in Serbia, of which 14 large HPPs provide 97% of the installed capacity. Small hydropower plants in Serbia (1 MW) currently contribute with 1% of the total installed capacity, while the share of medium-sized HPPs (1-10 MW) is 2%. However, small and medium capacity represent about 88% of the capacity of all HPPs in Serbia. Overall, Serbia has the highest installed capacity (3,060 MW) among the countries examined.
The Montenegrin TRDs have the lowest number of hydropower plants (11 HPP) in the studied area. Similar to other countries, one large HPP in Montenegro contributes most to the total installed capacity (96%), while small and medium-sized HPPs represent 91% of all HPPs numerically.

Expected future development of hydropower plants

According to the National Renewable Energy Action Plans (NREAP) of selected SEE countries, the planned increase in renewable energy generation is expected mainly in the hydropower sector. Under the plans, countries will provide state financial subsidies (e.g. fixed feed-in tariffs, feed-in premiums) for hydropower plants with installed capacity of up to 5 MW in Slovenia and up to 30 MW in Serbia (where tariffs increase as capacity decreases, with the highest tariff for HPPs ranging from 0.2 to 0.5 MW), and up to 10 MW in Croatia and Bosnia and Herzegovina.
This means that Slovenia and Croatia do not plan to develop any new small hydropower plants, while Bosnia and Herzegovina and Serbia plan a major increase in the currently installed capacity of small hydropower plants.
It is planned to construct 1,315 HPP projects on TRD rivers in Slovenia, Croatia, Bosnia and

Herzegovina, Serbia and Montenegro, most of them small HPPs (883), while 294 medium and 138 large HPPs.
The geographical distribution of the planned HPPs is as follows: 150 in Slovenia, 106 in Croatia, 266 in Bosnia and Herzegovina, 780 in Serbia and 53 in Montenegro. In addition, current plans call for further exploitation of the large Drava and Sava rivers by building large hydropower plants. Also, the expected geographical distribution of future small hydropower projects is intended to utilize the currently undamaged rivers.
Of the 1,315 HPP projects, 255 (19.4%) were planned in Natura 2000 and other protected areas. Of these, 67 HPPs are planned in protected areas in Slovenia (45% of all planned HPPs in Slovenia), 57 in Croatia (54% of all planned in Croatia), 18 in Bosnia and Herzegovina (7% of all planned in Bosnia and Herzegovina), 109 in Serbia (14% of all planned in Serbia) and 4 in Montenegro (8% of all planned in Montenegro).

Size distribution of hydropower plants

Several studies have already explored the global distribution of hydropower plants, including the Global Database for reservoirs and dams (GranD), but without consideration of small hydropower plants. Several lists of HPPs have also been published in Europe, including the following: (a) an incomplete dataset focusing on large dams in Romania; and (b) Greece; (c) a very detailed list of hydropower plants in Austria; and (d) Poland; and finally, e) an outdated list of small hydropower plants in Serbia.
This analysis represents the first regional review of hydropower utilization based on available data sources for assessing the environmental impact of hydropower plants outside the Alps. Furthermore, this series of data on existing hydropower plants for TRD rivers in Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro includes small and medium-sized HPPs, excluding dams and reservoirs that are not used by the hydropower sector.
The situation with hydropower plants mostly being small and only slightly contributing to the generation of hydroelectric power is similar in other regions of Europe; for example, in Austria small HPPs accounted for 87% of the total number of HPPs, but with only 3% of the contribution in terms of electricity generation in 2014.
In such countries, water has been used for centuries to power flour mills or sawmills. In the early 20th century, this early form of hydropower was gradually upgraded with the installation of turbines generating electricity at former mills. As a consequence, small hydropower plants occur in large numbers regionally, especially in Slovenia, where the start of construction of small hydropower plants was encouraged in the early 1980s 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.
In contrast, in other countries, construction activities have first focused on large, state-owned hydropower plants, while the construction of small ones has only recently been encouraged by the Renewable Energy Directive and related subsidy schemes. Therefore, their overall environmental impact may exceed the impact of a small number of large hydropower plants. If the environmental impacts of HPPs are estimated taking into account the impact of power generated per MW, small hydropower plants have similar environmental impacts as large HPPs. However, there is a lack of knowledge and ability to assess the local and cumulative environmental impacts of small hydropower plants as well as their socio-economic effects.

Factors affecting the size distribution of hydropower plants

The construction of hydropower plants of a certain size in recent years is likely to be determined by several factors, such as the previous availability of unused hydroelectric potential, regional electricity demand, availability of high-voltage electricity grid and the structure of financial subsidy programs.
In order to achieve the objectives of the EU Renewable Energy Directive, a system of financial subsidies for RES generation, such as fixed feed-in tariffs and/or feed-in premiums, has been established in most EU Member States. These financial incentives are intended to be most favourable to small hydropower plants, and appear to be attractive enough to trigger the current boom in small hydropower construction in the study area as well as around the world, although the study by Nielsen et al. (2019) aims to negate the hydropower boom. Furthermore, the study by Nicolini et al. (2017) showed that there is a positive correlation between financial subsidies and the generation of subsidized renewable energy.
According to a 2015 study by the International Monetary Fund, Serbia and Bosnia and Herzegovina were among the top ten countries in the world in terms of energy subsidies based on gross domestic product. The large number of small hydropower plants with low electricity generation raises the question of whether these financial support schemes provided at the national level for small hydropower plants are effective in terms of increasing the share of renewable electricity generation.
The efficiency of using public money to subsidize the development of renewable energy generation might therefore need to be assessed in terms of newly built renewable energy

capacity per million euros of subsidies, for example. In addition, environmental impacts caused by different ways of subsidizing renewable energy generation can be taken into account. Efficiency could then be assessed in terms of newly constructed renewable energy capacity per million Euros of subsidies, but also on the basis of the environmental impact of 1 MW of newly built renewable capacity, for example.

Most of the planned hydropower plants in the study area are small, although they can still cause significant damage, as they cover almost all rivers and, unfortunately, are often built on rivers of high environmental value. Unlike in SE Europe, where there are plans to build a large number of small hydropower plants, small hydropower plants in the US are increasingly seen as major candidates for dam removal.

The fact that 19.4% of all new hydropower projects are planned in protected areas show that this practice is contrary to the guidelines for hydropower development, which emphasize protected areas as no-go areas and set very high thresholds in terms of mitigating the impact and compensation for doing so.

Previous research has already shown that the development of hydropower plants may be the most important cause of protected area degradation. In this way, planned hydropower projects are likely to have a significant impact on the biodiversity focus in SE Europe. It is important to note that the total internal area protected in Bosnia and Herzegovina and Serbia is small; indeed, the percentage of the total national territory is well below the European average (1.4% in Bosnia and Herzegovina, 7.56% in Serbia).

Furthermore, since they are not EU Member States, they do not yet have a Natura 2000 network. This in turn means that the percentage of planned HPPs that would significantly affect EU-protected species within the Natura 2000 network would be much higher than the 7% mentioned above for Bosnia and Herzegovina and Herzegovina and 14% for Serbia.