ACTION TOWARDS INCREASE IN SUSTAINABLE HYDROPOWER: A PAN-EUROPEAN ASSESSMENT AND STRATEGY

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ABSTRACT

Hydropower plays a pivotal role in Europe's energy landscape, offering significant contributions to its power generation mix. However, amidst the global imperative for sustainable development, there is a pressing need to focus on the sustainability of hydropower resources. This entails not only mitigating its social and environmental impacts but also adapting to the challenges posed by climate change. To face these new challenges, it is imperative to develop new technologies and new policy measures.
These dimensions were identified in the COST networking Action 21104 – Pan European Network on Sustainable Hydropower (PEN@Hydropower). PEN@Hydropower consists of five working groups incorporating technical, environmental, economic, and social issues. More than 275 working group members exchange their research topics, results, and experiences leading to new views and common studies at a European level.
The paper provides a review of PEN@Hydropower discussions in Workgroups. We reviewed reasons for unused hydropower technical potential in four European countries. We identified a reason for this as a legislative gap in the EU level of stakeholders' interaction between climate neutrality (i.e. European Green Deal) and environmental protection (i.e. Water Framework Directive).

1 INTRODUCTION

Hydropower has long been considered the most environmentally friendly type of energy generation through its use of a naturally and regeneratively available source, water. However, over time the definition of "sustainable" changed to an extent where environmental and social impacts also counted and were put above pure emission exhaustion of a "fuel".
By life-cycle analysis, hydropower until today is not only the generation with the lowest emission level within all types of (fossil and non-fossil) generation but also among renewables. It is not zero-carbon, but the lowest-carbon in comparison within an LCA benchmark.

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1.1 Hydropower sustainability assessment

To declare hydropower as sustainable by incorporating environmental and social impacts, however, today is much more demanding than in the past. Reputation for the sector and its projects worsened through a series of mega projects (for example the Aswan High Dam, China Three Gorges Dam, and more recently Nova Kakhovka Dam, but there are more) until the WCD (World Commission on Dams) report was published in 2000 calling for a total stop of all projects in doubt, without a tangible measuring tool to prove good or best practice in place. For this reason, a multi-stakeholder process, initiated through the International Hydropower Association (IHA) and its partners worked over years to establish an assessment tool for proven best practice and sustainability of hydropower projects. The developed Hydropower Sustainability Protocol was declared Hydropower Sustainability Standard (HSS) in 2023 and made operational after testing various versions for different stages, of projects, confirmed by a series of trial assessments in existing or planned hydropower plants all over the world. Also, the governance organization of the Protocol was detached from IHA's organization to become the completely independent Hydropower Sustainability Alliance (HSA) formally and officially in October 2023, during IHA's World Hydropower Congress in Bali, Indonesia. HSA meanwhile was relocated away from IHA's headquarters near London/UK to Lisbon in Portugal. The years of development of the HSS also included stakeholder consultations from banks and finance, through developed and developing countries, industry, consultants, environmental and social NGOs, etc., whose input then was implemented into this complex assessment tool.

Assessments on projects are published (https://www.hs-alliance.org/sustainability-assessments) and showcase the spearheading efforts of quite some operators around the globe. Quality assurance and transparency safeguard good governance in the application of the Standard, and so do the qualified training and capacity-building activities in the HSA.

The HSA ensures further development of the Hydropower Sustainability Standard including additions of themes like transboundary issues, based on hard law of countries, but also to be combined with soft law like the HSS, and safeguarded in many cases by institutions that already exist transboundary, such for instance as the Mekong River Commission and others. Those transboundary issues will become even more important in the future as climate impacts will raise even bigger problems in large areas of the planet.

1.2 PEN@Hydropower COST Action

Approaches like the Hydropower Sustainability Standard consider a wider, more holistic view of the entire topic and consider many different knowledge experiences than only technical ones. Environmental, economic, and social skills complement the technical ones which have been applied for decades. These dimensions were identified during the establishment of COST Action 21104 – Pan European Network on Sustainable Hydropower (PEN@Hydropower). COST (**Co**operation in **S**cience and **T**echnology) is one of the oldest funding schemes in Europe. The idea behind this is the support of networking and knowledge exchange throughout all disciplines and affiliations. Members of COST Actions come from COST Member countries and are delegates of them, individuals affiliated to any entity like for example universities, research institutions, or companies. There is no limitation to joining the COST Action and to working within one of the working groups. PEN@Hydropower consists of five working groups incorporating technical, environmental, economic, and social issues. This structure ensures that all three interdependent pillars of hydropower sustainability - economic development, environmental protection, and social justice (Vassoney et al., 2017, Kumar et al., 2015) are considered. As of 2024, the PEN@Hydropower COST Action consists of more than 275 members from 34 member states, among them 21 Inclusiveness Target Countries. Cost Actions and working group members exchange their research topics, results, and experiences leading to new views and common studies at a European level.

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1.3 Objectives of the paper

The paper is organised as follows. In section 2 the PEN@Hydropower COST Action will be introduced. Later in section 3, we will provide examples of four countries, relevant to the discussion here, emphasizing the hydropower situation and challenges they are facing. The link between the above-mentioned parts will provided in section 4, where we will show how a legislative gap, identified through a stakeholder mapping procedure, influences and supports the current hydropower situation in the four considered countries. We will also discuss further steps and how PEN@Hydropower COST Action may help.

2 TECHNOLOGY AND CLIMATE-RELATED CHALLENGES

Electric energy production and thus hydropower is facing several gradually increasing challenges. Understanding the new role of HPP and PSHPP within the power sector in the coming decades 2030-2050 and beyond is urgently required, considering the flexibility and energy storage needs of the future renewable energy systems dominated by electricity systems, along with water hydraulics and ecology issues. The new role is addressed in PEN@Hydropower with working groups WG1, WG2, and WG3.

2.1. Technology requirements

Despite being largely perceived as a mature technology, hydropower faces current and foreseeable challenges that demand significant scientific research and technological development. The past substantial investment in hydropower has led to a conservative approach, focusing mainly on incremental improvements while preserving the simple and robust technical solutions established over a century ago. However, it is increasingly clear that this cautious, technology-oriented strategy is unlikely to yield highly innovative solutions.

The PEN@Hydropower COST Action identified and addressed the following technical challenges, related to the future role of hydropower:

- increasing flexibility,
- optimisation of operations and maintenance through digitalisation, and
- resilience of electromechanical equipment and infrastructures.

2.2 Climate changes

The impacts of climate change and its subsequent impacts on the natural water cycle imply an absolute necessity to reassess and enhance the sustainability of hydropower production. Climate change is altering the dynamics of water availability, precipitation patterns, and temperatures, posing both threats and opportunities for hydropower generation (Finger et al. 2012):

- changes in precipitation patterns,
- glacier melting.
- increased frequency and intensity of extreme weather events,
- risks to the infrastructure and stability of hydropower facilities,
- climate-informed planning including advanced weather forecasting and climate modeling, and
- climate change impacts across regional and national borders.

Sustainable hydropower management involves balancing energy production with environmental conservation even in climate change considerations can inform operational strategies that prioritize ecosystem health and biodiversity. Timely release of water during periods of low flow to sustain downstream ecosystems and mitigate the impact of droughts is essential for responsible hydropower operation.

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3 STATUS OF HYDROPOWER IN THE EU AND THE WORLD

Europe is by far the global leader in installed hydropower capacity – with 202 GW 58 % of available potential is utilized. In second place are Asia and the Pacific with 37 % (IHA, 2023). The value presented here excludes the pumped storage hydropower, which in Europe additionally adds another 55 GW (Quaranta et al, 2023).
In COST PEN@Hydropower we identified for this paper four European countries with relatively small hydropower electric energy production and large possibility for additional hydropower capacity. The selection includes Slovenia (small country, medium share of hydropower energy production), Poland (large country and small share of hydropower energy production), Lithuania (small country, small share of hydropower energy production), and Iceland (small country and large share of electric energy production). Not all countries have not used all technically available hydropower potential. Besides focusing on the untapped generation potential, a brief review of the hydropower sector including the situation with PSHPP is provided for each country.

3.1 Example: Slovenia

Slovenia is a country in the south of Central Europe region. Year 2023 was a good year for HPPs in Slovenia, in total HPPs provided for 4.9 TWh of energy production (41.99 % of total national electric energy production, excluding the share of production in nuclear power plant Krško, owned by Croatia). The average yearly production of electric energy from hydropower is lower and is estimated at 4.2 TWh. The gross energy potential of Slovenian rivers is estimated at 19.4 TWh/year (Kryžanowski and Rosina, 2012). Of this, 9.1 TWh/year is of technically usable potential, and economically between 7 and 8.5 TWh/year. Currently installed potential represents 47 % of the total technically available potential. HPPs on the middle Sava River are one of the most important renewable projects of the national power plants operator Holding Slovenske Elektrarne group. Currently, all placement procedures are underway, in accordance with Spatial Planning Act legislation. Investors want the first of the three hydroelectric power plants on the middle Sava to start supplying electricity to the grid by 2030, a very challenging desire, bearing in mind the very uncertain and complicated legislative procedures for the placement of energy facilities in Slovenia. This means that the amounts and costs of impact studies exceed the normal limits that the investors are still willing to finance and endure, with some of them being based on the conditioning system and some being evaluated several times. For the introduction of new HPP generation capacity, the building of HPP Mokrice (the last HPP in Slovenia on the lower Sava River cascade of 5 HPPs) has suffered a new setback. The administrative court annulled the government's decision on the public benefit of the Mokrice HPP construction. The administrative court ruled in favor of the appellants in the lawsuit of the Society for the Study of Fishes of Slovenia due to the government's decision on the predominance of the public benefit of electricity production over the public benefit of nature conservation when issuing a construction permit for HPP Mokrice. This means that the decision on further steps regarding HPP Mokrice is again in the hands of the government. But before that, the court's decision will have to be thoroughly analyzed, especially because this procedure was used for HPPs in Slovenia for the first time.
With the increase in the share of renewable and volatile production sources in the power system, the need for electricity storage units naturally increases. One such project is the Kozjak pumped hydroelectric power plant on the Drava River. It is currently in the process of revising the conceptual project and preparing the expert basis for the environmental report. There are several other projects in preparation or under consideration for the construction of PSHPPs on the Drava River in Slovenia.
The Slovenian National Energy and Climate NECP plan was under re-evaluation procedure in 2023. The re-evaluated NECP envisages increased production using solar and wind power plants, but like with the current one, no significant change in HPP electric energy production is expected until 2030. The introduction of new PSHPPs is envisaged under the dimension of Energy Security and is listed as one of the key objectives.
In the light of long-lasting procedures and thus uncertain introduction of renewables, a national project *Facilitating Renewable Energy Deployment in the Electricity Sector of Slovenia*, funded by the EU, was

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performed. It included analyses of the potential for new installation of renewables for electricity production. The project helped to identify risks and potential regions where further development at the national level is possible. For new large HPPs, the middle Sava River and lower Sava River were identified, however, in both cases the report identified high environmental risks.
The main barriers to hydropower development in Slovenia are social and environmental. Although HPP operators have tried to build new units, they were in the last few years not successful. It remains to be seen if PSHPP will fare better.

3.2 Example: Poland

Poland is a country in the Eastern Europe region. In 2023 electricity consumption in Poland was 167.5 TWh and generation amounted to 163.6 TWh. Nett imports exceeded exports by nearly 4 TWh. Out of the generated amount 26.8 % came from renewable energy sources. There are no data available on generation from different renewable energy sources in 2023 but in 2022 hydropower was the fourth biggest source of electricity from renewable sources in Poland, after wind, solar, and solid biofuels. Hydropower generated 1.97 TWh of electricity or 5.22 % from all renewables. This excludes the electricity generated from the pumped storage hydropower plants, which generated an additional 1.22 TWh (Polish Power Grids – PSE, Statistics Poland – GUS).
The overall installed capacity of hydropower plants in Poland is 2421 MW of which the capacity of hydropower plants generating electricity from the natural flow of water and excluding pumped storage plants is 989 MW. Poland has 782 renewable hydropower plants and six pumped storage ones. Of these, 775 are PSHPP plants up to 10 MW with a combined installed capacity of 296 MW (Polish Power Grids – PSE, Energy Regulatory Office - URE).
The total theoretical hydropower potential of Polish rivers has been estimated to be 23.6 TWh/year, with a technical potential of 13.7 TWh/year. Out of this, the technical hydropower potential of PSHPP (up to 10 MW) is estimated to be approximately 5 TWh/year. This indicates that only about 15 percent of the country's technical hydropower potential has been developed so far (Hoffmann and Hoffmann,1961).
The main regulations in Poland related to PSHPPs include the Act on Renewable Energy Sources and the Energy Law (which outline rules of electricity production and support schemes for renewable electricity producers), the Water Law and the Water Basin Management Plans (which outline rules of water management, water use for hydropower purposes, rules for water installations, requirements for residual flow, fish migration and some restrictions in developing new hydropower projects in line with the EU Water Framework Directive). Additional regulations include the Act on Nature Protection and the Act on Accessibility of Information concerning the Environment and its Protection, Participation of the Society in the Protection of the Environment, and Assessment of Impact on the Environment.
Support schemes for hydropower projects include auctions (for plants up to 5 MW), FITs (up to 500 kW), and FIPs (up to 1 MW) as well as discounts for prosumers in micro-installations. With the FITs and FIPs, which are the financial support schemes most used by small hydropower producers, the guaranteed prices amount to 90 or 95 percent of the reference prices assigned each year for auctions. Producers are entitled to the guaranteed price within auctions in either a FIT or a FIP for 15 years.
The main barriers for hydropower development and operation in Poland include:

- long-lasting, complicated, and costly administrative procedures (especially in terms of environmental assessment) and lack of simplified procedures for small and micro-hydropower,
- high investment and operational costs of projects, resulting from the obligation of hydropower plant operators to provide services connected to water regulation and maintenance of state-owned water facilities, channels, and riverbeds as well as to continuously adapt throughout the whole lifespan of the plant to increasingly rigorous environmental requirements (e.g., building fish passes and fish barriers, increasing residual flow),
- adoption of water pricing for hydropower since 2018 and the increase in fees paid for using damming structures and inundated lands owned by the state,
- lack of effective and uniform regulations allowing utilization of existing weirs for hydropower purposes,

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- support period of 15 years not adjusted to the lifespan of HPP projects (typically 60–70 years) and financial difficulties with the upkeep of HPPs after the expiry of the support period,
- lack of spatial development plans that include HPP, and
- lack of predictability of legal regulations and dependency on the regulated renewable energy market, which is especially difficult for small investors.

Enabling factors for hydropower development in Poland include the following:

- the FIT/FIP scheme offers stable support for newly constructed PSHPP plants,
- a very large number (over 8,500) of previously constructed water facilities across the country that could be refurbished or re-equipped as PSHPP plants, and
- possible increases in potential hydropower generation under optimistic climate change scenarios.

3.3 Example: Lithuania

Lithuania is a country in the Northern Europe region. In 2023, 45 % of its energy demand (12.6 TWh) was generated locally. Out of this locally generated amount, 67.6 % came from renewable energy sources. Hydropower, after wind and solar, was the third biggest source of renewable energy in the country in 2023. Hydropower generated 0.45 TWh of electricity or 11.6 % from all renewables. This excludes the electricity generated from the Kruonis pumped storage hydropower plant, which generated an additional 0.52 TWh (Litgrid.eu).

The overall installed capacity of hydropower plants in Lithuania is 1029 MW of which large hydropower is 101 MW (Kaunas hydropower plant) and pumped storage hydropower is 900 MW (Kruonis pumped storage hydropower plant). The rest capacity comes from 98 small hydropower plants that operate in the country (Litgrid.eu). The last small hydropower plant in Lithuania was commissioned in 2017 and no small hydropower development is foreseen soon. On the other hand, the development of large hydropower is being carried out. The update of the Kruonis pumped storage hydropower plant by constructing the fifth penstock is underway.

In Lithuania, there are no specific governmental plans, strategies, and programs targeting hydropower development. Overall country targets described in the National Energy Independence Strategy are ambitious. They include a 100 % share of consumed electricity to be generated domestically and an 80 % share of renewable energy in final consumption. This means that the goal for 2050 is to generate all electricity demand locally from renewable energy sources. To reach this goal, significant development of wind power, biomass, and solar power is predicted (Ministry of Energy of the Republic of Lithuania, 2018).

Accordingly, such a strategy was moved to the National Energy and Climate Plan (NECP.eu). In NECP there is no target for hydropower development at all. A huge part in this play other national legal documents such as the Renewable Energy Resources Law (Seimas of the Republic of Lithuania, 2011) that came into force in 2011 which prioritise damless hydropower projects.

The latest, 2019, amendment to the National Water Law removed 170 rivers and their stretches from no-go areas in Lithuania for hydropower development. In the current wording, this law prohibits dam construction in protected areas and forbids such constructions if they do not meet the good water status requirements according to Directive 2000/60/EB. This means that new hydropower development is possible, but new projects will be forced to go through strict environmental impact assessment procedures. After the amendment of the National Water Law, none of these procedures were started.

Overall, it means that the main barriers to hydropower development in Lithuania are political and environmental. While the main enabler in theory is also environmental, although unused.

The evaluated unused technical hydropower potential in Lithuania is 853 GWh/year. It corresponds only to small hydropower as the two largest rivers in Lithuania, that could be used for large hydropower is protected from damming. Nearly 20% of this unused potential, including environmental constraints, can be utilized by retrofitting the old water mills' sites and currently unpowered dams and weirs (Kasiulis et al., 2020).

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3.4 Example: Iceland

Iceland produces about 55 MWh per capita of green energy, representing the largest per capita green energy production in the world (Orkustofnun, 2024). About three-quarters of the energy comes from hydropower plants. The large icecaps, numerous rivers and lakes, and high precipitation present ideal conditions for hydropower production (Finger, 2018). The largest hydropower plant is the Karahnjukar Hydropower Plant: Located in the eastern part of the country, it is one of the largest hydropower projects in Europe. Ljosafoss Power Station is situated on the River Sog, it is one of the oldest hydropower stations in Iceland and has been expanded over the years. Altogether the current annual hydropower production accounts for about 13 TWh, while the technically feasible potential hydropower potential lies between 55 and 64 TWh a-1. With a total annual production of over 20 TWh of renewable energy Iceland has enough green energy to export significant amounts in the form of energy-intensive products. Today, about 80 % of the domestic electricity production is used in aluminium smelting to produce aluminium for exports and further manufacturing. Nevertheless, recent discussion includes the production of green hydrogen, data centers, silicon production, and other energy-intensive industries.
While hydropower is a renewable energy source, the construction of large dams has environmental impacts on local ecosystems and wildlife. Iceland has considered these factors in its hydropower projects and aims to balance energy development with environmental sustainability.
In summary, hydropower plays a significant role in Iceland's energy portfolio, complementing its extensive geothermal resources. The country's commitment to renewable energy has positioned it as a leader in clean and sustainable power generation.

3.5 Summary of reasons for unused capacity

All the above-discussed countries have still a lot of uninstalled capacity (Table 1), however, the reasons vary. In Slovenia, Poland, and Lithuania environmental concerns prevail over energy generation, although in Slovenia and Lithuania use of electric energy is much larger than the domestic production. In Poland, production and consumption are roughly balanced.

Table 1. Status of hydropower in the selected countries (without pumped storage)

	Technical potential, TWh/year	Installed capacity, MW	Average generation, TWh/year	Share among renewables, %
Slovenia	9.1	1172	4.2	91.4
Poland	13.7	989	2.0	5.2
Lithuania	2.1	128	0.5	11.6
Iceland	64.0	2096	13.0	69.1

The situation in Iceland is remarkably different than in the aforementioned three countries, with electric energy production greatly exceeding domestic consumption. Being an island with no connection to the EU or the United Kingdom grid, the excess electric production is being used in aluminum smelters and later exported. Iceland thus is in a good position to add hydropower capacity and reduce CO_2 emissions in the transportation and fishing industry sectors.

4 DISCUSSION ON LEGISLATION AND STAKEHOLDER'S INTERACTION FOR SUSTAINABLE HYDROPOWER

In this section, the stakeholder's interaction for sustainable hydropower will be reviewed and the above findings from four selected examples will be discussed. We aim to understand and in the future address gaps in legislation and stakeholder interaction.

4.1 Overview of stakeholder mapping

The overview of the preliminary results was achieved through surveys, workshops, and data collection and analysis within working groups WG4 ("Clean Energy Transition and Policy Measures") and WG5

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("Holistic Assessment and Stakeholder Interaction"). Mapping of crucial stakeholders to support cooperation among partners and stakeholders with European, national, regional, and local hydropower operators was done during a dedicated Thematic Workshop of the PEN@Hydropower COST action. The Thematic Workshop was held in Reykjavík**,** the capital city of Iceland, on the 14th of September 2023. It was organized as a part of the yearly Management Committee (MC) meeting. In this workshop, the following stakeholder description for hydropower was used:

- a stakeholder has a vested interest in a company (organization, project, etc.) and can either affect or be affected by a business's operations and performance, and
- stakeholders in the same "category" may have different interests depending on location (different countries or regions).

The Cost Action MC members identified the following critical stakeholder groups (Figure 1) by importance starting with the most important at the top.

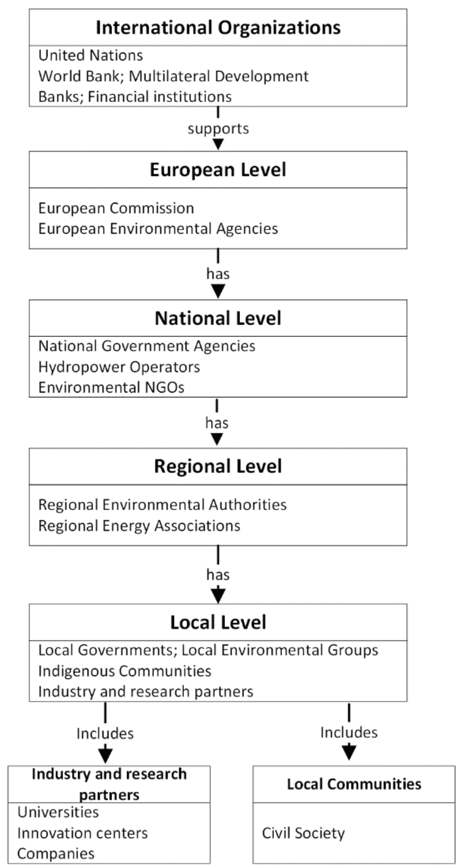

Figure 1: Diagram with critical stakeholders for the hydropower sector

At the **first stakeholder interaction level** is the organization of the United Nations UN, providing for top-level commitments, among them Sustainable Development Goals SDGs, created with the aim of "peace and prosperity for people and the planet". World Bank and Multilateral Development Banks can provide financing and expertise for sustainable hydropower projects. Financial Institutions like Commercial Banks and Investors ensure access to funding, which is crucial for the development of sustainable hydropower projects, making financial institutions important partners.

The above-introduced highest stakeholder level of the United Nations UN supports the **second stakeholder interaction level**, the European level. Here the European Commission as a regulatory body plays a significant role in shaping hydropower policies and standards on the European continent. European Environmental Agencies provide valuable expertise on environmental impact assessments and

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conservation efforts, while both the European Commission and European Environmental Agencies through Natura 2000, Water Framework Directive, etc. provide the legal framework for new and refurbishment HPP and PSHPP projects. PEN@Hydopower COST MC members have realized a discrepancy and **legislative gap** here, namely European Green Deal favors green energy transition, while European Environmental Agencies favor nature conservation. We are committed to both, and in the following, we will show later, that this discrepancy translates to and is amplified at lower levels of stakeholder interaction.

The third stakeholder interaction level is occupied by European National Government Agencies, hydropower operators, and national non-governmental organizations NGOs. National Government Agencies overlook ministries responsible for energy, environment, and water resources, and are key partners for implementing policies and regulations. Environmental organizations advocate for sustainable practices and hold operators accountable. PEN@Hydopower COST MC members concurred that environmental and social non-governmental organizations (NGOs) are of growing importance because they have a lot of impact on public view. The example of NGOs' power was reported by the COST MC member from Bosnia and Herzegovina, where citizens' protest against the construction of small hydroelectric power plants on the Neretvica River, in the south of Bosnia and Herzegovina, resulted in a ban on the construction, adopted in June 2020 (Radio Free Europe, 2020). COST MC members emphasize the public opinion importance because it can influence policy, but emphasizing also that public opinion should be shaped by receiving balanced and fair information. Scientists, politicians, and social media influencers and celebrities compete to influence on shape people’s perception of the important questions: "Where do we buy the energy from?, Should there be opposition to building new HPPs and PSHPPs? etc". The example of Dr. Boldea, Prof. Emeritus with the University Politehnica Timisoara, Romania, author of several books on electric machinery, was brought up during the workshop discussion. This example highlights the importance of university academics in shaping public opinion and balancing the currently prevailing social media influence. According to PEN@Hydropower MC members' experience, university researchers are often reluctant to participate in public discussions, since there is no room to sufficiently enlighten the complexity of the questions asked. With a lot of scientists involved, PEN@Hydropower attempts to change that. The workgroup WG5 surveyed in 2022, asking members to report what stakeholder role they represent. Although multiple responses were possible, the majority of members associated themselves with science (86 %), 29 % with industry, 21 % with associations, 21 % with power producers, and 14 % with policymakers.

As discussed above, the legislative gap identified at the second European level is amplified at the third national level and translates to further regional and local levels.

The fourth stakeholder's interaction level is represented by Regional Environmental Authorities and Regional Energy Associations. Regional Environmental Authorities have jurisdiction over specific water bodies and ecosystems, making their involvement crucial for localized sustainability efforts. Collaboration with regional energy associations can help coordinate hydropower efforts within specific geographic regions, ensuring a coordinated approach.

The fifth stakeholder's interaction level comprises Local Governments, Indigenous Communities, Local Environmental Groups, and Industry and Research Partners. Municipalities and local authorities are key partners in granting permits, land use planning, and ensuring community engagement. Indigenous Communities provide input and consent in areas with indigenous populations. Their input and consent are crucial, as hydropower projects may impact their traditional lands and livelihoods. Local Environmental Groups often have a deep understanding of local ecosystems and can provide valuable insights into conservation efforts. Involving local communities and civil society organizations in decision-making and project development is essential for social acceptance and sustainability.

At the fourth and fifth levels, most of the proposed HPP and PSHPP projects are rejected. PEN@Hydropower identified this as a **legislation gap**, originating from the second (European) stakeholders' interaction level, propagating and amplifying through the national (third) level, and being brought to its full in both regional and local levels (fourth and fifth stakeholder interaction levels). In small countries like Slovenia, Lithuania, and Iceland, there is often little difference between regional and local stakeholders' interaction levels.

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To address in the section 3 identified problems of adding new hydropower generating capacity, and to address the legislative gap and its consequences identified above, the PEN@Hydropower COST action has identified the most critical stakeholders for hydropower projects. These should be informed about proceedings, roadmaps, and database systems produced by PEN@Hydropower COST action: 1) Financial institutions, 2) NGOs, 3) Authorities, 5) Associations, and 6) the Public. This outcome closely mimics the findings of Vassoney et al., 2017. Authors developed the analysis tool for sustainable hydropower planning and management and quoted Diduck et al., 2013, stating that the "*local community is now being recognized as a key stakeholder*".
Although the industry (producers of hydropower equipment) is not on the top of the list of critical stakeholders (production is running based on tenders and is subjected to operators' requests), collaboration with the operators is vital for collecting data and implementing sustainable practices and innovative solutions. Therefore, the stakeholder mapping outcome will shape the activities in the action in the future, while following the initial intention declared in the PEN@Hydropower COST Action Memorandum of Understanding (COST Action CA21104 MoU, 2024) to create proceedings and roadmaps for operators and suppliers in the first place.

4.2. Are assessment procedures biased?

The above findings on stakeholders are generally in line with the Hydropower Sustainability (HS) Standard, developed by the HS council. The council includes the main stakeholder groups of the Hydropower Sustainability Certificate Scheme, represented by 7 chambers, namely: 1) Hydropower consultants, contractors, or equipment suppliers; 2) Hydropower operators or developers; 3) Environment or conservation organizations; 4) Social impacts, project affected communities, and Indigenous Peoples' organizations; 5) Financial organizations; 6) Emerging and developing economy country governments; 7) Advanced economy country governments".
Since seven chambers include all the critical stakeholders identified by the PEN@Hydropower Cost Action Management Committee, cooperation with the International Hydropower Association (IHA) will play a key role in distributing the results of the action. MC members agreed that associations are the best partners for distributing the results of the action. In addition to IHA, there are also other associations to cooperate with, e.g. EERA Hydropower, the International Energy Association, and local associations like the Georgian Renewable Energy Development Association (GREDA).
Assessing the sustainability of HPPs according to the Hydropower Sustainability Standard is a tremendous task and must be based on the widely defined understanding of economic, environmental, and social aspects combined, as a paramount principle. Under this perspective the proof of evidence for hydropower projects to be planned, built, and operated can today be delivered as an assessment of evidence found against a standard. However, the assessment usually determines the suitability of adding a new HPP (while also proposing mitigation measures), and sustainability assessments performed by other stakeholders like Environmental organizations and NGOs on regional and local levels are usually negative. Hence, one or the other, but probably both assessment procedures are biased. Addressing the legislation gap will probably help in improving the assessment procedures.

4.3 Discussion on cooperation among stakeholders

To declare hydropower as sustainable by incorporating environmental and social impacts today is much more demanding than in the past because the perception of sustainability has changed a lot, with the environmental part gaining importance Many projects had not been executed in a way that involved stakeholders from both areas – society or environment – or no benefits for others than operators or recipients of the generated energy were produced. In quite some cases local population after project completion neither had benefits from HPP projects like labor opportunities or adequate compensation for land loss, etc., with the local population having a sense of injustice. Such practice has not helped improve the hydropower public image.
In the future, cooperation among the stakeholders will need to be improved, if Europe wants to achieve the goals of the European Green Deal. Failing to do so will keep our way of life fueled by CO_2-producing energy sources like gas, oil, or coal. One of the most crucial goals should be the harmonization of

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all standards and evaluation procedures from stakeholders and their organizations. With easier and non-duplicating efforts to reach sustainable implementation and operation of hydropower plants operators could drive development faster, more economically, and more efficiently.

5 CONCLUSIONS

In the face of the technical requirements of an ever-increasing amount of non-dispatchable energy sources in the energy mix and changing climate, the sustainable development of hydropower is essential for ensuring a reliable and resilient energy future. By integrating novel technical solutions for flexibility, digitalization, and resilience and by allowing climate change considerations into planning, operations, and policies, the hydropower sector can continue to contribute significantly to the global energy mix while minimizing environmental impacts.
COST Action PEN@Hydropower represents a vibrant networking community of over 275 members, working in 5 working groups, where the future challenges of hydropower are discussed and addressed. In the paper, a review of 4 countries with significant unused hydropower potential has shown that the addition of new HPP-generating capacity is not possible. The stakeholder mapping performed within PEN@Hydropower WG 4 and WG5 has shown a significant legislation gap in the second European level of stakeholder interaction between climate neutrality (i.e. European Green Deal) and environmental protection (i.e. Water Framework Directive). The gap propagates down to regional and local levels, where the majority of new hydropower projects in the four addressed countries are rejected because of the hydropower impact on the environment.

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