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The public's perception of run-of-the-river hydropower across Europe

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ABSTRACT

A large share of future European hydropower projects will be run-of-the-river schemes. To understand the potential for RoR hydropower development and modernization of the technology as an opportunity for sustainable decentralization, we use the Q-methodology to compare public values about RoR hydropower in German, Portuguese and Swedish case studies. Four perspectives on the importance of RoR hydropower emerged from our analysis: (i) maintain regional control, (ii) fight climate change, (iii) promote citizen well-being and (iv) protect natural ecosystems. Strong preferences for regional control imply RoR should be managed as distributed generation rather than viewed as part of a centralized, national system like traditional large-scale reservoir hydropower. Based on the importance of citizen well-being and ecological measures, operators could adopt strategies such as river widening and the reconstruction of secondary channels, which help control floods, create recreational opportunities as well as enhance ecological habilitation and biodiversity. Additionally, policymakers could support rigorous monitoring programs to assess the ecological impact of RoR.

1. Introduction

In the European Union, hydropower represents an important component of a renewable energy transition, in part due to its existing infrastructure. Europe has a long history of hydropower and much of its available potential has been exploited. As the majority of sites for large-scale plants have already been developed, approximately 75% of future projects will be small or medium in capacity (Kelly-Richards et al., 2017; Paish, 2002). Plant capacity is politically important as member states primarily impose regulations on hydropower based on the size of the plant: smaller plants are usually held to less stringent environmental requirements and benefit from financial support (Kampa et al., 2017).

The majority of these small hydropower plants are run-of-the-river (RoR) schemes (Manzano-Agugliaro et al., 2017). To distinguish between different technologies, RoR hydropower generates power from the natural flow of rivers by using barriers (i.e., weirs or dams) to direct water to an in-channel turbine (Anderson et al., 2015). There are three different types of RoR schemes: high-head, low-head diversion and low-head in-weir schemes. While high-head schemes are found in mountainous regions with high natural gradients, low-head schemes are found in rivers with low gradients (Anderson et al., 2015). Low-head turbines are considered particularly fish-friendly due to their slow turbine speed (Overhoff and Keller, 2015). There are also RoR schemes with pondage, which allow for small scale short-term energy storage (Sharma and Singh, 2013). In contrast, reservoir hydropower uses a dam or another barrier to store water in a reservoir and discharges it when power is needed. Finally, a pumped-storage scheme pumps (often with renewable power) water from a lower reservoir to an upper reservoir so that water can be released through the turbines when there is demand (Kucukali, 2014).

Because RoR plants do not require large reservoirs, they are often viewed as environmentally benign and less likely to be subject to public protest (Anderson et al., 2015; Bilotta et al., 2016; Manzano-Agugliaro et al., 2017). However, such generalizations should be avoided as multiple RoR plants within the same catchment may lead to a significant compounding effect on river ecosystems (Bridge et al., 2013; Jaccard et al., 2011; Kelly-Richards et al., 2017). Further, size may be an inappropriate indicator of a hydropower plant environmental impact as

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smaller ones may have a greater impact per energy unit produced (Edenhofer et al., 2011) and different definitions of small hydropower create inconsistencies within the European Union (Frey and Linke, 2002). While financial and political support is often linked to plant size, the technological scheme of the hydropower plant may be a more consistent lens for evaluating the ecological and social impact of hydropower.

RoR hydropower may also represent an opportunity for sustainable decentralization as it has a greater capacity factor, efficiency and predictability compared to other renewable micro systems (Kaundinya et al., 2009; Sharma and Singh, 2013). In contrast, large-scale reservoir hydropower and pumped-storage hydropower are viewed as key components to a more centralized European energy system. For example, recent literature has investigated the feasibility of European cooperation with Germany using Norwegian hydropower reservoirs for electricity storage (Gullberg, 2013; Gullberg et al., 2014). However, future hydropower development in the European Union is unlikely to be characterized by large scale cooperation as political feasibility assessments show a trend of incremental change (Gullberg, 2013; Wolsink, 2013). Instead, a large share of future hydropower plants in Europe are likely to be small RoR schemes given technical, economic and socio-political constraints (Manzano-Agugliaro et al., 2017).

The public acceptance of RoR developments requires further attention. It is important to note that public acceptance differs from social acceptance and that the community level is often falsely presented as the main "barrier" to renewable innovation (Wolsink, 2013). Although previous investments in centralized technologies have been driven by the current structure and regulation of the electricity and gas markets, the scale of the sustainable energy transition (i.e. centralized or decentralized) will be closely linked to the public's social and economic values and behaviors (Watson and Devine-Wright, 2011). Researchers have highlighted the importance of public participation in decision-making for future hydropower development (Kelly-Richards et al., 2017; Shaw, 2011; Stirling, 2014; Tabi and Wüstenhagen, 2017). While locals often demonstrate support for renewable energy policy goals that are generic and global in scale, support may wane when such changes lead to disproportionate local impacts (Jaccard et al., 2011). Because acceptance is empirically distinguishable from support, it is important to study specific case studies to understand the values associated with RoR hydropower (Aas et al., 2014). For RoR projects, it is particularly difficult to balance conflicting local interests and values towards water use, recreation, biodiversity, nature conservation, fish protection and land use (Eckberg, 1985; Jaccard et al., 2011; Northwest Power Planning Council, 2000). Integrating local views into the early stages of decision-making is therefore crucial for increasing public acceptance and understanding public interest in decentralized technologies. To understand the potential for RoR hydropower development and modernization, we use the Q-methodology to compare public values about RoR hydropower in German, Portuguese and Swedish case studies. We selected three case studies to enable conclusions with greater generalization and view the public as a diverse group of stakeholders.

The remainder of this study is organized into four additional sections. The second section presents an overview of the current situation of RoR hydropower in Europe. The third section provides a detailed description of the methodological framework and case studies, while results of this study are presented and discussed in sections four and five, respectively. Finally, section six offers policy conclusions.

2. Run-of-the-river (RoR) hydropower in Europe: Development, governance and instruments

Hydropower represents the largest renewable energy source in Europe with a total capacity of 155 GW in 2017, from which approximately 15% is from RoR schemes (Eurostat, 2019). The majority of hydropower plants are small (less than 10 MW) and 91% of the plants produce only 13% of total hydropower production (Devoldere et al., 2011). European hydropower is governed by the recast RED II (EU Directive 2018/2001) of the Renewable Energy Directive (European Commission, 2009) as well as the Water Framework Directive – WFD (European Parliament, 2000).[1]

Germany, Sweden and Portugal have adopted different approaches to the European energy transition using hydropower, which is the product of their historical development and regulatory frameworks. While European directives set mandatory targets, member states must transpose them into national legislation meaning that national hydropower operators face different legislation for ecological restoration and public procurement. Table 1 shows the categories each country addresses in its national legislation including water protection, (renewable) energy, nature protection, environmental impact assessment, water infrastructure and fisheries.

All three countries address water protection and renewable energy, but Sweden notably lacks regulation on nature protection, environmental impact assessment and water infrastructure. The absence of such regulation is likely linked to Sweden's history of centralized power production and large hydropower. Hydropower accounts for approximately half of Swedish installed power capacity (Swedish Energy Agency, 2016). Until the reform of the "Swedish Model" in 1996, large players dominated the Swedish power sector and today there are limited examples of grassroots energy initiatives (Kooij et al., 2018). A challenge for distribution is that large hydropower development was in the north, while demand is high in the more densely populated south (Kooij et al., 2018; Lindström and Ruud, 2017). In southern Sweden, hydropower plants are mostly small and RoR schemes (Svensson, 2000).

Historically, the Swedish state prioritized rapid hydropower development to meet growing industry demand and created Vattenfall, a state-owned electricity company, to support large-scale hydropower exploitation (Högselius, 2009). Vattenfall was intended to act as a price setter to limit the monopoly power of other private actors stemming from special area concessions and a system of unlimited hydropower permits (Högselius, 2009; Kampa et al., 2017). Although unlimited permits catalyzed expansion, they hindered river restoration as the renewal of permits is the primary mechanism for enforcing ecological improvement. Today, around 90% of Sweden's hydropower operators have permits that do not expire (Rudberg, 2013). According to the European Commission's 2019 complaint, the Swedish hydropower concession process also lacks transparent and impartial selection procedures (European Commission, 2019).

To address the lag in environmental standards, Sweden established a national strategy for hydropower. It provides a framework for regulating rivers with modern environmental standards in accordance with the Water Framework Directive (Lindström and Ruud, 2017). To make efforts known to the public, Sweden uses green power labels including the NGO label Bra Miljoeval, which is based on ecological criteria and the "Good Environmental Choice". To receive the latter, the operator must contribute annually to an environmental project fund in proportion to energy sold (Kampa et al., 2017, p. 82).

Although Portugal has legislation related to hydropower, it currently lacks a legal framework for energy (Kampa et al., 2017). Since the 1950s, hydropower has played an important role in Portuguese energy production and is economically competitive with traditional fossil-based technologies (Ribeiro et al., 2014). Because of its dependence on external fossil fuels, Portugal has a high share of renewables and there are no old fossil fuel companies that might block renewable development (Reiche and Bechberger, 2004).

Approximately 38% of Portugal's hydropower capacity (Table 2) comes from RoR plants (Eurostat, 2019). Until recently, Portuguese legislation offered support to hydropower plants based on size. Large

[1] Note that the content referring to hydropower does not differ in the RED and RED II.

Table 1
Focus of national policies related to hydropower (Adapted from Kampa et al., 2017).

	Water protection	Energy	Nature Protection	Envir. Impact Assessment	Water Infrastructure	Fisheries
Germany	✓Yes	✓Yes	✓Yes	✓Yes	✓Yes	–
Portugal	✓Yes	✓Yes	✓Yes	✓Yes	✓Yes	✓Yes
Sweden	✓Yes	✓Yes	–	–	–	✓Yes

hydropower plants were supported through longer permits which allowed them to recover high initial investment costs (Kampa et al., 2017). Very small hydropower plants (<10 MW) were supported through feed-in-tariffs until 2012. In the 2019 complaint, Portuguese legislation was contrary with European Union law as the renewal or extension of hydropower concessions can be approved without tender procedures (European Commission, 2019). Due to the passing of recent legislation, the sector faces ambiguity as to the expected permit duration and energy selling price system and there are currently no instruments to support hydropower in the absence of a new legal framework (Kampa et al., 2017).

Until the 1990s, hydropower was the primary renewable source in Germany (Burger and Weinmann, 2014). Hydropower plays a relatively smaller role today, ranking behind other renewables such as wind and biomass (Spänhoff, 2014). However, it is more significant in the southern states of Bavaria and Baden-Württemberg, which account for 80% of Germany's potential (BMU, 2010). Approximately 37% of German hydropower comes from RoR installations (Table 2). Although RoR hydropower represents a small share of the capacity, a majority of hydropower plants are small and RoR schemes. From an estimated 7300 hydropower plants in Germany, approximately 6900 are less than 1 MW in capacity and around 6000 are less than 0.1 MW (International Hydropower Association, 2019).

Germany's energy transition is approached as a national project focused on replacing state electricity coverage with centralized electricity infrastructure (Goldthau, 2014). However, the energy transition requires decentralization as demonstrated by Freiburg, Germany which locally produces solar, wind, small hydropower and biomass to limit their dependence on centralized infrastructure (Goldthau, 2014; Rohracher and Späth, 2014). Unlike the Nordic region with vast hydropower potential, Germany's goal to increase the share of renewable energy must be met with other sources and has been supported through the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz* - EEG) through various financial incentives. Related to hydropower, the EEG offered financial support for the modernization of existing plants, feed-in-tariffs and green power labels. These incentives have rendered previously unprofitable hydropower sites more attractive, but critics argue that strict environmental regulations and land use restrictions will prevent further development of new plants (Kampa et al., 2017). In previous versions of the EEG, feed-in-tariffs for hydropower were conditional on the implementation of ecological improvement, but this has been removed in the newest version. Green power labels exist but arguably play a minor role in Germany due to the EEG tariffs (Kampa et al., 2017). Similar to Sweden, Germany was also criticized for the absence of a transparent and impartial selection process for the authorization of hydropower concessions (European Commission, 2019).

Table 2
Hydropower, small hydropower (SHP) and run-of-the-river (RoR) capacity in Germany, Portugal and Sweden.

Country	Capacity from all hydropower (MW) in 2017	Installed capacity from SHP (MW) in 2010	Capacity from RoR plants (MW) in 2017
Germany	11,120	1732	4097
Portugal	7225	450	2754
Sweden	16,502	1194	*Not Available*

Note: The net maximum electrical capacity from all hydropower and RoR plants is from Eurostat (2019). The installed capacity from SHP is from Manzano-Agugliaro et al. (2017).

3. Research methodology

3.1. Overview and applicability of Q-methodology

We chose the Q-methodology (henceforth Q-method) as a structured and rigorous approach to evaluate points of consensus and contention among locals living in RoR hydropower regions. In the method, a sample of participants (P-set) rank different opinion statements (Q-set). The set of statements represents the variety of views of a given topic and are identified using qualitative methods (Brown, 1980). The rankings of the statements are used in a principal component analysis, in which the factors extracted can be interpreted as "qualitative categories of thought" (Brown, 1993).

The Q-method is a suitable tool for studying the acceptance of energy technologies including wind power (Ellis et al., 2007; Wolsink and Breukers, 2010), biomass (Cuppen et al., 2010), transmission lines (Cotton and Devine-Wright, 2011), shale gas (Cotton, 2015; Cuppen et al., 2016), photovoltaic systems (Lu et al., 2018; Naspetti et al., 2016) and hydropower (Díaz et al., 2017; Pagnussatt et al., 2018). Similarly, it has been used to explore aspects of environmental infrastructure policy (Wolsink, 2010) and river water management (Focht, 2002; Raadgever et al., 2008; Vugteveen et al., 2010). The approach is suitable for comparing respondents from multiple regions as demonstrated by Wolsink and Breukers (2010), who use the Q-method to compare on-shore wind development in the UK, Germany and the Netherlands.

Our application of the Q-methodology includes the following steps: (i) literature review on public perception of hydropower,[2] (ii) development of the Q-set (statements), (iii) identification of survey sites, (iv) implementation of the surveys that consist of three stages (entry interview, Q-sort and exit interview) and (v) analysis of the output of the surveys.

3.2. Development of the Q-Set

Our Q-set reflects the concourse surrounding local values of RoR hydropower. Based on the dimensions of social acceptance described by Wüstenhagen et al. (2007), we focus on community level acceptance from residents and locals. We identified six main categories including economic costs and benefits, quality of life, ecological effects, public participation and policy (Table 3). Research has shown that locals are more likely to support hydropower when they observe economic benefits in their region including job creation, tax revenues, access to electricity in remote areas and low electricity prices (Bergmann et al., 2008; Malesios and Arabatzis, 2010; Saha and Idsø, 2016; Tabi and Wüstenhagen, 2017). More broadly, improvements to energy security through energy independence can be viewed as additional benefits (Karlstrøm & Ryghaug, 2014; Qazi et al., 2019). On the contrary, acceptance is limited when hydropower is seen to negatively affect other sectors such as agriculture (Ribeiro et al., 2014).

RoR hydropower can affect the local quality of life by changing the landscape, places of cultural heritage and recreational opportunities

[2] The literature review is part of section 3.2 "development of the Q-set".

Table 3
Categories and qualifiers of statements.

Category	Qualifiers	No.	English version
Economic costs & benefits	Economic development	1	It is important to me that hydropower creates jobs in the region (e.g. construction, maintenance, tourism).
		2	I am concerned that hydropower negatively affects tourism.
		3	I am concerned that hydropower negatively affects agriculture and forestry.
	Energy prices	4	Low electricity prices are important to me.
	Energy security	5	It is important to me that hydropower allows [name of country] to reduce energy imports.
Quality of life	Recreational opportunities	6	Recreational opportunities on rivers are important to me (e.g. fishing, bathing, boating, going for a walk).
	Flood protection	7	It is important to me that hydropower dams protect citizens from floods.
	Health and safety issues	8	I am concerned that hydropower negatively affects the quality of drinking water.
		9	I am concerned about accidents linked to hydropower plants (e.g. drowning, dam breaks).
	Place attachment	10	I do not want to live near a hydropower plant.
	Cultural identity	11	I am proud of [name of country]'s hydropower.
	Ideal of nature	12	Rivers are meant to flow freely.
	Landscape aesthetics	13	Hydropower plants disturb the natural scenery.
Ecological effects	Biodiversity and habitats	14	I am concerned that hydropower disturbs natural habitats.
	Fish safety	15	Hydropower should be fish-friendly.
	Emissions	16	I appreciate that hydropower fights climate change.
Public participation	Planning	17	If citizens disagree with the (re) construction of a hydropower plant, it should not be built.
	Profit-sharing	18	Local municipalities should receive part of the profit from hydropower production.
Energy policy	Ownership	19	Hydropower plants should not be owned by foreign companies.
		20	Hydropower plants should be owned by the state.
	Subsidies	21	[name of country] needs to financially support the expansion of hydropower.
Energy preferences	Comparison to other renewables	22	I prefer hydropower to other forms of renewable energy.
	Modernization	23	Existing hydropower plants should be modernized before new ones are built.
	Flexibility	24	I appreciate that hydropower is a flexible energy source.
	Energy storage	25	I appreciate that hydropower can store energy.

(Bakken et al., 2012; Botelho et al., 2016; Klinglmair et al., 2015; Loubier et al., 2005; Mattmann et al., 2016; Saha and Idsø, 2016). These can be positive or negative impacts. While there are limited studies on the impacts of RoR on other aspects of quality of life, RoR schemes were found to benefit recreational fishing (Jager and Bevelhimer, 2007; Kotchen et al., 2006). RoR can also provide flood protection in the diversion stretch during flood events (Tarroja et al., 2016) or developing ecological measures (Baptist et al., 2004).

There are concerns related to the quality of drinking water (Saha and Idsø, 2016) and accidents in rivers. A Swedish study found that the perceived threats along regulated rivers distresses locals (Öhman et al., 2016) whereas Swiss citizens estimated the risk of hydropower accidents as low (Volken et al., 2019) For regions with a long history of hydropower, the technology has been formative as part of the "nation-building process" and is a source of pride (Lindström and Ruud, 2017).

The ecological impact is a decisive public acceptance factor. On the one hand, switching to RoR schemes can replace coal with cleaner fuels and natural gas (Kotchen et al., 2006). Thus, improvements in air quality and reductions of greenhouse gas emissions contribute to fighting climate change. On the other hand, studies on small hydropower find that concerns about ecological effects on fish and natural habitats can decrease acceptance, particularly when the negative impact is greater than the benefits of greenhouse gas reduction (Gullberg et al., 2014; Malesios and Arabatzis, 2010; Mattmann et al., 2016; Ribeiro et al., 2014; Tabi and Wüstenhagen, 2017). Enabling public participation in the decision-making and planning process is also decisive for public acceptance of small hydropower (Díaz et al., 2017). Energy policies (e.g. subsidies) can also play a role in public acceptance (Ntanos et al., 2018; Tabi and Wüstenhagen, 2017). Finally, a number of acceptance studies compare the public attitudes toward different renewable energies (Botelho et al., 2016; Ribeiro et al., 2014; Schumacher et al., 2019).

To build the Q-set, we collected 140 initial statements from scientific literature and media sources. We reduced the number of statements by grouping similar ideas into categories, deleting duplicates and balancing positive and negative statements[3] (Watts and Stenner, 2005). This process resulted in 38 semi-final statements, which were reviewed and tested in a validation and pilot phase. To ensure all views were covered, we conducted expert interviews and validated our set of statements at regional hydropower stakeholder workshops with hydropower operators, policymakers, representatives of NGOs and researchers. We used a survey for validation, which allowed stakeholders to provide feedback on each statement, change statements and suggest additional statements. When at least two respondents provided the same feedback, we adopted the changes for our pilot Q-set. Finally, our Q-set consisted of 25 statements (Table 3), organized into six categories with 17 qualifiers.

3.3. *Case study regions*

We established the following criteria to select suitable sites (Table 4): 1) location is in a hydropower region with several hydropower plants near the case study town; 2) towns are in proximity to RoR hydropower plant(s); 3) main hydropower plant of interest has a capacity of less than 20 MW; 4) plants have a fish-related or ecological measure; 5) plant is within a 40 km radius of an urban area with sufficient interview sites (town centers, parks, etc.) with comparable urban areas; 6) towns are smaller in size (i.e. <80,000 inhabitants) because larger towns are likely

Table 4
Population, main RoR plant and capacity of case study sites.

Case Study	Population (Thousands)	Main RoR Plant	Capacity (MW)
Landshut, Germany	70	Altheim	17.8
Vila Real, Portugal	52	Terragido	10.0
Örnsköldsvik, Sweden	32	Anundsjø	5.0

[3] Positive and negative refers to the implied stance towards RoR hydropower. For example, statements that begin with "I am concerned that …" represents a statements that highlights negative aspects of the technology. Watts and Stenner (2005) recommend including a mix of positive and negative so long as it reflects the array of opinions.

to draw more visitors or recent transplants; 7) interview site is accessible to the interview teams via public transportation. Based on the above criteria, we selected the towns of Landshut in Germany, Vila Real in Portugal and Örnsköldsvik in Sweden (Fig. 1).

Landshut (Germany) is located along the banks of the Isar river. Several hydropower plants are located along the Isar near Landshut, including the Altheim plant. Built in 1951, Altheim is a RoR hydropower plant with an installed capacity of 17.8 MW and a mean annual output of 91.4 GWh. Currently, it is operated by Uniper Hydro Germany. In 2015, a fish pass was installed to facilitate upstream fish migration. Upstream of the Altheim plant, there are three smaller hydropower plants. The water body is classified as poor ecological status and there is a low risk for wide-scale flooding along the Isar near Landshut.[4]

Örnsköldsvik (Sweden) is located on the Moälven (Mo River). The Anundsjö power station was built in 1953 and produces 26 GWh of power in a typical year. It is operated by Statkraft, a company owned by the Norwegian state. The dam represents a barrier for migration of species and traps sediments. In addition to the Anundsjö plant, there are two smaller hydropower plants. The whole basin of Moälven is a Natura 2000 site and legally protected from further hydropower development. The ecological status for the waterbodies affected by the plant are natural and below good ecological status. In 2015, a two-way natural fishway was constructed based on requirements from the authorities. Both local and national stakeholders were supportive of the €2.7 million project.

Vila Real (Portugal) is situated in the north. The district is home to eight small hydropower plants and three large ones are currently under construction. The owners of these plants include German and Spanish companies as well as Portuguese companies. The oldest of these plants is Terragido (10 MW). Since its construction in 1992, it has implemented mitigation measures to support fish migration and maintain environmental flows in accordance with its water license (Ramos and Almeida, 2000). The Corgo River and other smaller Douro tributaries frequently flood, although the impacts are usually negligible. In contrast, large floods along the Douro River have large impacts and the river banks in the Régua region have been identified as high-risk areas within the Flood Risk Management Plans (EU Floods Directive). According to the Portuguese Douro River Basin Management Plan, the natural water body is below Good Ecological State. In addition to the hydro-morphological pressure imposed by the hydropower plants, diffuse pollution from agriculture affects the river's status and the sewage treatment plant of Vila Real discharges into the Corgo River. The Corgo River is also used for recreation and irrigation of the Douro vineyards.

3.4. Surveys in the field

Q-studies traditionally compare the range of views between stakeholders in a case study. While these cases often represent locals as a single stakeholder, locals share diverse views ranging from hydropower consumers to other energy consumers, environmental activists to anti-environmentalists and many other groups with a wide range of socio-demographic characteristics. We view the locals from each of the case studies as a group and aim to understand the similarities and differences among them. Rather than imposing assumptions about their views, we use the Q-method to segment a population into groups (see Cools et al., 2009) and strategically sample in a given location (Watts and Stenner, 2005). Through our relatively large sample, we can compare the wide spectrum of views among locals.

We interviewed participants face-to-face in each case study town from September to January 2019. We used the place intercept survey method and strategically sampled in public spaces such as city centers, libraries and universities (Lewis-Beck et al., 2003). We only included locals in our analysis (Bavaria in Germany, Norte in Portugal and Ångermanland in Sweden), which we identified using postal codes. Interviews consisted of three parts: entry interview, Q-sort, and exit interview. The entry interview collected demographic information about the participant and their knowledge on hydropower. As the nearest hydropower plant was RoR, participants were primed by asking about their awareness of a nearby hydropower plant. Only respondents who answered positively are included in our analysis. In the second part, participants were directed to the Q-board and asked to read the opinion statements and rank them according to the degree they agreed with each statement. In the exit interview, we asked participants to reflect on the statements they agreed and disagreed with most.

Materials used for the Q-sort included a large poster displaying the Q-board and statement cards from the Q-set. Both the Q-board and the statement cards were laminated and participants were asked to attach the statement cards to one of the squares of the Q-board. Fig. 2 shows the Q-board with example numbers of a participant's statement sorting. The coloration of the rows served as a visual cue to participants that rows shared the same ranking.

3.5. Data analysis

To extract factors (or principal components) from the correlating statements, a principal component analysis (PCA) of all Q-sorts was performed with varimax rotation using the *Qmethod* package in R (Zabala, 2019).[5] In the Q-literature, both PCA and centroid factor analysis have been used. Researchers use methodological considerations to select the factoring solution (Dziopa and Ahern, 2011). We use PCA as it is more common in recent applications (Zabala, 2019). Because the same Q-set is used across regions, a combined analysis allows for the easiest identification of overlapping themes across regions.[6]

As the Q-method can be effective with a sample size of 40–60 participants (Stainton Rogers, 1995), using our full sample is a deviation from the norm. The number of extracted factors can be based on eigenvalues, visual inspection for a discontinuity in eigenvalues with the Scree-Test (Cattell, 1966) and theoretical significance (Watts and Stenner, 2005). When large samples are used, researchers select the number of factors based on total explained variance and theoretical significance (Carmenta et al., 2017; Clarke, 2002; Davies and Hodge, 2007; Milcu et al., 2014). For Q-studies conducted with larger P-sets, it is typical that a share of participants do not load significantly on any factor (Carmenta et al., 2017; Clarke, 2002; Davies and Hodge, 2007; Milcu et al., 2014). As long as the total explained variance ranges between 50 and 60%, it is likely that fewer factors can explain the range of responses (Carmenta et al., 2017).

4. Results

We interviewed a total of 270 participants from the three case studies. We restricted our analysis to high quality responses from locals who knew of a nearby hydropower plant. This reduced our sample to 148 respondents with 45 from Germany in 2018, 63 from Portugal in

[4] This is according to the Bayerisches Landesamt für Umwelt map "Überschwemmungsgefährdete Gebiete – Wassertiefen HQ100". This evaluation criteria are the guidelines used by operators when providing flood protection. There is a low risk of wide-scale flooding because there the water could rise approximately 1–2 m. However, there could be damage to homes with basements and not all of the area near Landshut has been measured.

[5] The term "component" would be more accurate in PCA, but we refer to factors to be consistent with the Q-literature (Zabala and Pascual, 2016).

[6] We also conducted PCA for the regions individually. These results can be requested from the authors.

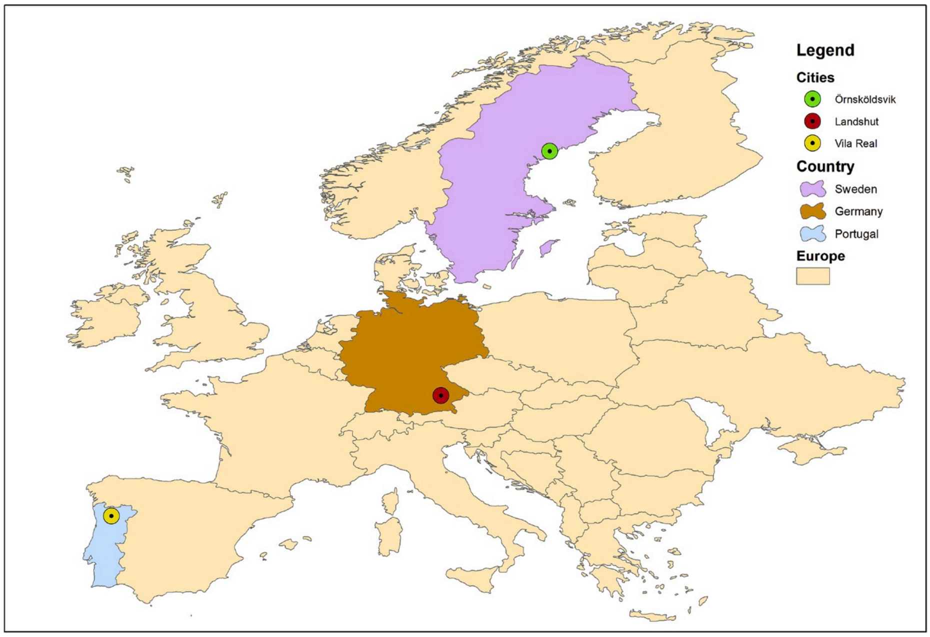

Fig. 1. Maps of the case studies and respective countries.

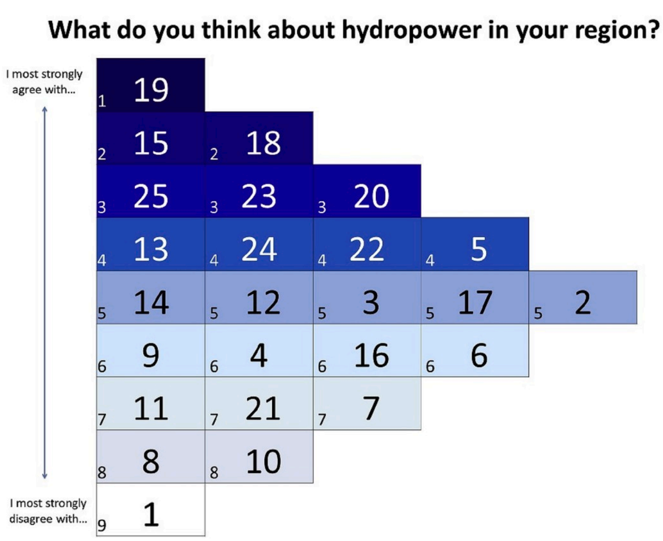

Fig. 2. Q-Board to Rank Q-set Statements from "Strongly Agree" (Top) to "Strongly Disagree" (Bottom).
Note: The bolded numbers in the Q-Board are an example of a participant's allocation of statements.

October 2018 and 40 from Sweden in January 2019.[7] Based on the 148 Q-sorts from the combined three regions, four factors accounting for 49.6% of the total variance were extracted. Four factors were extracted based on the total variance explained, the number of significantly loading Q-sorts and theoretical significance. When we extracted five factors, the fourth and fifth were similar when qualitatively interpreted and the fifth factor explained only 4% more variance. Additionally, more Q-sorts loaded significantly on the four factors (110 Q-sorts) than when five factors (104 Q-sorts) were extracted. Of the participants, a total of 110 were significantly associated with the four factors: 49 were associated with Factor 1, 29 were associated with Factor 2, 22 were associated with Factor 3, 10 were associated with Factor 4 and the remainder did not significantly load on any factor.

These factors represent unique perspectives across the case study regions. Four perspectives were extracted. They represent views on the role of RoR hydropower in their region including fighting climate change, maintaining regional control, promoting citizen well-being and protecting natural ecosystems.

The main concerns for each factor in Table 5 were determined by how strongly positive a statement scores on a factor. Fig. 3 shows the factor scores of each statement with consensus statements at the top and distinguishing statements at the bottom. The level of controversy is determined by the spread of the z-scores of the five factors. The statements with the greatest spread, and hence, the most controversial concepts were preferences for state ownership (20), the status of free-flowing rivers (12), preferences against foreign ownership (19), preferring hydropower to other forms of renewable energy (22) and the impact on biodiversity and habitats (14). On the other hand, all groups agree that existing hydropower plants should be modernized before new ones are built (23), locals should receive part of the profit (18) and recreational opportunities are somewhat important (6). The perspectives also agreed that hydropower's contributions to energy imports are important (5), while hydropower does not negatively affect tourism (2) or other industries (3). Further, the results show that respondents do not mind living near a hydropower plant (10) and agree that hydropower should be fish-friendly to some extent (15). Given that the z-score is between 0 and 1, this implies that they agree, but not as extremely as they do with other statements (i.e. z-score of 2 or 3). If a statement's z-score is unique to one factor, the symbol is filled in. This is identified based on whether the absolute difference between factor z-scores is significantly (p-value <0.05) larger than the standard error of differences (Zabala, 2019).

The perspective **"hydropower to fight climate change"** (factor 2) prioritizes the production of clean energy. Respondents support hydropower because it helps mitigate climate change, which is "the main problem the planet is debating" (V 81). It is thus important that "renewable energy sources reduce the dependence on fossil fuels and mitigate climate change" (V 101). This group values the flexibility and

[7] To ensure quality responses, participants were removed if their responses were illogical or if they lost motivation during the sorting. This information was recorded by the interviewer after each interview. To ensure locals, we removed those whose postal codes were outside the district of interest. To ensure that they answered respective to RoR hydropower, we removed those who did not know of a nearby hydropower plant.

Table 5
Description of factors.

	Factor 1	Factor 2	Factor 3	Factor 4
Description	Maintaining regional control	Fight climate change	Protect natural ecosystems	Promote citizen well-being
Most Important Topics[a]	Ownership (19, 20), security (5), prices (4), subsidies (21)	Climate change (16), flexibility (24), storage (25), economic development (1), security (5)	Free flow of rivers (12), fish (15), ownership (19), biodiversity and habitats (14), profit-sharing (18)	Flood protection (7), prices (4), fish (15), economic development (1), recreation (6)
Percentage of Explained Variance	19.6	12.3	10.4	7.3
Number of Significantly Loading Q-Sorts	49	29	22	10
Eigenvalues	29.047	18.168	15.39	10.78
Number of Significantly Loading Q-Sorts Per Region				
Landshut, Germany	22	6	9	0
Vila Real, Portugal	15	16	6	10
Örnsköldsvik, Sweden	12	7	7	0

[a] Note: The number of the statement (Table 3) is shown in parentheses.

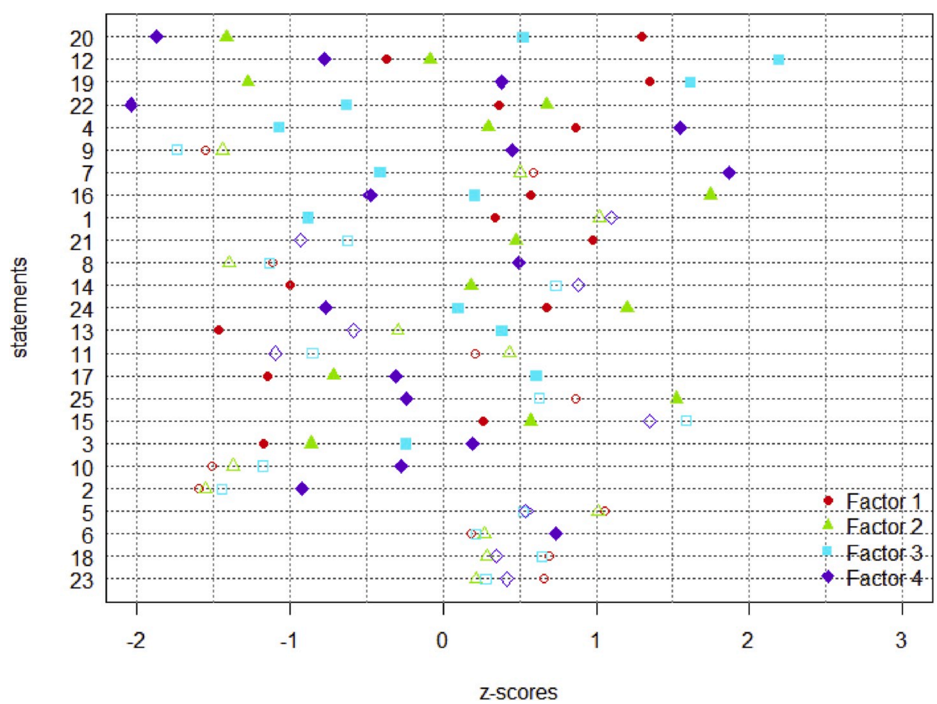

Fig. 3. Ranking of Statements from Most Controversial (top) to Least Controversial (bottom). Note: Z-scores are the scores of each statement on each factor. Statements are ranked by how far the scores are spread out (i.e., their level of controversy). Filled symbols indicate that the difference between z-scores is significantly larger than the standard errors of differences.

storage for energy and is less concerned about foreign ownership: "Being [Portuguese] or foreign is irrelevant. The plant has to be managed in the best way, independent of the nationality of the owners" (V 65). However, respondents were against state ownership: "the state should regulate hydropower production but plants should be owned by the investors" (V 86) because "society cannot be totally dependent on the state. The state should only legislate" (V 134) and "the state is a bad owner" (V 66). One Swedish respondent noted, "There should be more private individuals who can own hydroelectric power plants and rebuild them" (Ö 11).

The perspective **"hydropower to maintain regional control"** (factor 1) focuses on the economic benefits of hydropower production. Respondents support low energy prices and want their country to be energy independent: "it is not good to be dependent on other countries and their politics" (L 67). Ownership is a central topic. The state should own RoR plants and their country should benefit. This means that no foreign companies should operate the hydropower plants in their region. The following comments illustrate this view:

> "It should not be that our companies are taken over by foreign firms" (L 60)

> "It is important for Sweden that the municipalities should own the hydropower plants. And that no foreign company should own them." (Ö 55)

> "[Portugal]'s energy should be independent of foreign interests" (V 64)

Additionally, respondents feel that "water should not be privatized" (L 69) and "it is best if [hydropower] is kept public" (L 79), particularly "since energy is needed by all citizens, it should be owned by the state" (V 59). In comparison to other energy sources, RoR hydropower is viewed as "unproblematic" (L 41).

The perspective **"hydropower to promote citizen well-being"** (factor 4) focuses on the individual economic and social effects of RoR hydropower and only respondents from Vila Real loaded significantly on this factor. Respondents value low energy prices, ecological mitigation and job creation in the region. They are concerned about ecological impacts and the potential for flooding, especially as "floods cause many damages and are increasingly common" (V 50). The critical view was further demonstrated by respondents' preferences for other forms of renewable energies: "Some spatial diversity is needed. Too many hydropower plants exist already in the region" (V 46). Respondents were opposed to the idea that the state should own hydropower plants. For example, one respondent said that "The state should have other duties. It should directly manage water and other common goods, but not energy" (V 82). Another respondent stated that "private companies and cities should also be able to own hydropower plants" (V 111). Moreover, in their view it is not the role of the state to produce energy. One respondent explained that the state should focus on its duties like preserving "water and other common goods, but not energy" (V 82).

Respondents linked to the perspective **"hydropower to protect ecosystems"** (factor 3) are concerned about the negative ecological impacts. For this group, hydropower plants "disturb nature" (V 2) and "interventions in nature are always bad" (L 43). They prefer untouched river systems: "it is important that one allows the rivers to flow freely with natural flow" (Ö 47) because "rivers without hydropower are beautiful" (Ö 24). They believe that hydropower production should either be low-impact and well-integrated into the natural river flow, or restricted to certain rivers or river section: "It is important to let the rivers already [developed] be used and maintained so that no new hydropower plants will be built" (Ö 9). This group is concerned with ownership, particularly if it means losing influence over the local water bodies: "We should protect our most precious resource, water, from big investors" (L 73). There is also a preference against foreign ownership: "Hydropower in Sweden should be owned by state or Swedish companies and benefit the municipality where it is located" (Ö 10).

As a large number of Q-sorts ($n = 148$) relative to a small number of statements ($n = 25$) can be mathematically problematic for PCA, we compare the combined results to the regional analyses for robustness. For Germany, we extracted four factors, which account for 60.0% of the total variance with 38 of the 45 Q-sorts loading significantly on a factor. For Portugal, we extracted four factors, which account for 50.1% of the total variance with 44 of the 63 Q-sorts loading significantly on a factor. For Sweden, we extracted four factors, which account for 55.8% of the total variance with 28 of the 40 Q-sorts loading significantly on a factor. Based on the individual results, the four factors closely resemble the combined PCA results as the main perspectives of fighting climate change, protecting regional control and protecting natural ecosystems are present in all of the individual results. There is some deviation when it comes to the ranking of the consensus and controversial statements (compare to Fig. 3), but there is sufficient overlap to argue that the deviations are consistent with the combined analysis. For example, some of the most controversial statements for Portugal are state ownership (20) and the impact on natural habitats (14), which are also controversial for Germany. One of the most controversial statements for Germany is low electricity prices (4), which is also controversial for Sweden. One of the deviations for controversial statements is the Portuguese ranking of accidents (9), but this is consistent with the combined PCA as only Portuguese Q-sorts load significantly on "promoting citizen well-being" (factor 4). Because the results of the regional analyses do not differ substantially from the overall analysis, we conclude that there is sufficient stability of our results.

5. Discussion

Ownership emerges as significant, although only two statements focus on ownership. There are strong views on whether hydropower is a private, common or public good. From an economic perspective, the distinction in the classification of goods based on their status as (non-) exclusive and (non-) rivalrous can be unclear. Renewable energy can be viewed as a common good as the source (i.e. sun and wind) is free for all. Small-scale RoR hydropower, however, may be considered private as free access is less evident and the space needed to build plants is exclusive and rivalrous. On the other hand, energy is often considered essential, thus qualifying as a public good. While locals are averse to foreign companies owning hydropower plants, there is no consensus as to whether one type of ownership is best. In our results, the perspective "maintain regional control" (factor 1) and the nature of RoR hydropower as dispersed, smaller energy sources implies that RoR should be managed as distributed generation rather than viewed as part of a centralized, national system like traditional large-scale reservoir hydropower. Particularly for small hydropower, the importance of prioritizing local communities over centralized planning was emphasized by Stadelmann-Steffen et al. (2020). As micro and small hydropower (<1 MW) including RoR present opportunities for co-operative, shareholder and single owner co-production and participation schemes (Wolsink, 2018), these should be explored in later studies.

Others view ownership as an underutilized marketing tool given the strong preferences for certain owners and the spatial proximity of distributed generation to consumers (Kalkbrenner et al., 2017; Tabi and Wüstenhagen, 2017). While no other schemes in Europe exist, German policymakers introduced a labeling scheme for marketing regionally generated electricity (BMWi, 2016; EEG, 2016). Kalkbrenner et al. (2017) found empirical support for marketing regionally generated electricity and ownership. Thus, regional labeling schemes could be incorporated with existing green power labels to increase public support for new plants.

Our results show a consensus that modernization (23) is preferred to new construction. Because this statement and preferences to other renewables (22) do not explicitly refer to RoR, we cannot draw any conclusions about whether new RoR plants are preferred compared to other schemes. Maintaining consistency with the framing question, we did not refer specifically to RoR because the term may have elicited confusion from respondents. Assuming they answer in respect to the nearby RoR plant, modernization of RoR is unlikely to result in protest but new developments may face local concern. Decision-makers may therefore approach future developments with caution, even if they are relatively smaller and low impact.

A closer analysis of how permits for hydropower are granted may lend insight into how the process might be influenced by local views. In Germany, there appears to be no competitive application process for granting permits. Instead, the decision is made at the discretion of the local authorities without clearly defined criteria (Glachant et al., 2015). Because the license to use water is granted on a case-by-case basis in a process involving local stakeholders and concerned authorities, objections to a potential owner could pose significant barriers to expansion. Projects in Sweden and Portugal are less likely to be sensitive to local opinions. Although Sweden does not have an established competitive process, unlimited hydropower permits are rarely revoked and Portugal has established competitive processes for granting permits (Glachant et al., 2015). However, the concession process in all three countries will be subject to changes in light of the recent complaints (European Commission, 2019). Incorporating transparency into the competitive concession process may foster efforts for local co-production.

The overarching goal of renewable decentralized generation is climate change mitigation, which is highlighted in factor 2. Notably, storage and system flexibility are important to participants, yet RoR plants provide little potential for either. As a side note, energy storage (statement 25) does not explicitly refer to RoR, it was included because experts noted that some RoR schemes (pondage RoR) can store small amounts of energy (Jurasz and Ciapała, 2017; Sharma and Singh, 2013). A high ranking of this statement implies that plants with storage potential would be preferred over those without (i.e. RoR plants) if the public would compare the different technologies.

RoR hydropower may have substantial spatial effects and operators can contribute significantly to river management, especially flood prevention. This is particularly salient for the Portuguese respondents (factor 4) as areas along the Douro River have been identified as flood prone (Araújo et al., 2013). Comparatively, the other factors do not prioritize flood prevention, likely because RoR hydropower leads to less flooding compared to other schemes (Goodland, 1994; Kumar and Katoch, 2014). Based on the importance of flood control (factor 4) and ecological measures (factor 3), operators could adopt strategies such as river widening and the reconstruction of secondary channels which help control floods, enhance ecological habilitation and biodiversity as well as increase opportunities for recreation (Baptist et al., 2004; Loomis et al., 2000; Tapsell, 1995; Tunstall et al., 2000).

Although RoR is often assumed to be more ecological, respondents from all three regions were concerned about the technology's impact (Anderson et al., 2015; Bilotta et al., 2016; Manzano-Agugliaro et al., 2017). As many respondents demonstrated misconceptions about ecological measures and voiced concern about their efficacy, policymakers should reevaluate how the public is made aware of such efforts and the degree to which operators monitor ecological measures. Although EU member states are required to assess the hydro-morphological and ecological status of water bodies on a systematic and comparable basis (European Parliament, 2000), there are no specific mandated methods for monitoring and few studies on the ecological impact of RoR (Bilotta et al., 2016). Thus, current monitoring is inadequate (Cooke and Hinch, 2013; Dworak et al., 2005; Roscoe and Hinch, 2010). Policymakers should determine whether a common European standard for monitoring for cross-site comparison (Kampa et al., 2011) or a site-by-site basis for evaluating based on the river's previous state (Nieminen et al., 2017) is preferable. Based on more rigorous monitoring programs, the public can be informed about the ecological impact of RoR plants.

Finally, our results show that the importance of maintaining low electricity prices are viewed as controversial, particularly when management changes translate to higher consumer prices. The extent to which price affects consumer willingness-to-pay for ecological hydropower has been quantified using discrete choice experiments in Sweden (Kataria, 2009; Sundqvist, 2002), Portugal (Botelho et al., 2017), Switzerland (Tabi and Wüstenhagen, 2017), Austria (; Klinglmair et al., 2015) and Korea (Han et al., 2008) among others. A meta-analysis of the valuation of hydropower externalities conducted by Mattmann et al. (2016) concluded that although there is a strong public emphasis on mitigating the negative effects of hydropower, there appears to be a limited willingness to pay for it. Thus, it is important that policymakers and operators note the discrepancy between the perceived importance of ecological measures and actual consumer willingness to pay.

6. Conclusion and policy implications

Small-scale decentralized generation will be an important component of the renewable energy transition. A large share of future hydropower projects will be smaller, run-of-the-river (RoR) hydropower schemes. Thus, RoR hydropower represents an opportunity for sustainable decentralization and co-production. As the scale of the sustainable energy transition will be driven by the public's social and economic values and behavior, understanding local views on RoR is key.

Our results about local views on RoR are relevant for hydropower operators and policymakers. Strong preferences for regional control imply that RoR should be managed as distributed generation rather than viewed as part of a centralized, national system like traditional large-scale reservoir hydropower and that local involvement (as opposed to centralized planning) can help facilitate community acceptance. Given the inherently exploratory nature of the Q-methodology and the potential geographic diversity in RoR sites, further investigation is needed for specific national case studies not discussed here. Future research may focus on the merits of local and regional control in different regional contexts as well as opportunities for co-operative, shareholder and single owner co-production or participation schemes for small RoR.

Although RoR is often assumed to be more ecologically sound, locals are concerned about their ecological impact. To inform decision-making and the public, policymakers should support rigorous monitoring programs. In turn, awareness campaigns are important, particularly when RoR can prevent floods, support ecological habilitation and provide recreational areas. Finally, our findings are relevant for regions where RoR development is planned and decentralized energy production is necessary for remote locations. While stimulating RoR hydropower development is promising for its contribution to greenhouse gas emissions reduction, community acceptance requires regulation that balances trade-offs between renewable energy and ecosystems but also ensures distributive justice to local populations.

Author contribution statement

TV: conceptualization, formal analysis, investigation, writing – original draft.
MH: conceptualization, writing – review & editing.
TB: conceptualization.
HG: conceptualization, project administration
FG: visualization, investigation, writing – review & editing.
BH: investigation.
AP: conceptualization, writing – review & editing.
JS: funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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