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Estimating the economic value of hydropeaking externalities in regulated rivers

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HIGHLIGHTS

- We study valuations for policies aiming to reduce hydropeaking in regulated rivers.
- There is an obvious trade-off between local and global hydropower externalities.
- People value improvements in fish stocks, recreational use, and ecological state.
- Potential increases in CO_2 emissions create disutility.
- Policy-makers and river managers should consider alternative operation regimes.

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ABSTRACT

Hydropower is a flexible form of electricity generation providing both baseload and balancing power to accommodate intermittent renewables in the energy mix. However, hydropower also generates various externalities. This study investigates individuals' preferences for policies aiming to reduce short-term regulations (i.e., hydropeaking in regulated rivers) while accounting for associated externalities with a discrete choice experiment. This is the first valuation study focusing on hydropeaking that considers both negative and positive externalities. The results imply that most individuals prefer stronger restrictions on short-term regulations to mitigate local environmental impacts. Individuals especially value improvements in recreational use, fish stocks, and the ecological state. On the other hand, potential increases in CO_2 emissions are linked with a clear disutility. The estimated benefits obtained from an improved state of the river environment due to such restrictions exceed the disutility caused by increased CO_2 emissions. The results also reveal unobserved preference heterogeneity among individuals, which should be accounted for in the willingness-to-pay (WTP) estimation using a model specification with correlated utility coefficients. Overall, the findings can inform policy-makers and environmental managers on the economic value of hydropeaking externalities and further guide the sustainable management of rivers regulated for hydropower generation.

1. Introduction

Global climate change mitigation measures and the electrification of economies are changing power markets to include an expanding share of renewable energy sources. The intermittence of these sources increases the need for balancing power in the local, national, and regional

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production and electricity markets. Hydropower is a significant and highly valuable source of flexible electricity that balances the increasingly fluctuating supply at sub-daily scales to meet electricity demand [1,2]. Thus, significant pressure exists to utilize regulated rivers more efficiently to balance the electricity market. This development has already altered the hydropower operating regimes by increasing sub-daily flow variation, an effect referred to as hydropeaking [3,4], in the Nordic countries [5,6]. Hydropeaking at sub-daily scales is likely to intensify further in the future as the share of intermittent renewable energy sources is expected to rise.

Hydropower production typically generates various externalities [7]. This study focuses on externalities caused by hydropeaking. Hydropeaking produces artificial flow patterns involving high variability in discharge, water level, and flow velocity with substantial environmental effects. For example, hydropeaking results in changes in sedimentation levels and water temperature, negatively affecting invertebrates [8] and fish [9,10]. It also causes erosion, degrading the river's ecological status [11]. Diverse recreational services, such as swimming, boating, kayaking, angling, skiing, or snowmobiling on river ice may also be affected by altered flow patterns as the water level and velocity change quickly. The influence of hydropeaking on recreational opportunities may be negative or positive depending, for instance, on the recreational activity and river section [12,13,14]. A positive environmental externality of hydropeaking is lower greenhouse gas emissions compared to most other electricity production forms [15].

Several previous valuation studies have investigated hydropower externalities, as summarized in a meta-analysis by Mattmann et al. [7]. The literature has often examined the environmental impacts of new hydropower projects [12,16,17,18], but there are also studies on the impacts of removing existing dams [19–21]. Closest to our study are the ones on alternative operation regimes of hydropower generation and other remedial measures for improving the ecological status of regulated rivers. For example, Kataria [22] estimated the value of environmental improvements in a hydropower-regulated river in Sweden, focusing on the river's ecological status using a discrete choice experiment (DCE). The results show that measures that enhance the conditions for environmental attributes have a significant welfare increasing impact. In another study, Jones et al. [23] examined individual preferences for operational changes in flow regimes to obtain environmental improvements in a regulated Colorado river in the US using a contingent valuation method. The findings indicate that preferences are highly sensitive to information about additional value dimensions beyond downstream environmental flow impacts, such as effects on rural communities and air emissions.

In this study, we investigated individual preferences for policies aiming to reduce hydropeaking while accounting for associated externalities with a DCE. To our knowledge, this is the first valuation study focusing on hydropeaking. Our study also differs from previous research in attribute selection because we considered both positive and negative hydropower externalities and their tradeoffs. Our main objective was to determine how people perceive and value the effects of hydropeaking on the river's recreational use, ecological status, fish stocks, and carbon dioxide (CO_2) emissions. We examined these issues in a large river system, the Kemijoki River in Finland. The Kemijoki River is an interesting and relevant river to study the effects of hydropeaking because it is the largest source of hydropower in Finland, directly influencing the balance between negative and positive externalities.

Our specific research questions are as follows: (i) What is the relative importance of the considered attributes in their contribution to willingness-to-pay (WTP) estimates? (ii) How are individual-specific factors associated with individuals' preferences? (iii) What are the welfare effects, in terms of compensating variation, of alternative policy scenarios to restrict hydropeaking? These are policy-relevant questions because the increasing changes in the sub-daily flow regimes deteriorate river ecosystem and river's recreational services; therefore, environmental managers and policy-makers need to consider this new pressure on river environments. Understanding individuals' preferences for hydropeaking regulation and environmental effects is crucial to inform an efficient and sustainable energy transition from fossil fuels to renewable energy sources. As a methodological insight for DCE modeling, we tested the technique proposed by Mariel and Artabe [24] for identifying behavioral correlations among utility coefficients and to investigate preference heterogeneity apart from scale heterogeneity.

The rest of the paper is organized in the following way. Section 2 presents the case study area, survey design, and empirical model. Section 3 focuses on the results, whereas Section 4 provides a discussion and the concluding remarks.

2. Data and methodology

2.1. Case study area

Kemijoki is one of the largest rivers in Northern Europe and Finland, flowing through the cities of Sodankylä, Kemijärvi, Rovaniemi, and Kemi to the Gulf of Bothnia, Baltic Sea. The Kemijoki watershed (50,683 km^2) covers a significant portion of northern Finland (Fig. 1).

There are 16 hydropower plants on the main part of the Kemijoki River (Fig. 1). Hydropower production was 4131 GWh in 2020, accounting for approximately 6% of all electricity production in Finland. The nominal capacity of the Kemijoki River power plants is 1098 MW, and seven power plants of the main part of the Kemijoki River are among Finland's ten largest hydropower plants. In addition, reservoirs have been built upstream, and Lake Kemijärvi is regulated (Fig. 1).

According to the classification of the European Water Framework Directive (2020/60/EC), the main channels of the Kemijoki River and Lake Kemijärvi are both designated as heavily modified. The modified and regulated main river system and tributaries include 1000 km^2 of lake basins and 685 km of river channels [25]. A recent ecological status assessment showed that the environmental goal of good ecological potential was reached only upstream of Lake Kemijärvi, whereas the middle and lower stretches were classified as moderate [25]. The main reason for lowering the ecological status is the lack of fish passages in the main channel, which would allow a bypass to non-constructed spawning grounds on the Kemijoki River. Overall, the building of hydrodams and regulations have changed waterbodies and discharge conditions in the watershed [26]. Construction has destroyed the rapid areas almost totally; the only remaining rapids are situated between the Valajaskoski and Vanttauskoski power plants, where the Sierilä power plant is planned and in the licensing phase (see Fig. 1). Regulation and water fluctuation also influence the riparian zone, with a reduction in protective littoral vegetation causing recruitment losses among fish species [25].

2.2. Survey development and data

The design of the DCE started by reviewing the literature to identify potential attributes [16,17,18,22,27,28,29]. Then, from discussions with researchers and experts, we constructed the current and alternative policy situations and determined the most relevant attributes and their levels. The development of the DCE lasted approximately one year and included several workshops and rounds of commentary. The survey and the DCE were also presented to the local hydropower operator and environmental regulator. Based on the feedback received, the survey and DCE were developed further. The pilot survey was conducted in April 2021. We collected responses and feedback from 27 individuals with different backgrounds. The pilot respondents included both people living in the study area and individuals who were familiar with the study area and/or topic. The pilot round enabled us to pretest the understandability and credibility of the survey questions and the DCE, conduct some preliminary analysis, and refine the experimental design.

The final survey was executed in June 2021 (see the survey in Appendix A). The survey was targeted to (i) 2500 individuals living in the

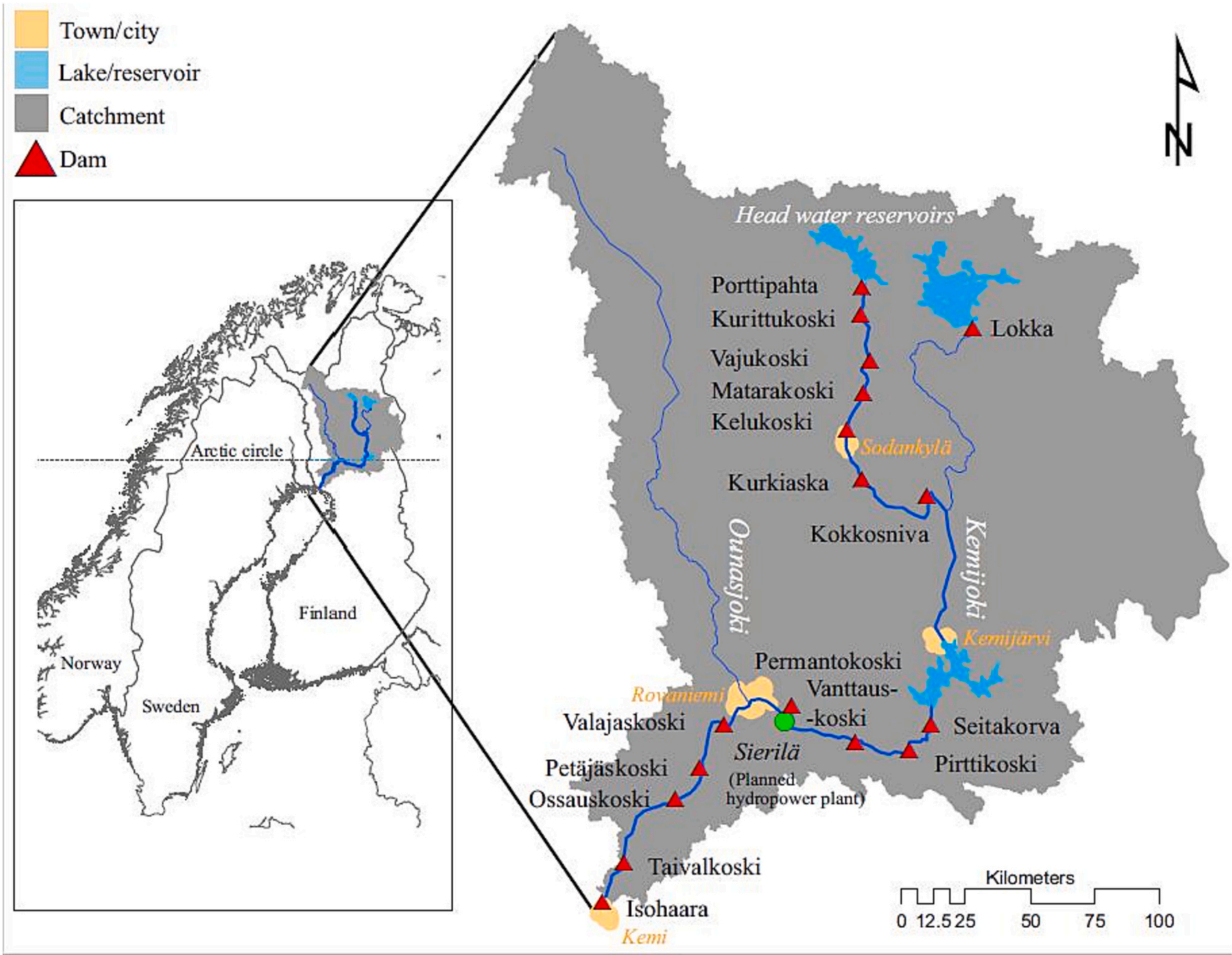


Fig. 1. The Kemijoki River study area.

municipalities in the Kemijoki watershed[1] and (ii) 1500 individuals living in other parts of Finland. Local individuals were the main target group of this study. In addition, we invited individuals living outside the study area to participate to the survey to explore the non-use value aspects and whether local preferences differ from the rest of the country. The participants were randomly drawn from the civil registry's database, and their ages varied between 18 and 80 years. The participants living in the Kemijoki watershed area were sent a printed questionnaire by ordinary mail that included instructions on how to respond to the online version, whereas the participants living outside the study area were sent an invitation by mail with instructions on how to respond to the online survey. The participants were incentivized to respond by being offered a chance to win a €100 voucher to a grocery store.

We received 396 responses, of which 264 were printed questionnaires and 132 were online responses. The response rate was higher among individuals living in the study area (13.0%) than among those living outside the study area (4.8%) as expected. Several factors may explain the low response rate of people living outside the study area. For instance, the unfamiliarity of the study area may have affected it. In addition, no reminder rounds were conducted, and individuals living outside the study area were only given with the possibility of answering the online survey due to budgetary constraints.

Table 1 presents the descriptive statistics for the local respondents, the total sample of respondents, and the corresponding populations. The respondents were representative of household size. However, the respondents were somewhat older and included more men than the corresponding populations. The collected sample was also slightly more educated than average for the local and the Finnish population of those over 15 years old. However, this difference is mitigated if we account for the fact that the collected sample only included individuals aged between 18 and 80. Unfortunately, the income distribution is not publicly available with the presented division. We acknowledge that the collected sample is likely to suffer from non-response bias, which warrants to be considered in the DCE analysis.

2.3. Discrete choice experiment design

The DCE included six hypothetical choice tasks. Before respondents started to answer the choice tasks, the attributes were described to them, and follow-up questions were used to ensure that they had familiarized themselves with the descriptions. Each choice task included three alternatives: one corresponded to the current situation, and two others presented hypothetical policy situations (see an example choice task in Appendix A). Six attributes described the choice alternatives: short-term regulations of hydropower production, recreational use, the ecological state, fish stocks, CO_2 emissions, and an increase in the annual electricity bill. Table 2 summarizes these attributes and their levels. In the table, the levels of the current situation are underlined. The choice and description of the attributes are justified in the next paragraphs.

According to the current permit conditions (i.e., the level "Current

[1] The municipalities were Kittilä, Rovaniemi, Sodankylä, Savukoski, Pelkosenniemi, Kemijärvi, Tervola, Keminmaa, and Kemi.

Table 1
Descriptive statistics of the respondents and the corresponding population.

	Local respondents (N = 324)	Local population	Total sample of respondents (N = 396)	Population
Sociodemographic traits				
Average age (years)	58.4	49.9[a]	57.7	50.2[c]
Average household size	2.33	2.34[a]	2.37	2.34[c]
Gender %				
Female	39	49.4[a]	38	48.8[c]
Male	60	50.6[a]	61.2	51.2[c]
Other	1	NA	0.8	NA
Household income (gross, €/month) %				
<2000	15.1	NA	13.6	NA
2000–3999	35.2	NA	33.5	NA
4000–5999	28.2	NA	27.8	NA
6000–7999	12.8	NA	14.2	NA
>8000	8.7	NA	10.9	NA
Education %				
Primary, secondary, or other	63	69.8[b]	60.3	67.4[d]
Polytechnic or university degree	37	30.2[b]	39.7	32.6[d]
Living in the Kemijoki River watershed area %	100	100	81.8	62.5[c]

NA = Not available.
[a] : Population refers to the random sample of locals (N = 2500) obtained from the civil registry.
[b] : Population refers to the locals of those over 15 years old in 2021 [30].
[c] : Population refers to the total random sample (N = 4000) obtained from the civil registry.
[d] : Population refers to the Finnish population of those over 15 years old in 2020 [31].

regulations”), short-term regulations can be utilized efficiently in the hydropower production of the Kemijoki River. This causes strong intraday and weekly variations in water flow and surface elevation. For example, during low flow, the shoreline is exposed, whereas during high flow, the water level rises, and the water flow rate is high. The intensity of the effects varies in different parts of the river. The effects are typically stronger near hydropower plants. In the future, the Kemijoki River could have stronger restrictions on short-term regulations to reduce harmful local environmental impacts.[2] The attribute “Short-term regulations of hydropower production” describes this new policy. The level “Somewhat more restrictions” refers to a situation where the short-term hydropower regulation will be moderately limited. Here, fluctuations in water flow and surface height within a day are smaller than under current regulations. The flow variation is reduced by approximately 50% compared to the present circumstances. The level “A lot more restrictions” means that the short-term regulations of hydropower will be severely restricted, clearly reducing hydropeaking use. Here, intra-day variations in flow and water level are hardly observed. On a weekly basis, some variation in water level is noted. The flow variation is reduced by about 80% compared to today. This policy attribute does not directly describe outcomes that people value, but it shows explicitly the magnitude of flow restrictions to the respondents and increases the comprehensibility and credibility of the policy situations under review.[3]

This attribute is included in the choice task also to indicate to the respondents that the outcomes of flow restrictions are somewhat uncertain as the levels of the other attributes vary within the flow restrictions. In addition, the restrictions may have some effects on, for example, security of energy supply and employment that the policy attribute can capture only indirectly.

Short-term regulations of hydropower may affect recreational use of the Kemijoki River. Flow fluctuations influence, among other things, the quality and usability of the beaches and safety for swimming, paddling, boating and fishing. Due to the strong variation in flow, fish move more, and angling may become more difficult. Fluctuations in the water level can damage fixed structures such as piers. Variation in water height and flow also impacts the durability of the ice cover in winter, impairing safe movement on ice. At present, fishing, swimming, and other water activities can be tricky in certain places (see the level “Current state”). The use of fixed beach structures can be difficult, and harm can result. In wintertime, ice cover can be weakened and become unpredictable in certain spots. The level “Improves somewhat” means that fishing becomes slightly easier. In addition, bathing and navigating the waters is easier and safer. The use of fixed structures on beaches is a little easier, and they are less likely to be damaged. The ice cover is a bit more durable in the winter. Related to the level “Improves a lot,” flow changes are more predictable, making swimming and navigating the waters easy and safe. The fixed structures on the beach are not harmed and are more functional. In winter, the ice cover is stronger and safer. Smiley faces were added to the graphical illustration of the recreational use attribute based on the received feedback in the piloting phase.

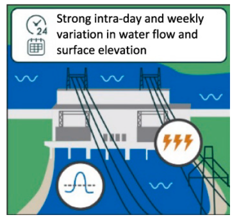
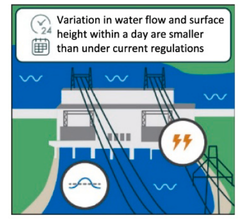
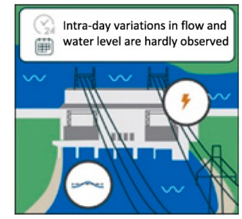
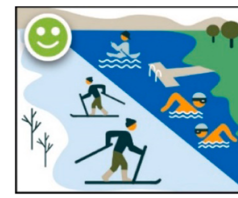
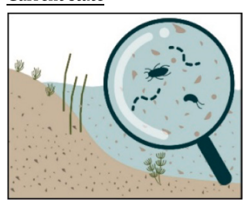
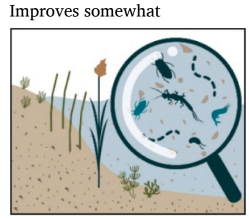
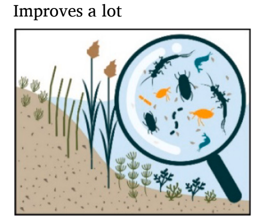
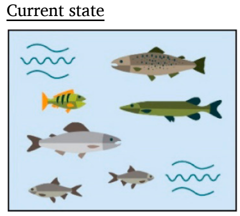
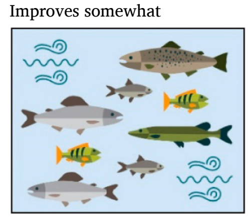
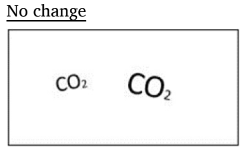
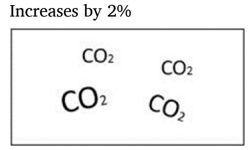
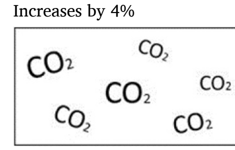
The short-term regulations of hydropower affect the ecological state of the Kemijoki River environment. The ecological state in this study is interpreted as the quality of the river’s habitats and the abundance of plants and benthos that live there. Strong short-term regulations increase riverbed and riparian wear and weaken natural benthic and plant communities. In the current state, the benthic fauna and flora of the river suffer from short-term regulations, and solids are released into the water. At the level “Improves somewhat,” the living conditions of benthic animals and plants in the river are assumed to improve slightly; communities will be more abundant and fewer solids are released into the water, whereas “Improves a lot” indicates that the river’s benthic and plant communities are close to the natural state and there are few solids in the water, in accordance with the Water Framework Directive (2000/60/EC).

Short-term regulations have a detrimental effect on the diversity and abundance of fish species in the Kemijoki River. Rapid and strong flow fluctuations reduce the abundance of almost all naturally reproducing fish species and degrade their habitats. Also, the stronger short-term regulations are, the less successful the stocking of artificially reared fish will be. Currently, common species in the slow-flowing river sections and lakes include pike, perch, pikeperch, roach, stocked brown trout, and stocked and introduced non-native rainbow trout. Species dependent on or benefiting from fast-flowing river habitat (grayling, whitefish) are scarce, and their natural reproduction is very low. If the state of fish stocks would “Somewhat improve,” fish species such as grayling would likely become more common, and natural reproduction would strengthen. Other fish species would also become more abundant, and stocking of artificially reared species is more successful. Notably, this attribute had only a moderate improvement level because expert evaluations revealed that it was not realistic to assume higher improvements in fish stocks. Baltic salmon, which was highly abundant in the river before its damming, was not included in this attribute because the number of salmon in the Kemijoki River cannot be increased by restricting short-term regulations without building well-functioning fish passages next to dams (which are currently lacking).

[2] The respondents were informed that any new restrictions would not apply to seasonal variation or flood protections.

[3] The feedback received during the development phase of the survey revealed that people preferred this attribute to be included in the choice task compared to not including it.

Table 2
Attributes and levels in the DCE.

Attribute	Levels		
Short-term regulations of hydropower production	Current regulations 	Somewhat more restrictions 	A lot more restrictions 
Recreational use	Current state 	Improves somewhat 	Improves a lot 
Ecological state	Current state 	Improves somewhat 	Improves a lot 
Fish stocks	Current state 	Improves somewhat 	
CO_2 emissions	No change 	Increases by 2% 	Increases by 4% 
Increase in electricity bill (€/year)	€0, €5, €15, €30, €50, €75, €105		

Significant changes in the timing of outputs of large hydropower plants are likely to increase CO_2 emissions[4] and market prices (which typically affect consumers' billing costs) in the Finnish system. If short-term regulations on hydropower are restricted, more expensive and polluting dispatchable production sources are needed. Hydropower generates low-emissions electricity and is especially useful when no intermittent wind power generation is available. We calculated rough estimates to understand the relationship between short-term hydropower restrictions and emissions as well as costs (see Appendix B). The

[4] Restricting the short-term regulations of hydropower production on the Kemijoki River would increase the CO_2 emissions of Finnish electricity production.

calculation results indicate that CO_2 emissions rise by 2.1 and 2.7% in the considered scenarios "Somewhat more restrictions," and "A lot more restrictions" compared to the original emissions in the scenario "Current regulations". Thus, the levels in the DCE for increase in CO_2 emissions were 0%, 2%, or 4%. The rough estimates for additional billing costs per household were approximately €3.5 in the scenario with somewhat more restrictions on hydropower output, and €4.6 when many more restrictions were put into action. To have higher variation across choice tasks in the DCE, the potential increases in the electricity bill varied between €0 and €105.

The DCE design was conducted with a Bayesian D-efficient design consisting of 36 choice tasks that were further divided into six blocks to minimize the respondent's burden. The prior parameter values for the design were obtained from the pilot study. To create feasible choice tasks, we added constraints to the design. Whenever the alternative in the choice task had the short-term regulations of hydropower attributed to the "A lot more restrictions" level and the other alternative to the "Somewhat more restrictions" level, then the attribute levels of the ecological state and recreational use were either better or at least equal and the attribute level of emissions was either higher or at least equal in the alternative with "A lot more restrictions" level compared to the alternative with the "Somewhat more restrictions" level. These restrictions were identified as important for the credibility of the choice alternatives during survey testing.

2.4. Empirical model

In the frequently used mixed logit (MXL) model [32], the utility for individual n, related to choice alternative j, is represented as:

$$U_{nj} = \beta_n^{'} x_{nj} + \varepsilon_{nj}, \tag{1}$$

where x_{nj} is a vector of attributes including an alternative specific constant (ASC), and β_n is the corresponding vector of estimated parameters. The idiosyncratic error ε_{nj} is independently and identically distributed and an extreme value one (EV1) type. β_n also includes random taste parameters that depend on the values of the population mean b and covariance matrix Ω of an underlying distribution $\varphi(\beta|\mathrm{b},\Omega)$.

The utility specification is presented in the preference space in Eq. (1). However, we re-parameterize the utility to the WTP space in which the estimated coefficients can be interpreted as marginal WT*P* values [33]. In the WTP space, the utility for individual n is

$$U_{nj} = \sigma\left(\alpha_n m_{nj} + \beta_n^{'} x_{nj}\right) + \varepsilon_{nj} = \sigma\alpha_n\left(m_{nj} + \beta'_n x_{nj}/\alpha_n\right) + \varepsilon_{nj}$$

$$= \sigma\left(\alpha_n m_{nj} + \upsilon_n^{'} x_{nj}\right) + \varepsilon_{nj}. \tag{2}$$

In Eq. (2), m_{nj} denotes the monetary attribute and α_n represents the estimated parameter for it, x_{nj} includes non-monetary attributes and β_n refers to the corresponding vector of estimated parameters. Above, we also have $\upsilon_n = \beta_n/\alpha_n$, a vector of marginal WTP for each non-monetary attribute. The scale parameter σ is normalized to 1. The WTP space specification enables convenient distributions for WTP because it avoids the need to consider the distribution of inverse coefficients [34].

In this study, non-monetary attributes were treated as random and assigned normal distributions, whereas monetary attributes were treated as random with lognormal distributions. The modeling was executed with 10,000 Sobol draws with random linear scramble and random digital shift. Analytically derived gradients were used. The estimations were conducted in MATLAB.[5]

In the analysis, we used the MXL model in the preference and WTP space with and without correlation. Overall, the MXL model that allows all parameters to be randomly distributed, and which estimates a full covariance matrix among them, is the most general form possible [24,35]. We allowed for a correlation between random coefficients because it was likely that the unobserved effects between different attributes and attribute levels would be correlated. Such a correlation is taken to reflect that an individual's preferences for one attribute are related to the preferences for another attribute. For instance, individuals who support increases in recreational possibilities can also be supportive of improvements in the fish stocks and/or ecological state. Alternatively, individuals who prefer improvements in the ecological state can also dislike increases in CO_2 emissions.

To test these behavioral hypotheses and interpret the obtained correlation matrix, we utilized the procedure proposed by Mariel and Artabe [24]. This procedure may help to disentangle behavioral interlinkages from scale heterogeneity. The correlation matrix captures not only the correlation between the random parameters, but also the correlation caused by the scale heterogeneity that cannot be identified separately [35,36]. The proposed procedure consists of two simple steps. First, the signs of the attributes corresponding to the utility that have a negative mean coefficient are reversed. Then, only negative correlations are interpreted. This enables to identify correlation resulting from a behavioral phenomenon.

To derive a welfare change estimate for policy scenarios describing the short-term regulations of hydropower production and associated effects, we employed the compensating variation (CV) from Hanemann [37]:

$$\mathrm{CV} = \frac{1}{\alpha}(V_0 - V_1), \tag{3}$$

where V_0 and V_1 are the utility expressions for the current and alternative policy scenarios. Denoting $\overline{V_0} = \frac{V_0}{-\alpha}$ and $\overline{V_1} = \frac{V_1}{-\alpha}$, the CV is calculated using the WTP space specification outcomes as follows:

$$\mathrm{CV} = \overline{V_1} - \overline{V_0}. \tag{4}$$

In addition to the MXL model, we applied the Latent Class (LC) model to identify segments of respondents with varying preferences for the studied attributes. For the readers interested in the technical details of the LC model, we refer to a study by Boxall and Adamowicz [38].

3. Results

3.1. General opinions on hydropower

The survey included several hydropower-related claims, which we measured on a 5-point Likert scale (Fig. 2). A vast majority (81%) of the respondents either strongly or somewhat agree that hydropower causes significant damage to migratory fish stocks. Hydropower is also clearly more negative than positive for recreational fishing (62% vs. 22%). In addition, 48% of the respondents strongly or somewhat agree that hydropower destroys riparian vegetation, and 53% find hydropower plants harmful from a landscape point of view.

On the other hand, most of the respondents think that hydropower is a low-emissions form of electricity generation (74% strongly or somewhat agree), that it increases the security of supply in the energy system (66% strongly or somewhat agree), that the municipal economy benefits from it (59% strongly or somewhat agree), and that it is an important energy production form of the future (56% strongly or somewhat agrees). The sample is clearly split with regard to the perceived effects on biodiversity, recreational use, land value, and electricity prices. Furthermore, the share of "do not know" answers was the highest related to impacts on land value, riparian vegetation, and the municipal economy. Overall, the findings indicate that the public is likely to have varying opinions on hydropower and its externalities. This is also reflected in the response distribution when asking whether the respondents disliked hydropower: 55% of those providing an answer to this claim either strongly or somewhat disagreed, 13% were indifferent,

[5] We utilized the DCE package, available here.

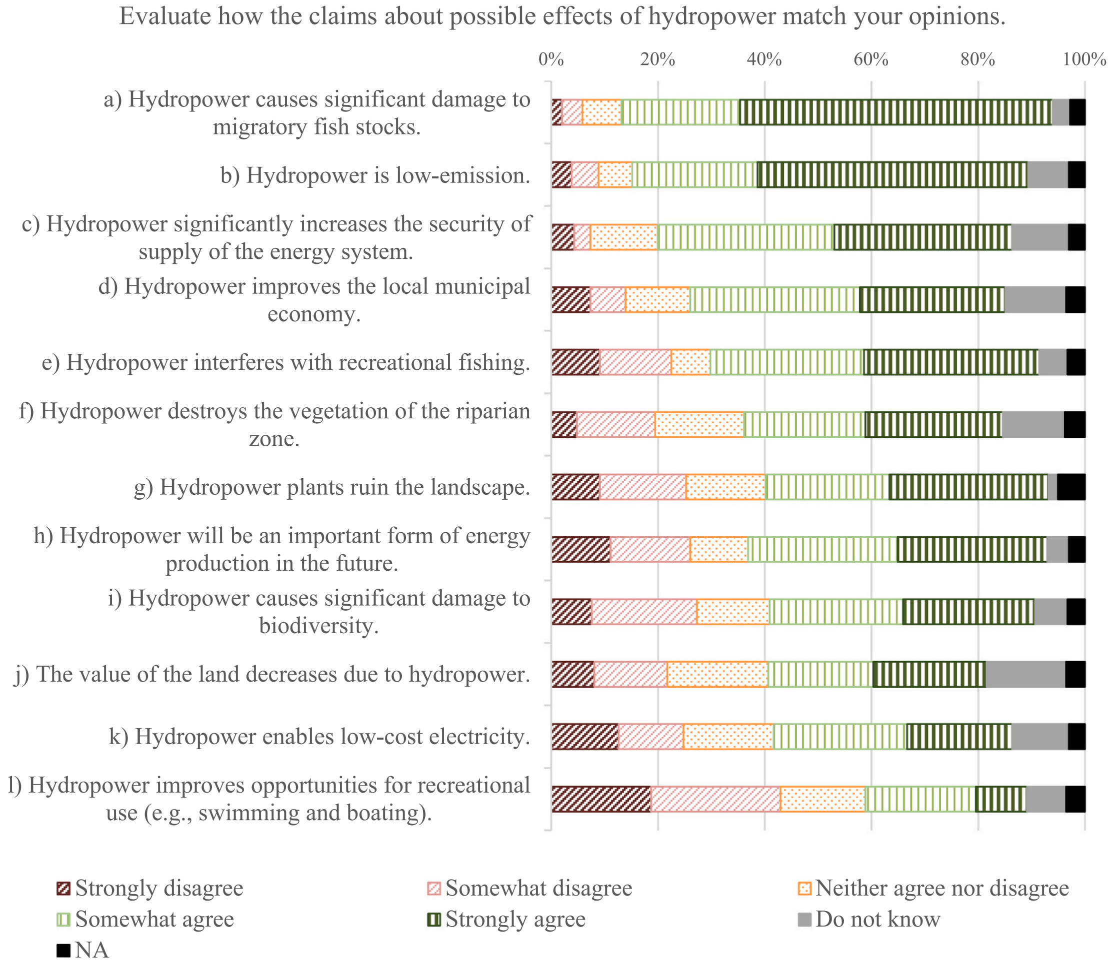


Fig. 2. Likert scale distribution of opinions on possible effects of hydropower ($N = 396$).

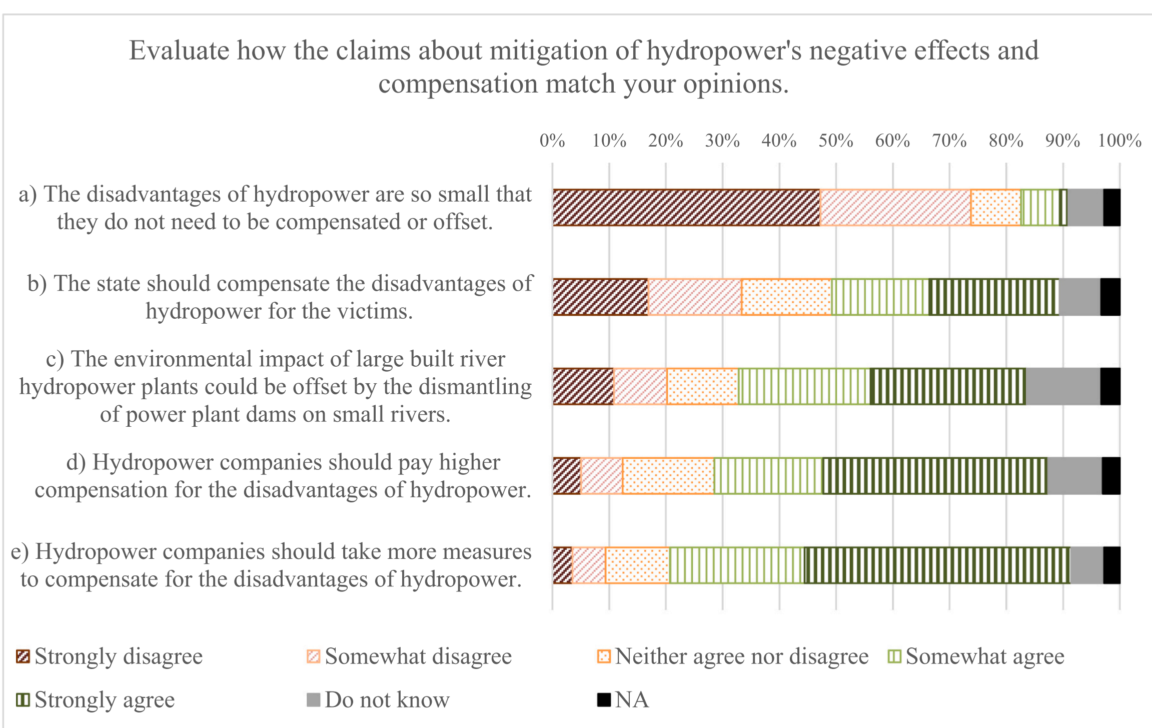


Fig. 3. Likert scale distribution of opinions on compensation and mitigation measures of the negative effects of hydropower ($N = 396$).

and 29% strongly or somewhat agreed with the claim.

The respondents were also presented with a series of questions about the mitigation measures and compensation requirements of the negative effects of hydropower (Fig. 3). Over 70% of respondents thought that negative externalities exist, which should be either compensated for or offset, and nearly as many stated that hydropower companies should take more measures in compensation activities. Additionally, 59% are willing to see higher monetary compensation. However, the respondents were divided based on whether the state should participate in compensating for the disadvantages of hydropower production. Interestingly, public support exists for ecological compensation, as 51% of the respondents either strongly or somewhat agreed that the environmental impacts of large hydropower plants could be compensated for by dismantling small power plants on other rivers.[6]

3.2. Valuation of hydropeaking externalities

Table 3 outlines the definitions of the attribute variables used in the discrete choice analysis. Current state levels for recreational use, the ecological state, and fish stocks, as well as no change level for CO_2 emissions, serve as reference categories. The MXL model with correlation outperformed the MXL model without correlation based on LL, McFadden pseudo R^2, and AIC (see Appendix C Table C1), thus suggesting that using the MXL model without a correlation could lead to biased estimation of the WTP values. Note that 20 respondents were excluded from the analysis due to missing responses to at least one of the choice tasks.

The results of the DCE are presented in Table 4. Models 1 and 2 are otherwise similar except for interactions with the ASC. The results of the MXL models (1 and 2) in the WTP space show that the variables have their expected signs. The coefficient of the ASC is negative, implying that respondents preferred the presented alternative policy situations over the status quo. Note, however, that the ASC captures both the utility related to the status quo alternative and the omitted dummy for the short-term regulations attribute, level REGUL_M. The coefficient for REGUL_H is statistically insignificant, meaning that the respondents were, on average, indifferent to the alternative short-term regulations, including more restrictions. Our interpretation is that the intensity of restrictions as such is not as important as the resulting effects are.

Table 3
Variable descriptions.

Variable	Notation	Type
ASC status quo	ASC	dummy-coded
Short-term regulations of hydropower production		
Somewhat more restrictions	REGUL_M	dummy-coded
A lot more restrictions	REGUL_H	dummy-coded
Recreational use		
Improves somewhat	RECREA_M	dummy-coded
Improves a lot	RECREA_H	dummy-coded
Ecological state		
Improves somewhat	ECOL_M	dummy-coded
Improves a lot	ECOL_H	dummy-coded
Fish stocks		
Improve somewhat	FISH_M	dummy-coded
CO_2 emissions to air		
Increases by 2%	EMIS_2	dummy-coded
Increases by 4%	EMIS_4	dummy-coded
Increase in electricity bill (€/year)	EBILL	continuous

The coefficients for improvements in recreational use and the ecological state are all positive and statistically significant. Moreover, the respondents derived higher value for recreational use than the ecological state and witnessed clear improvements in both attributes (RECREA_H and ECOLO_H). In Model 1, the WTP for RECREA_M is €32 [± €6], for RECREA_H it is €54 [± €8], for ECOL_M it is €29 [± €7], and for ECOL_H it is €35 [± €8]. The respondents also valued moderate improvements in fish stocks because the statistically significant WTP for FISH_M is €32 [± €5]. The coefficients for EMIS_2 and EMIS_4 are both negative and significant, which reflects a dislike for increases in CO_2 emissions. The respondents required, on average, a €26 [± €7] compensation for a 2% increase in emissions, and a €60 [± €9] compensation for a 4% increase in emissions. As expected, the coefficient for EBILL is negative and significant.

The statistically significant standard deviation coefficients imply clear variations around the estimated mean WT*P* values. Hence, respondents' preferences were heterogeneous. The correlation matrices for models 1 and 2 are available in Appendix C Table C2 and Table C3.

Preference heterogeneity exists among respondents with respect to ASC values. To investigate possible reasons and to control for potential representativeness issues (see Table 1), we introduced interactions between the status quo and respondents' demographic traits. This informed us whether age, higher education, gender, or living place affect the choice between the status quo and alternative river management scenarios. The weakly and statistically significant positive interaction between a respondent's age (AGE) and the ASC denotes that the choice probability of the status quo is higher among older respondents. This implies that a younger age is linked with higher valuation of more restrictive hydropower operations. In addition, the probability of choosing the status quo falls if the respondent is a male. Interestingly, we observed that living in the Kemijoki River watershed area (LOCAL) is not associated with a lower probability of choosing the status quo. This indicates that, on average, familiarity with the study area is not linked to a higher valuation of alternative regulation regimes. This finding also supports our decision to use the total sample of respondents (not just the sample of locals) in the analysis. Furthermore, a high education level (HIGHEDU) does not explain the probability of choosing the status quo alternative.

We also examined preference heterogeneity with the LC model. The results of the LC model are available in Appendix C in Table C4. The LC analysis reveals four groups of respondents. The first group accounts for 30% of the sample and includes respondents who prefer the current regulation regime, whereas the other three groups prefer a policy change. The second group (20.6% of the sample) values especially improvements in recreational possibilities and are sensitive for increases in electricity bill. The third group (16.8% of the sample) prefers improvements in local attributes (i.e., recreational use, fish stock and ecological state) and dislikes increases in emissions. Also, the fourth group (32.6% of the sample) values improvements in local attributes. However, they are not sensitive for increases electricity bill and dislike only the higher-level increase in emissions.

3.3. Policy scenarios

We created four scenarios to illustrate how environmental externalities affect individuals' economic welfare in terms of CV (Table 5). Policy scenarios 1 to 4 represent policies with stronger short-term regulations of hydropower production compared with the current regulations. Note that the likelihood of reaching the "Improves a lot" level in recreational use and the ecological state is higher in the case of high restrictions on hydropeaking (REGUL_H = 1) than in the case of moderate restrictions (REGUL_M = 1). All policy scenarios can generate moderate improvement in fish stocks. On the other hand, it is likely that the CO_2 emissions will increase more in scenario 2 than in scenario 1 with the current energy production mix. Policy scenarios 3 and 4 illustrate welfare effects associated with a decarbonized power system. In the

[6] Some small hydropower plants have already been dismantled in Finland to restore river ecosystems. In addition, it has been discussed whether larger hydropower units could compensate for their negative environmental impacts by dismantling small power plants on other rivers.

Table 4
Results of the MXL models in the WTP space.

		Model 1								Model 2 (ASC with interactions)							
		Means				Standard deviations				Means				Standard deviations			
Variable	Dist.	Coeff.[a]		St. Err.	P value	Coeff.		St. Err.	P value	Coeff.[a]		St. Err.	P value	Coeff.		St. Err.	P value
ASC	normal	−0.5274	***	0.1094	0.0000	1.2922	***	0.1983	0.0000	−0.6620	**	0.2585	0.0104	1.4037	***	0.2267	0.0000
REGUL_H	normal	−0.0523		0.0593	0.3780	0.4299	***	0.0621	0.0000	0.0454		0.0587	0.4396	0.4034	***	0.0661	0.0000
RECREA_M	normal	0.3237	***	0.0613	0.0000	0.4498	***	0.0741	0.0000	0.4017	***	0.0647	0.0000	0.4619	***	0.0755	0.0000
RECREA_H	normal	0.5369	***	0.0778	0.0000	0.6567	***	0.0927	0.0000	0.6549	***	0.0855	0.0000	0.7000	***	0.0981	0.0000
ECOL_M	normal	0.2889	***	0.0725	0.0001	0.6493	***	0.0928	0.0000	0.2218	***	0.0719	0.0020	0.6681	***	0.1036	0.0000
ECOL_H	normal	0.3506	***	0.0811	0.0000	0.8081	***	0.0882	0.0000	0.3490	***	0.0768	0.0000	0.7973	***	0.1021	0.0000
FISH_M	normal	0.3160	***	0.0521	0.0000	0.6008	***	0.0777	0.0000	0.5029	***	0.0600	0.0000	0.6007	***	0.0823	0.0000
EMIS_2	normal	−0.2625	***	0.0685	0.0001	0.6180	***	0.0888	0.0000	−0.3276	***	0.0707	0.0000	0.6094	***	0.0869	0.0000
EMIS_4	normal	−0.5970	***	0.0891	0.0000	0.9370	***	0.1123	0.0000	−0.6398	***	0.1062	0.0000	0.9791	***	0.1318	0.0000
EBILL/−100 EUR)	log-normal	2.8671	***	0.6364	0.0000	3.7137		0.8440	0.1258	2.7431	***	0.6171	0.0000	3.7496		0.8782	0.1100
AGE										0.0061	*	0.0032	0.0590				
HIGHEDU										0.0003		0.1180	0.9981				
MALE										−0.2176	*	0.1259	0.0839				
LOCAL										−0.1180		0.1363	0.3866				
Model diagnostics																	
LL at convergence	−1630.30									−1618.30							
LL at constant(s) only	−2472.66									−2472.66							
McFadden's pseudo-R^2	0.34									0.35							
Ben-Akiva-Lerman's pseudo-R^2	0.51									0.52							
AIC/n	1.50									1.50							
BIC/n	1.67									1.67							
n (observations)	2256									2256							
r (respondents)	376									376							
k (parameters)	65									69							

NA = Not available.
[a] Mean coefficients can be interpreted as marginal WTP values (€/year/household*100).

Table 5
Scenarios and compensating variations.

Scenario feature	Policy scenario 1: Moderate restrictions on hydropeaking	Policy scenario 2: High restrictions on hydropeaking	Policy scenario 3: Moderate restrictions on hydropeaking and decarbonized power systems	Policy scenario 4: High restrictions on hydropeaking and decarbonized power systems
ASC status quo + REGUL_M	1	1	1	1
Short-term regulations on hydropower production				
A lot more restrictions REGUL_H	0	1	0	1
Recreational use				
Improves somewhat RECREA_M	1	0	1	0
Improves a lot RECREA_H	0	1	0	1
Ecological state				
Improves somewhat ECOL_M	1	0	1	0
Improves a lot ECOL_H	0	1	0	1
Fish stocks				
Improves somewhat FISH_M	1	1	1	1
CO_2 emissions released into the air				
Increases by 2% EMIS_2	1	0	0	0
Increases by 4% EMIS_4	0	1	0	0
CV (€/year/household)	**13.87**	**2.68**	**40.12**	**62.38**

decarbonized system, hydropeaking is replaced with low-carbon production (e.g., wind, solar or nuclear power) and other solutions (e.g., large scale storage, electric vehicle batteries and demand response) that enables a 0% increase in CO_2 emissions. Currently, hydropeaking is likely replaced by carbon-emitting production (e.g., combusting combined heat and power production). The CV was calculated (see Eq. (4)) using the mean WTP values from Model 1 in Table 4.

In Table 5, a positive CV indicates a WTP for the presented policy scenario. All alternative policy scenarios induce positive welfare. Policy scenario 1, involving moderate restrictions on hydropeaking, results in greater welfare (€14) than in scenario 2, including high restrictions on hydropeaking (€3). This finding stems particularly from the high compensation requirement related to the 4% increase in CO_2 emissions. Scenario 4, with high restrictions on hydropeaking and decarbonized power systems, yields the highest welfare of €62, whereas scenario 3, with moderate restrictions, results in welfare of €40.

3.4. Interpreting correlations

Next, we focused on interpreting the estimated correlation matrices of the random coefficients and tested the procedure proposed by Mariel and Artabe [24]. Table 6 presents the correlation matrix without signs reversed non-cost attributes, whereas Table 7 displays the signs in the reversed version. The models were estimated in the preference space as was also done in Mariel and Artabe [24]; the full model outcomes are available in Appendix C Table C5.

Note that the positive correlations between the coefficients of non-monetary attributes cannot be interpreted according to the proposed rule. Only the negative correlation can be interpreted as resulting from behavioral aspects and apart from scale heterogeneity. In this study, the usage of the proposed procedure does not offer much valuable additional information on preference heterogeneity because a vast majority of the correlations were positive. Based on the procedure, we interpreted only the negative correlations between the coefficients of EBILL and ECOL_M, EBILL and ECOL_H, EBILL and FISH_M, and EBILL and EMIS_4, as well as the coefficients of ASC and EMIS_2, ASC and EMIS_4, and ASC and EBILL. The interpretation of the first three correlations must be made with a reversed sign because the sign of the monetary attribute is reversed. A positive correlation in these cases means that individuals with a high coefficient for ECOL_M, ECOL_H, and FISH_M have a low monetary coefficient, i.e., a higher valuation of these attributes. This is an expected finding. A negative correlation between the EBILL and EMIS_4 indicates that individuals with a high negative coefficient for EMIS_4 have a high monetary coefficient, i.e., a lower compensation requirement for this attribute. In addition, a negative correlation between the ASC and emissions attributes (EMIS_2 and EMIS_4) implies that individuals who dislike the status quo alternative are, on average, more likely to accept increases in CO_2 emissions.

4. Discussion and conclusion

The findings imply that most individuals prefer more rigorous restrictions on short-term hydropower regulation to mitigate local environmental impacts caused by hydropower generation in the Kemijoki

Table 6
Correlation matrix of random parameters (signs unchanged).

	ASC	REGUL_H	RECREA_M	RECREA_H	ECOL_M	ECOL_H	FISH_M	EMIS_2	EMIS_4	EBILL/−100 EUR
ASC	1.0000	0.1959	−0.3065	−0.3083	−0.3902	−0.2583	−0.3483	−0.2687	−0.1958	0.3305
REGUL_H	0.1959	1.0000	−0.3987	−0.4594	−0.1744	−0.1586	−0.1691	0.5384	0.5567	−0.3352
RECREA_M	−0.3065	−0.3987	1.0000	0.6169	0.5656	0.5780	0.6767	−0.3920	−0.0777	0.3529
RECREA_H	−0.3083	−0.4594	0.6169	1.0000	0.5808	0.3834	0.5969	−0.5450	−0.4284	0.2575
ECOL_M	−0.3902	−0.1744	0.5656	0.5808	1.0000	0.9457	0.7823	−0.3851	−0.3426	−0.2690
ECOL_H	−0.2583	−0.1586	0.5780	0.3834	0.9457	1.0000	0.6568	−0.3171	−0.2545	−0.2247
FISH_M	−0.3483	−0.1691	0.6767	0.5969	0.7823	0.6568	1.0000	−0.6020	−0.4301	−0.1522
EMIS_2	−0.2687	0.5384	−0.3920	−0.5450	−0.3851	−0.3171	−0.6020	1.0000	0.9015	−0.1805
EMIS_4	−0.1958	0.5567	−0.0777	−0.4284	−0.3426	−0.2545	−0.4301	0.9015	1.0000	0.1044
EBILL/−100 EUR	0.3305	−0.3352	0.3529	0.2575	−0.2690	−0.2247	−0.1522	−0.1805	0.1044	1.0000

Table 7
Correlation matrix of random parameters (reversed signs).

	ASC (sign reversed)	REGUL_H (sign reversed)	RECREA_M	RECREA_H	ECOL_M	ECOL_H	FISH_M	EMIS_2 (sign reversed)	EMIS_4 (sign reversed)	EBILL/−100 EUR
ASC (sign reversed)	1.0000	0.1075	0.2939	0.2121	0.3390	0.2293	0.2569	**−0.3710**	**−0.2983**	**−0.3911**
REGUL_H (sign reversed)	0.1075	1.0000	0.4133	0.4191	0.1346	0.1033	0.1400	0.5479	0.5349	0.3809
RECREA_M	0.2939	0.4133	1.0000	0.6129	0.6388	0.6323	0.6871	0.3928	0.0900	0.3720
RECREA_H	0.2121	0.4191	0.6129	1.0000	0.7022	0.4675	0.6336	0.5662	0.4603	0.1287
ECOL_M	0.3390	0.1346	0.6388	0.7022	1.0000	0.9393	0.7500	0.4275	0.3812	**−0.2387**
ECOL_H	0.2293	0.1033	0.6323	0.4675	0.9393	1.0000	0.6418	0.3727	0.3118	**−0.1689**
FISH_M	0.2569	0.1400	0.6871	0.6336	0.7500	0.6418	1.0000	0.5924	0.4206	**−0.2004**
EMIS_2 (sign reversed)	**−0.3710**	0.5479	0.3928	0.5662	0.4275	0.3727	0.5924	1.0000	0.9118	0.1469
EMIS_4 (sign reversed)	**−0.2983**	0.5349	0.0900	0.4603	0.3812	0.3118	0.4206	0.9118	1.0000	**−0.1210**
EBILL/−100 EUR	**−0.3911**	0.3809	0.3720	0.1287	**−0.2387**	**−0.1689**	**−0.2004**	0.1469	**−0.1210**	1.0000

River. In the DCE, respondents choose alternative policy situations more often than the current situation (64% vs. 36%). Moreover, respondents value fish stocks improvements, recreational use, and ecological conservation in that order. They are willing to pay an additional €29–54 per household per year in increased electricity bills to obtain improvements in these attributes. However, potential increases in CO_2 emissions are associated with a clear disutility, demonstrating an obvious trade-off between local and global hydropower externalities.

The WTP value of approximately €32 for the moderate improvement in fish stocks reflects the importance of recreational fishing in the Kemijoki River and the existence of fish stocks and option values. The fish stocks attribute was defined for the respondents in the survey as not containing Baltic salmon, but some respondents may have considered salmon along with non-migrating fish species when assessing the importance of the fish stocks attribute. Thus, some respondents may have overestimated the importance of the fish stocks. Previous studies on regulated rivers with existing fish passages in northern Sweden have found significant values associated with salmon in these rivers [13,39]. Likewise, recovering the natural life cycle of salmon is likely an important issue for many locals in the Kemijoki River area. Overall, the presence of fish stocks has been among the most valued attributes in previous studies on regulated rivers [22].

Respondents place a relatively high value on improvements in recreational use in the Kemijoki River. Similarly, Getzner [14] found that recreational value is higher on free-flowing sections than on dammed stretches of rivers for diverse recreational activities on the Mur River in Austria, and Immerzeel et al. [40] reported that recreation is among the most valued ecosystem services in Nordic catchments. On the other hand, recreational use might not be that important for all individuals. Our findings provide some evidence for this, as respondents' preferences for improvements in recreational use were heterogeneous. In contrast to our findings, the value of recreational opportunities was clearly lower than the value of fish protections in regulated rivers in Bavaria in Germany [41]. One potential explanation for this difference is that the study by Venus and Sauer [41] includes the construction of fish passage structures, which likely increase the value of fish protections.

The value of the ecological state was significant, although it was the least valued attribute among the negative externalities considered in our study. Numerous prior investigations have also found a significant value for the ecological state of rivers [22,42,43]. Our results are also in line with studies that have considered more broadly defined ecological attributes, such as ecological impacts [44], fauna and flora [17], and nature and landscapes [28]. In their meta-analysis on the external effects of hydropower, Mattmann et al. [7] found significant evidence for public aversion toward deterioration of the landscape, vegetation, and wildlife caused by hydropower projects, but only weak evidence of WTP for mitigating harmful effects. It is possible that people living near hydropower-regulated rivers are accustomed to the river's ecological state and hence do not value its improvement as much. In addition, consistent with risk aversion [45,46], people tend to value deterioration in absolute terms more than improvement in an attribute [47,48].

For the Kemijoki River, we found that respondents significantly value the mitigation of greenhouse gas emissions. Previous studies have obtained similar outcomes [28,44,49]. Mattmann et al.'s [7] meta-analysis on the valuation of hydropower externalities revealed that reducing greenhouse gas emissions is valued positively and significantly more in countries with a higher share of hydropower in electricity production, probably because the people in these countries may have a greater level of awareness regarding the positive effect of hydropower on greenhouse gas emissions. In Finland, the share of hydropower is not especially high in the total energy mix, but there has been much public debate on the role of hydropower as a balancing source and in mitigating climate change. It is therefore likely that Finnish people are aware of hydropower's emissions mitigation potential. This is also supported by our findings, as a vast majority of respondents thought that hydropower is a low-emission form of electricity generation (Fig. 2).

Our sample was not fully representative of the population. In particular, male respondents were overrepresented. We also found comparatively weak evidence that male respondents were more willing to accept hydropeaking regulation policies than females. Hence, to some extent, we may have overestimated the number of individuals who prefer stricter restrictions on hydropower generation in the Kemijoki River. In contrast, older respondents (overrepresented in our sample) were more willing to accept current policies, thereby tweaking potential bias in the opposite direction. Kataria [22] also used these two individual-specific factors to explain preference heterogeneity for environmental improvements in hydropower-regulated rivers in Sweden, but their influence was not statistically significant. When comparing preferences for the alternative operation regimes between the local population and individuals living outside the study area, we did not find statistically significant differences. This finding indicates that non-use values were of great importance in our study. It is also worth mentioning that we found four groups of respondents in the data that had differing preferences toward the studied attributes and operation regimes. Hence, when generalizing our results, it should be noticed that hydropeaking regulation policies involve both winners and losers, as has been also found in previous studies on environmental policies (e.g., [50]).

To gain further insight into preference heterogeneity, we elaborated on the correlations among the utility coefficients. We expected that the correlations would have an influence on the results of our DCE, as all the attributes (excluding costs) described different environmental factors. For example, respondents valuing improvements in the ecological state would likely value improvements in fish stocks. Thus, we used a model specification with correlated coefficients. The interpretation of correlations is not straightforward, because the correlation matrix of the utility coefficients captures both scale and behavioral heterogeneity [35]. To identify the influence of the latter, i.e., to better understand individual's preferences, we applied the procedure proposed by Mariel and Artabe [24]. In our data, this method did not help much in interpreting the correlations. Although the signs of the estimated correlations were as expected, the correlations were only negative in a few cases, enabling us to verify that they were due to behavioral phenomena. This was also the case in Frings et al. [51]. Notwithstanding, this issue requires more research, as preferences for environmental attributes can be correlated and model specifications with correlated parameters are increasingly used in the valuation literature [24].

Overall, our results reinforce the view that in regulated river systems policy-makers and river managers should consider alternative operation regimes which support river-specific needs and account for different (and sometimes contradictory) targets. Our results suggest that restricting hydropeaking would significantly increase the welfare of individuals due to the river's improved environmental state. On the other hand, positive externalities caused by a reduction in CO_2 emissions would decrease and create disutility. However, based on the policy scenario analysis, the benefits obtained from the improved state of the river's environment would probably exceed the disutility caused by the rise in CO_2 emissions. Given the current energy production mix in Finland including also combusting technologies, it might not be socially desirable to implement strong restrictions on hydropeaking due to the increase in CO_2 emissions. However, the situation may change in the near future as Finland is striving toward a carbon neutral electric system. This system requires economically viable and technically implementable low carbon balancing solutions such as non-combusting power production, storage technologies and demand response. As these solutions become mainstream, hydropower regulation should be re-evaluated. Another factor that may necessitate re-evaluation is foreseen climate change. It is likely that flow conditions in rivers will change in the foreseeable future with increasing likelihood of floods or droughts. There may also be changes in air and water temperatures. These changes can further affect ecosystems and recreational possibilities in river environments.

Although our findings provide new understanding on the valuation of hydropeaking externalities and policies, they are context specific with electricity market, energy infrastructure, regulation, climate, and environmental conditions for hydropower operation. The findings are, however, valuable for other areas sharing similar characteristics, like other areas in Finland or the Nordic countries, which are part of the same electricity market and have similarities in the climate, regulation, energy infrastructure and cultural background.

Based on our results, we conclude that the total welfare effect of decreased hydropeaking in the Kemijoki River system would be positive. However, we did not consider how a reduction in hydropeaking would affect revenues from hydropower generation. Our findings can be incorporated into a cost–benefit analysis to determine if the net environmental benefits would exceed the opportunity costs. Furthermore, policy-makers need to account for some other effects related hydropeaking restrictions, such as changes in tax revenues or local employment, which were not considered in this study. These are interesting avenues for future research.

CRediT authorship contribution statement

Enni Ruokamo: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Artti Juutinen:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Funding acquisition, Conceptualization. **Faisal Bin Ashraf:** Writing – review & editing, Visualization, Methodology, Conceptualization. **Ali Torabi Haghighi:** Writing – review & editing, Methodology, Conceptualization. **Seppo Hellsten:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Hannu Huuki:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Santtu Karhinen:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Maria Kopsakangas-Savolainen:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Hannu Marttila:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Eva Pongracz:** Writing – review & editing, Methodology, Conceptualization. **Atso Romakkaniemi:** Writing – review & editing, Methodology, Conceptualization. **Jan E. Vermaat:** Writing – review & editing, Methodology, Conceptualization.

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.

Data availability

The authors do not have permission to share data.

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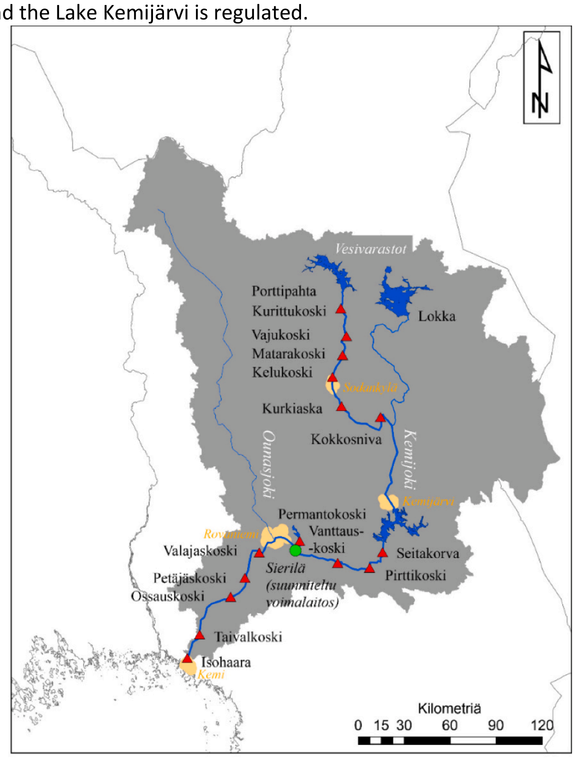
Appendix A. Questionnaire

A.1. Section A: Your relationship to the river kemijoki research area

The River Kemijoki is one of the largest rivers in Finland, which flows through Kemijärvi and Rovaniemi into the Gulf of Ostrobothnia. The Kemijoki watershed covers a significant part of Northern Finland. Many hydropower plants have been built on the River Kemijoki and its top branch in Kitinen. In addition, reservoirs have been built upstream of the river and the Lake Kemijärvi is regulated.



Map. *The River Kemijoki watershed (gray area), the power plants of the constructed main bed (red triangles) and the largest regulating basins (Lokka, Porttipahta and Kemijärvi). River areas whose flows are affected by power plant construction are marked on the map with a thick blue line. In the future, these areas will be called the main built-up riverbed of the River Kemijoki. The planned power plant in Sierilä is marked with a green circle. Some settlements along the main riverbed are marked in beige.*

A1. For what purpose have you used the River Kemijoki watershed (gray area on the map)? (Select more than one option if necessary.)

- ☐ I currently live in the area
- ☐ I have previously lived in the area
- ☐ I am currently visiting the area (e.g., camping and day trips)
- ☐ I have visited the area before
- ☐ I currently work in the area
- ☐ I have worked in the area before
- ☐ I've just traveled through the area
- ☐ Other, what?____________________________________
- ☐ I have not used or visited the River Kemijoki watershed area

A2. How far do you live from the main constructed riverbed of the River Kemijoki (the thick blue line on the map)? (Distances of less than a kilometer are given in such a way that, for example, 500m is marked as 0.5 km.)

__________ km

A3. Do you currently own one or more properties in the River Kemijoki watershed (see the gray area on the map)? (Select more than one option if necessary.)

- ☐ I own an apartment or house
- ☐ I own a holiday home
- ☐ I own a farm
- ☐ I own a forest property
- ☐ Other, what? ____________________
- ☐ I don't own properties in the area

A4. Have you conducted recreational activities (e.g., walking, swimming, fishing, skiing, other outdoor activities) on the constructed main riverbed of the River Kemijoki or near its shore (line of sight) during the last 12 months?

- ☐ Yes
- ☐ No → ***Go to Section B (next page).***

A5. How often have you conducted recreational activities on the constructed main bed of the River Kemijoki or near its shore (line of sight) during the last 12 months?

Approximately _________ times during the last 12 months

A6. What is the duration of your typical visit? _________ hours

A7. How far from your home is the place where you typically conduct recreational activities on the built-up main bed of the River Kemijoki or near its shore?

_________ km

A8. How do you typically travel to that place? (Choose only one option.)

- ☐ By walking
- ☐ By bike
- ☐ By car
- ☐ By bus
- ☐ By train
- ☐ By motorcycle
- ☐ Other, what? ____________________

A9. What is the area of the River Kemijoki main bed where you typically refresh yourself (see map)?

- ☐ Porttipahta – Kurittukoski
- ☐ Kurittukoski – Vajukoski
- ☐ Vajukoski – Matarakoski
- ☐ Matarakoski – Kelukoski
- ☐ Kelukoski – Kurkiaska
- ☐ Kurkiaska – Kokkosniva
- ☐ Kokkosniva – Kemijärven keskusta
- ☐ Kemijärven keskusta – Seitakorva
- ☐ Seitakorva – Pirttikoski
- ☐ Pirttikoski – Vanttauskoski
- ☐ Vanttauskoski – Rovaniemen keskusta
- ☐ Rovaniemen keskusta – Valajaskoski
- ☐ Valajaskoski – Petäjäkoski
- ☐ Petäjäkoski – Ossauskoski
- ☐ Ossauskoski – Taivalkoski
- ☐ Taivalkoski – Isohaara (Kemi)
- ☐ Isohaara (Kemi) – Perämeri
- ☐ Cannot say

A10. What do you typically do on the constructed main bed of the River Kemijoki or near its shore? (Select more than one option if necessary.)

- ☐ Walking
- ☐ Running
- ☐ Biking
- ☐ Nature observation, nature photography
- ☐ Berry or mushroom picking
- ☐ Collecting firewood
- ☐ Hunting
- ☐ Management of my property (e.g., forestry)
- ☐ Other, what? ____________________
- ☐ Cross-country skiing
- ☐ Riding a snowmobile
- ☐ Motor boating
- ☐ Riding a jet ski
- ☐ Rowing, canoeing
- ☐ Fishing
- ☐ Swimming
- ☐ Visiting a cultural heritage site
- ☐ Other stay in nature

A.2. Section B: Your views on hydropower production in Finland

Electricity production is increasingly based on low-emission forms of production, of which hydro, nuclear and wind power are important in Finland. Hydropower is utilized in electricity production as a balancing power, which means that hydropower production can be adjusted quickly as needed. Balancing power is needed now and in the future. With its help, it is possible to produce electricity even when weather-dependent wind and solar power are not available.

B1. How acceptable do you consider the production forms presented below in terms of Finnish electricity production?

	1 Not acceptable at all	2 Very little acceptable	3 Somewhat acceptable	4 Acceptable	5 Very acceptable	*Do not know*
a) Hydropower	☐	☐	☐	☐	☐	☐
b) Wind power	☐	☐	☐	☐	☐	☐
c) Nuclear power	☐	☐	☐	☐	☐	☐
d) Solar power	☐	☐	☐	☐	☐	☐

B2. Evaluate how the general statements related to hydropower production correspond to your opinions.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	*Do not know*
a) Hydropower is the most important source of domestic energy.	☐	☐	☐	☐	☐	☐
b) I don't like hydropower.	☐	☐	☐	☐	☐	☐
c) More hydropower is needed.	☐	☐	☐	☐	☐	☐
d) Hydropower is an important part of flood protection.	☐	☐	☐	☐	☐	☐

B3. Evaluate how the statements related to the possible effects of hydropower correspond to your opinions.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	*Do not know*
a) The hydropower plants strengthen the distinctiveness of the area.	☐	☐	☐	☐	☐	☐
b) Hydropower interferes with recreational fishing.	☐	☐	☐	☐	☐	☐
c) Hydropower improves possibilities for recreational use (e.g., swimming and boating).	☐	☐	☐	☐	☐	☐
d) Hydropower decreases the value of the land.	☐	☐	☐	☐	☐	☐
e) Hydropower causes significant damage to biodiversity.	☐	☐	☐	☐	☐	☐
f) Hydropower is financially too profitable for producers.	☐	☐	☐	☐	☐	☐
g) Hydropower significantly complicates the fishing industry.	☐	☐	☐	☐	☐	☐
h) Hydropower is low-emission.	☐	☐	☐	☐	☐	☐

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	*Do not know*
i) Hydropower causes significant damage to migratory fish stocks.	☐	☐	☐	☐	☐	☐
j) Hydropower will be an important form of energy production in the future.	☐	☐	☐	☐	☐	☐
k) Hydropower mitigates climate change.	☐	☐	☐	☐	☐	☐
l) Hydropower significantly increases the security of supply of the energy system.	☐	☐	☐	☐	☐	☐
m) Hydropower destroys the vegetation of the riparian zone.	☐	☐	☐	☐	☐	☐
n) Hydropower plants ruin the landscape.	☐	☐	☐	☐	☐	☐
o) Hydropower improves the local municipal economy.	☐	☐	☐	☐	☐	☐
p) Hydropower enables low-cost electricity.	☐	☐	☐	☐	☐	☐

Hydropower production is subject to a permit and the use of water is governed by many different laws. Hydropower companies are obliged to compensate for damages caused by hydropower (e.g., fisheries obligations). Hydropower companies also take voluntary measures to prevent harmful effects.

B4. Evaluate how the statements related to hydropower's harm-reducing actions and compensation matters correspond to your opinions.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	*Do not know*
a) The disadvantages of hydropower are so small that they do not need to be compensated or offset.	☐	☐	☐	☐	☐	☐
b) Hydropower companies should take more measures to compensate for the disadvantages of hydropower.	☐	☐	☐	☐	☐	☐
c) Hydropower companies should pay higher compensations for the disadvantages of hydropower.	☐	☐	☐	☐	☐	☐
d) The state should compensate the disadvantages of hydropower for the victims.	☐	☐	☐	☐	☐	☐
e) The environmental impact of large built river hydropower plants could be offset by the dismantling of power plant dams on small rivers.	☐	☐	☐	☐	☐	☐

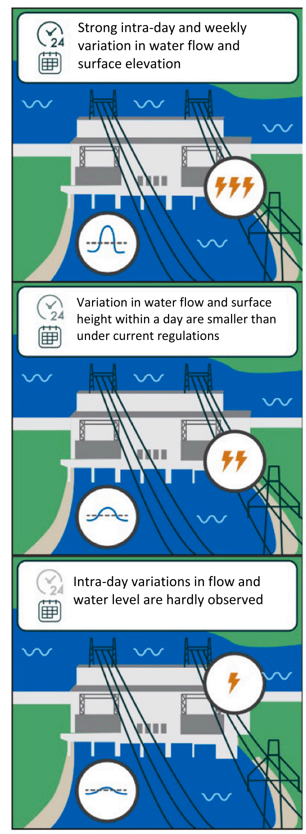
A.3. Section C: Effects of hydropower production and regulation of the River Kemijoki

A total of 21 hydropower plants have been built on the River Kemijoki watershed, and it is Finland's largest hydropower production area. The power plants in the River Kemijoki produce about a third of the domestic hydropower production.

Hydropower production as a balancing power often causes strong intra-day and weekly variations in the water flow and surface elevation. This is called <u>short-term regulation</u>. Variations in water flow and water surface elevation affect the river environment, biota, and recreation activities in the area. The need for balancing power and short-term regulation have increased in recent years and will continue to increase as intermittent wind and solar power production increases.

<u>Short-term regulations of hydropower production</u>: According to the current permit conditions, short-term regulations can be utilized efficiently in the hydropower production of the Kemijoki River. This causes strong intra-day and weekly variations in water flow and surface elevation. The intensity of the effects varies in different parts of the river. In the future, the Kemijoki River could have stronger restrictions on short-term regulations to reduce harmful local environmental impacts. Any new restrictions do not apply to seasonal variation or flood protection. Next, an option describing the current state of regulation and two possible regulation alternatives are presented:

- **Current state:** According to the current permit conditions, hydropower and short-term regulation is efficiently used as a balancing power to complement intermittent renewable energy production. This causes strong intra-day and weekly variations in water flow and surface elevation. For example, during low flow, the shoreline is exposed, whereas during high flow, the water level rises, and the water flow rate is high.
- **Somewhat more restrictions:** Short-term hydropower regulation will be moderately limited and the utilization as balancing power decreases from the current situation. Here, fluctuations in water flow and surface height within a day are smaller than under current regulations. The flow variation is reduced by approximately 50% compared to the present circumstances.
- **A lot more restrictions:** Short-term regulations of hydropower will be severely restricted, clearly reducing hydropeaking and balancing power use. Here, intra-day variations in flow and water level are hardly observed. On a weekly basis, some variation in water level is noted. The flow variation is reduced by about 80% compared to today.

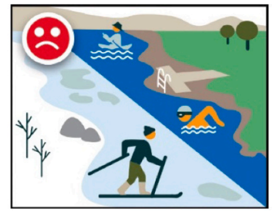


C1. Do the changes in the water elevation and flow of the Kemijoki River cause damage to you or your household?

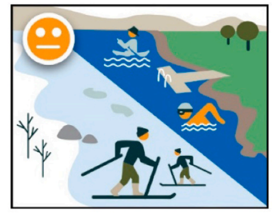
No damage at all	Some damage	A lot of damage	*Do not know*
☐	☐	☐	☐

<u>Recreational use</u>: Short-term regulations of hydropower may affect recreational use of the Kemijoki River. The intensity of the effects varies in different parts of the river. Flow fluctuations influence, among other things, the quality and usability of the beaches and safety for swimming, paddling, boating and fishing. Due to the strong variation in flow, fish move more, and angling may become more difficult. Fluctuations in the water level can damage fixed structures such as piers. Variation in water height and flow also impacts the durability of the ice cover in winter, impairing safe movement on ice. Next, an option describing the current state of recreation and two possible alternatives are presented:

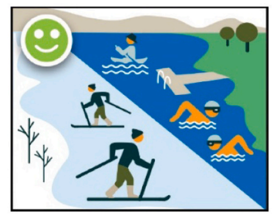
- **Current state:** Fishing, swimming, and other water activities can be tricky in certain places. The use of fixed beach structures can be difficult, and harm can result. In wintertime, ice cover can be weakened and become unpredictable in certain spots.



- **Improves somewhat:** Fishing becomes slightly easier. Swimming and navigating the waters is easier and safer. The use of fixed structures on beaches is a little easier, and they are less likely to be damaged. The ice cover is a bit more durable in the winter.



- **Improves a lot:** Flow changes are more predictable, making swimming and navigating the waters easy and safe. The fixed structures on the beach are not harmed and are more functional. In winter, the ice cover is stronger and safer.

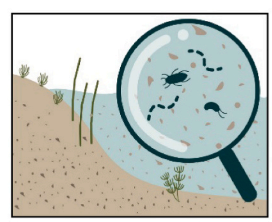


C2. How important do you consider to be that the damages of short-term regulation on the recreational use of the Kemijoki River would be reduced?

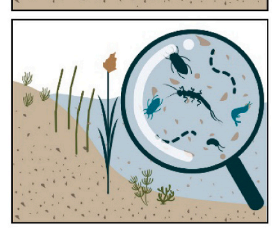
Not important at all	Somewhat important	Very important	*Do not know*
☐	☐	☐	☐

<u>Ecological state</u>: The short-term regulations of hydropower affect the ecological state of the Kemijoki River environment. The ecological state in this study is interpreted as the quality of the river's habitats and the abundance of plants and benthos that live there. Strong short-term regulations increase riverbed and riparian wear and weaken natural benthic and plant communities. Next, an option describing the current situation of the ecological state and two possible alternatives are presented:

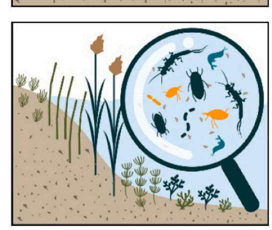
- **Current state:** The benthic fauna and flora of the river suffer from short-term regulations, and solids are released into the water.



- **Improves somewhat:** The living conditions of benthic animals and plants in the river are assumed to improve slightly, communities will be more abundant and fewer solids are released into the water.



- **Improves a lot:** The river's benthic and plant communities are close to the natural state and there are few solids in the water.

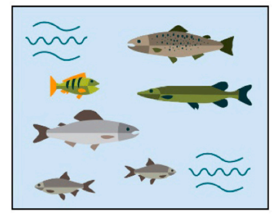


C3. How important do you consider to be that the damages of short-term regulation on the ecological state of the Kemijoki River would be reduced?

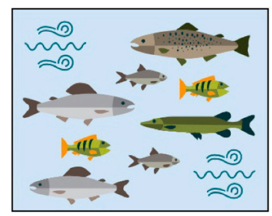
Not important at all	Somewhat important	Very important	*Do not know*
☐	☐	☐	☐

<u>Fish stocks</u>: Short-term regulations have a detrimental effect on the diversity and abundance of fish species in the Kemijoki River. Rapid and strong flow fluctuations reduce the abundance of almost all naturally reproducing fish species and degrade their habitats. Also, the stronger short-term regulations are, the less successful the stocking of artificially reared fish will be. Next, an option describing the current situation of the fish stocks and one possible alternative are presented:

- **Current state:** Common species in the slow-flowing river sections and lakes include pike, perch, pikeperch, roach, stocked brown trout, and stocked and introduced non-native rainbow trout. Species dependent on or benefiting from fast-flowing river habitat (grayling, whitefish) are scarce, and their natural reproduction is very low.



- **Improves somewhat:** Fish species such as grayling depending on flowing river sections would likely become more common, and natural reproduction would strengthen. Other fish species would also become more abundant, and stocking of artificially reared species is more successful.



C4. How important do you consider to be that the damages of short-term regulation on the fish stock of the Kemijoki River would be reduced?

Not important at all	Somewhat important	Very important	*Do not know*
☐	☐	☐	☐

<u>CO_2 emissions</u>: Restricting the short-term regulations of hydropower production on the Kemijoki River would increase the CO_2 emissions of Finnish electricity production. Hydropower generates low-emissions electricity and is especially useful when no intermittent wind power generation is available. Usually, alternative production forms cause more emissions than hydropower, thus meaning, that hydropower is beneficial in reaching the climate neutrality targets.

C5. Do you consider to be important that the short-term regulation of the Kemijoki River reduces CO_2 emissions?

Not important at all	Somewhat important	Very important	*Do not know*
☐	☐	☐	☐

<u>Increase in electricity bill</u>: Restricting the short-term regulations of hydropower production on the Kemijoki River would increase electricity production costs. Hydropower is a low-cost form of electricity production, which is replaced by more expensive production or electricity storage, such as electric batteries or gas turbines, when short-term regulation is limited. This can be reflected as an increase in the electricity bill for households.

C6. Would you be willing to pay a higher electricity bill for the mitigation of local environmental damages caused by the hydropower production?

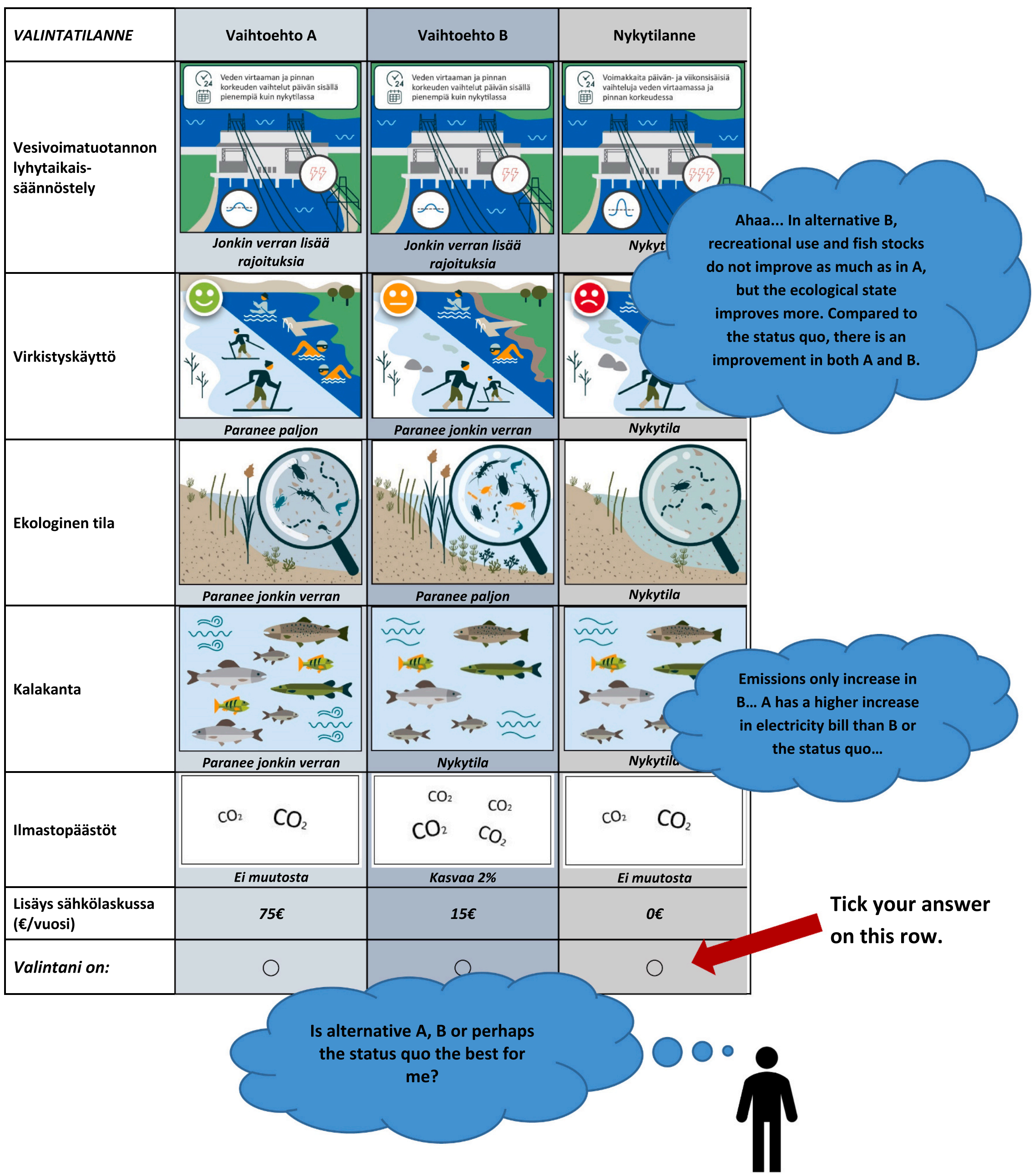
No	Maybe	Yes	*Do not know*
☐	☐	☐	☐

CHOOSE YOUR HYDROPOWER PRODUCTION OPTION

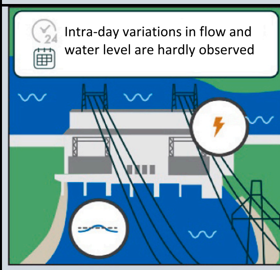
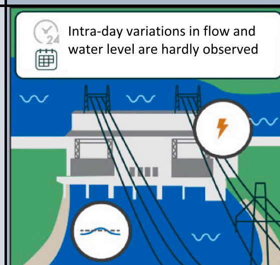
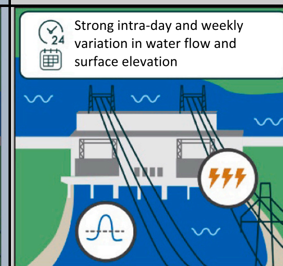
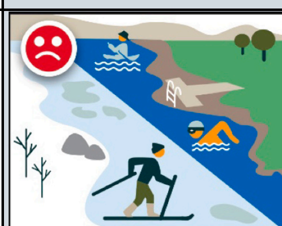
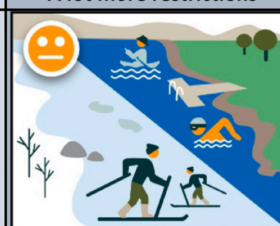
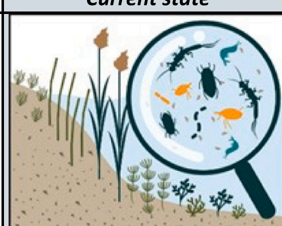
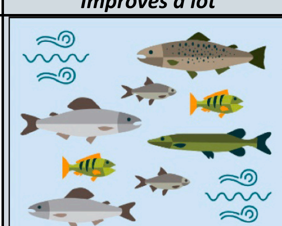
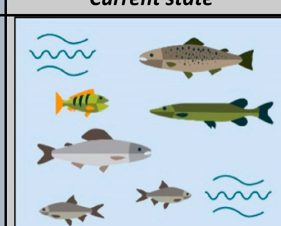
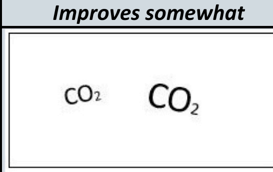
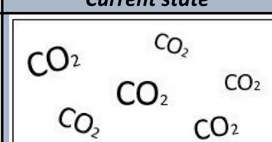
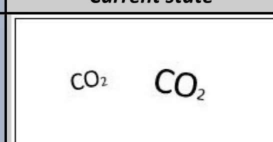
Next, you will be presented with six **choice tasks**, which describe the different options of hydropower production and its effects. In the alternative that describes the **status quo** the limitations of short-term regulation will not change and the effects of hydropower will remain unchanged. **Alternatives A and B** are hypothetical situations where the short-term, regulation of hydropower production is restricted more than at present and the effects of hydropower change.

The characteristics of the alternatives offered to you in the choice tasks vary. **Answer each choice task by comparing the alternatives with each other and choose the best option in your opinion.** Choice tasks present separate new situations, so your answer to the current choice task does not depend on how you have answered previous choice tasks. Keep in mind that there are no "right" or "wrong" choices, but everyone makes a choice according to their own personal views.

The choice task example below illustrates the selection situations starting on the next page.



Imagine the following choice tasks and choose the best option A, B or the status quo from your point of view in each choice task. Place a check mark at the option row to indicate your choice.

1. CHOICE TASK	Alternative A	Alternative B	Status quo
Short-term regulations of hydropower production	 *A lot more restrictions*	 *A lot more restrictions*	 *Current regulations*
Recreational use	 *Current state*	 *Improves somewhat*	 *Current state*
Ecological state	 *Improves a lot*	 *Improves somewhat*	 *Current state*
Fish stocks	 *Improves somewhat*	 *Current state*	 *Current state*
CO_2 emissions	 *No change*	 *Increases by 4%*	 *No change*
Increase in electricity bill (€/year)	*50€*	*15€*	*0€*
I choose:	○	○	○

*** Five more choice tasks included here ***

C7. When you made your choices, did you <u>not consider</u> some of the attributes?

No ☐ → ***Go to question C8.***

Yes ☐ Choose the attributes which you did <u>not consider</u>

- ☐ Short-term regulations of hydropower production
- ☐ Recreational use
- ☐ Ecological state
- ☐ Fish stocks
- ☐ CO_2 emissions
- ☐ Increase in electricity bill

C8. Did you choose the status quo alternative in ALL of the choice tasks?

No ☐ → ***Go to question C9.***

Yes ☐ because (Choose only one option.)

- ☐ Status quo alternative was truly the best one in all choice tasks
- ☐ I cannot afford to pay higher electricity bill than I currently pay
- ☐ I did not find the choice tasks believable
- ☐ The choice alternatives were too difficult
- ☐ I do not accept the increase in the electricity bill
- ☐ In my opinion, many of the attributes presented in the choice tasks were irrelevant
- ☐ In my opinion, households should not have to pay for actions that reduce the damages of hydropower production
- ☐ I did not like the survey
- ☐ I did not have enough information on the topic
- ☐ In my opinion, the choice tasks were missing some relevant attributes such as ______________________________
- ☐ Other reason, what? ______________________________

C9. Evaluate to what extent you agree or disagree with the following statement:
"I believe that the results of this kind of survey will be taken into account in the decision-making regarding the development of hydropower production."

1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	*Do not know*
☐	☐	☐	☐	☐	☐

C10. Do you support the construction of the Sierilä hydropower plant (see map)?

- ☐ Yes
- ☐ No
- ☐ Do not know

C11. ***Short-term regulation of hydropower production can be replaced either by other production technologies or <u>demand response</u> offered by households. In demand response, the household would give permission to the energy company to remotely control the home's space heating and/or domestic hot water heating. In remote load control, the heating units would be turned on and off as needed. Remote load control would be implemented in such a way that no changes would be noticed in the room temperature and/or warm domestic water.***
Would you be ready to participate in demand response like the one described above?

- ☐ Yes
- ☐ No
- ☐ Do not know

A.4. Section D: Environmental views

D1. Evaluate how the environmental claims presented below correspond to your opinions.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	*Do not know*
a) We are approaching the maximum number of people the earth can support.	☐	☐	☐	☐	☐	☐
b) People have the right to change the natural environment according to their needs.	☐	☐	☐	☐	☐	☐
c) When humans modify nature, it often causes disastrous consequences.	☐	☐	☐	☐	☐	☐
d) Human ingenuity guarantees that we do not make the Earth unlivable.	☐	☐	☐	☐	☐	☐
e) People heavily abuse the environment.	☐	☐	☐	☐	☐	☐
f) The earth has plenty of natural resources if we only learn how to utilize them.	☐	☐	☐	☐	☐	☐
g) Plants and animals have the same rights as humans.	☐	☐	☐	☐	☐	☐
h) The balance of nature is strong enough for nature to cope with the effects caused by modern industrialized countries.	☐	☐	☐	☐	☐	☐
i) Despite their special characteristics, humans are still subject to the laws of nature.	☐	☐	☐	☐	☐	☐
j) The so-called ecological crisis faced by people has been clearly exaggerated.	☐	☐	☐	☐	☐	☐
k) The Earth is like a spaceship with very little space and resources.	☐	☐	☐	☐	☐	☐
l) Man is meant to control nature.	☐	☐	☐	☐	☐	☐
m) The balance of nature is very delicate and easily upset.	☐	☐	☐	☐	☐	☐
n) Eventually, humans will learn to understand the workings of nature well enough to control it.	☐	☐	☐	☐	☐	☐
o) If things continue their current course, we will soon experience a major ecological disaster.	☐	☐	☐	☐	☐	☐

A.5. Section E: Background information

E1. Gender

- ☐ Female
- ☐ Male
- ☐ Other

E2. Year of birth _____________

E3. Education (Choose your highest level of education.)

- ☐ Basic education
- ☐ Secondary school (matriculation and/or professional degree)
- ☐ Lower tertiary degree
- ☐ Higher tertiary degree
- ☐ Other education, what? ____

E4. Number of persons in the household is ___________, of whom under the age of 18 is _____________

E5. Professional position

- ☐ Employee
- ☐ Entrepreneur
- ☐ Pensioner
- ☐ Other (e.g., unemployed, student)

E6. Profession (Choose your previous profession if you are e.g., retired.)

- ☐ Agriculture
- ☐ Forestry
- ☐ Construction
- ☐ Industrial production
- ☐ Energy supply
- ☐ Fishery
- ☐ Services
- ☐ Healthcare
- ☐ Education
- ☐ Public sector
- ☐ Environmental sector
- ☐ Other, what? ____

E7. Total household monthly income before tax (gross €/month)

- ☐ Under 2000€
- ☐ 2000€ – 3999€
- ☐ 4000€ – 5999€
- ☐ 6000€ – 7999€
- ☐ 8000€ – 9999€
- ☐ Over 10000€

E8. House type

- ☐ Detached or semi-detached house
- ☐ Terraced house
- ☐ Apartment building
- ☐ Other, what? ____

E9. Primary heating mode

- ☐ Electric heating
- ☐ Ground heating
- ☐ Air-to-water heat pump or exhaust air heat pump
- ☐ District heating
- ☐ Wood heating

- ☐ Other, what? ______________________________
- ☐ Do not know

E10. Your estimate of your household's annual electricity consumption

- ☐ Under 3000 kWh (typically: apartment building, no electric heating)
- ☐ 3000-8999 kWh (typically: terraced or detached house, no electric heating)
- ☐ 9000-14999 kWh (typically: terraced house, electric heating)
- ☐ 15000-21999 kWh (typically: detached house, electric heating)
- ☐ Over 22000 kWh (typically: a big detached house, electric heating)
- ☐ Do not know

E11. Current living environment

- ☐ Countryside or sparsely populated area
- ☐ Municipality center or city

E12. Postal code of permanent residence ______________

E13. What do you typically do in nature? (Select more than one option if necessary.)

- ☐ Walking
- ☐ Running
- ☐ Biking
- ☐ Nature observation, nature photography
- ☐ Berry or mushroom picking
- ☐ Collecting firewood
- ☐ Hunting
- ☐ Management of my property (e.g., forestry)
- ☐ Other, what? ______________________
- ☐ Cross-country skiing
- ☐ Riding a snowmobile
- ☐ Motor boating
- ☐ Riding a jet ski
- ☐ Rowing, canoeing
- ☐ Fishing
- ☐ Swimming
- ☐ Visiting a cultural heritage site
- ☐ Other stay in nature

Appendix B. Emissions and cost calculations

B.1. Emissions

When estimating potential changes in greenhouse gas emissions and consumers' billing costs we solve the optimal water reservoir operation of the hydropower generator scaled to match the aggregated generation capacity of the Kemijoki-river. The optimal hourly hydropower output in (MWh), h_t, is solved for all hours of year, $t \in \{1, 2, \dots, T = 8760\}$. We use year 2019 hourly electricity prices, p_t $(\frac{€}{MWh})$, as reward for hourly hydropower output [52]. We assume that the Kemijoki-river hydropower plants represents 35% of total annual hydropower generation in Finland. Using the aggregated hydropower generation data in Finland [53], we scale the hourly maximum and minimum hydropower generation levels, inflow, and reservoir level with this scaling factor of 0.35. The minimum hourly hydropower output, $\underline{h}$, is 158.6 (MWh) and the maximum hourly hydropower output, $\overline{h}$, is 938.7 (MWh). Hydropower reservoir level in energy units can vary between the minimum level, $\underline{s}$, of 253.0 (GWh) and the maximum level, $\overline{s}$, of 1701.2 (GWh). Total annual inflow energy, $\sum_{t=1}^{T} i_t$, is 4350.0 (GWh).

The simulated hydropower operator can offer up- and down-balancing energy once the hourly balancing requirement is realized. We assume the maximum up-balancing hydropower energy is 30% of the maximum hourly generation: $\overline{b}^{up} = 0.3\overline{h}$ [54]. The probability distributions, $P(Q^b)$ and $P(p^b)$, for balancing quantities, Q^b (MWh), and balancing prices, p^b $(\frac{€}{MWh})$, are calculated based on the 2015–2019 balancing market data [55].

Hydropower operator chooses hourly hydropower output, h_t, and balancing shares, $share_t^{up}$ and $share_t^{down}$, for each hour-of-year $t = \{1, 2, \dots, T = 8760\}$, so that the expected revenue from electricity and balancing markets is maximized:

$$\max_{h_t, share_t^{up}, share_t^{down}} E\left\{ \sum_{t=1}^{T} \gamma^{t-1} r\left(h_t, b_t, p_t, p_t^b, s_{t+1}\right) \right\}, \tag{B.1}$$

such that

$$\underline{s} \le s_{t+1} = s_t + i_t - h_t - b_t \le \overline{s}, \tag{B.2}$$

$$\underline{h} \le h_t + b_t \le \overline{h}, \tag{B.3}$$

$$\overline{b}^{up} = 0.3\overline{h} \tag{B.4}$$

$$\begin{cases} Q^b = 0 \Rightarrow b_t = 0 \\ Q^b > 0 \Rightarrow \overline{b}_t = min\left\{Q^b, min\{\overline{b}^{up}, \overline{h} - h_t\}, max\{0, s_t - \underline{s} + i_t - h_t\}\right\} \\ Q^b < 0 \Rightarrow \underline{b}_t = max\left\{Q^b, -(h_t - \underline{h})\right\}, \end{cases} \tag{B.5}$$

$$\begin{cases} Q^b > 0 \Rightarrow b_t = share_t^{up}\overline{b}_t, share_t^{up} \in [0.333, 1] \\ Q^b < 0 \Rightarrow b_t = share_t^{down}\underline{b}_t, share_t^{down} \in [0.333, 1], \end{cases} \quad (B.6)$$

$$r(q_t, b_t, p_t, p_t^b, s_{t+1}) = h_t p_t + b_t p_t^b. \quad (B.7)$$

The optimal hourly hydropower allocation problem is solved by using a dynamic programming algorithm, with reservoir level, s, and hour-of-year, t, as state variables:

$$V(s,t) = \max_{h,b} E\{r(h, b, p, p^b, s') + \gamma V(s', t+1)\}, \forall s \in S, t = \{1, 2, \ldots, T\}, \quad (B.8)$$

according to the conditions in Eqs. (B.2)–(B.7). Based on the reservoir level data, the initial reservoir level, s_1, is set to 1202 (GWh). The problem is solved through a backward recursion, where a large negative terminal value (fine) is if the reservoir level after the optimization period, s_{T+1}, is below the initial reservoir level s_1.

Under the restricted hydropower regulation scenarios, the hourly hydropower output limits in eq. (B.3) are tightened. In Scenario 1, hourly hydropower output can vary ±50% of the hourly inflow in energy units, i_t. In Scenario 2, hourly hydropower output can vary ±25% of the hourly inflow i_t.

Using the optimal policies, we model the reservoir allocation under the hydropower regulation scenarios'Current regulation' (BAU), 'Somewhat more restrictions' (Scenario 1) and 'A lot more restrictions' (Scenario 2). It is assumed that the restricted hydropower output is compensated with other conventional dispatchable electricity generation sources. In other words, we now have three alternative scenarios, BAU, Scenario 1 and Scenario 2, where the residual generation profiles differ.

To understand how the emissions differ across alternative residual generation profiles, it is essential to understand the relationship between them in the historical datasets. Graphical illustration of hourly emissions data [56] and electricity generation without hydropower [55] in Fig. B1 shows some evidence of possible non-linear relationship between them. Similar relationship has been demonstrated previously in Huuki et al. [57].

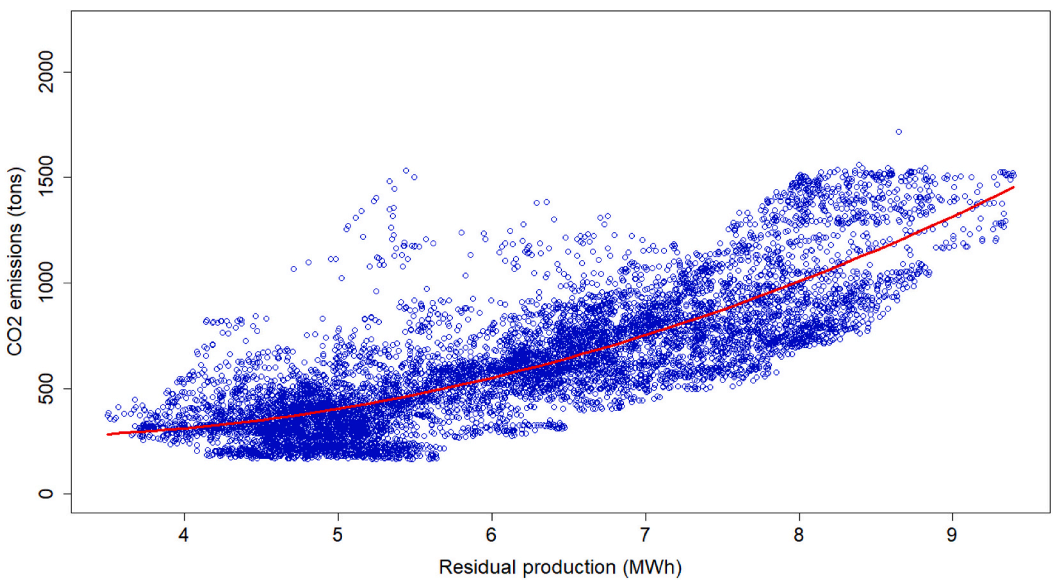


Fig. B1. Relationship between electricity generation without hydropower and CO_2 emissions.

Therefore, by utilizing emissions data from year 2019 [56], the hourly CO_2 emissions (Em_t) [tCO_2] were modelled as a function of hourly electricity generation [58] without hydropower output (q_t) [GWh] as follows:

$$Em_t = \alpha + \beta_1 q_t + \beta_2 q_t^2 + \varepsilon_t, \quad (B.9)$$

where $t = (1, \ldots, 8760)$ denotes hours in a year and ε_t is the error term. Heteroskedasticity and autocorrelation robust standard errors are applied. Results in Table B1 shows that the quadratic term q_t^2 is statistically significant so it is included in the model when predicting emissions with restrictions on hydropower output.

Table B1
Regression results.

	Dependent variable: tons of carbon dioxide emissions (tCO_2)	
	Model 1	Model 2
Intercept	−539.71*** (111.01)	476.59 (303.78)
q_t	189.46*** (19.65)	−149.18 (26.93)

(continued on next page)

Table B1 (*continued*)

	Dependent variable: tons of carbon dioxide emissions (tCO_2)	
	Model 1	Model 2
q_t^2		26.93***
		(9.37)
Adjusted R^2	0.650	0.671
Number of observations	8760	8760

Given that $\beta_2 > 0$, the second order derivative with respect to residual generation is positive:

$$\frac{dEm}{dq} = \beta_1 + 2\beta_2 q \Rightarrow \frac{d^2Em}{dq^2} = 2\beta_2 \geq 0. \tag{B.10}$$

Predicted hourly emissions with simulated residual generation profiles for Scenarios 1 and 2 are shown in Fig. B2. The volatility of residual generation increases because hydropeaking is reduced in Scenarios 1 and 2. The standard deviation of residual generation increases from 1.33 (GWh) in the BAU scenario to 1.51 (GWh) in Scenario 1 and to 1.56 (GWh) in Scenario 2.

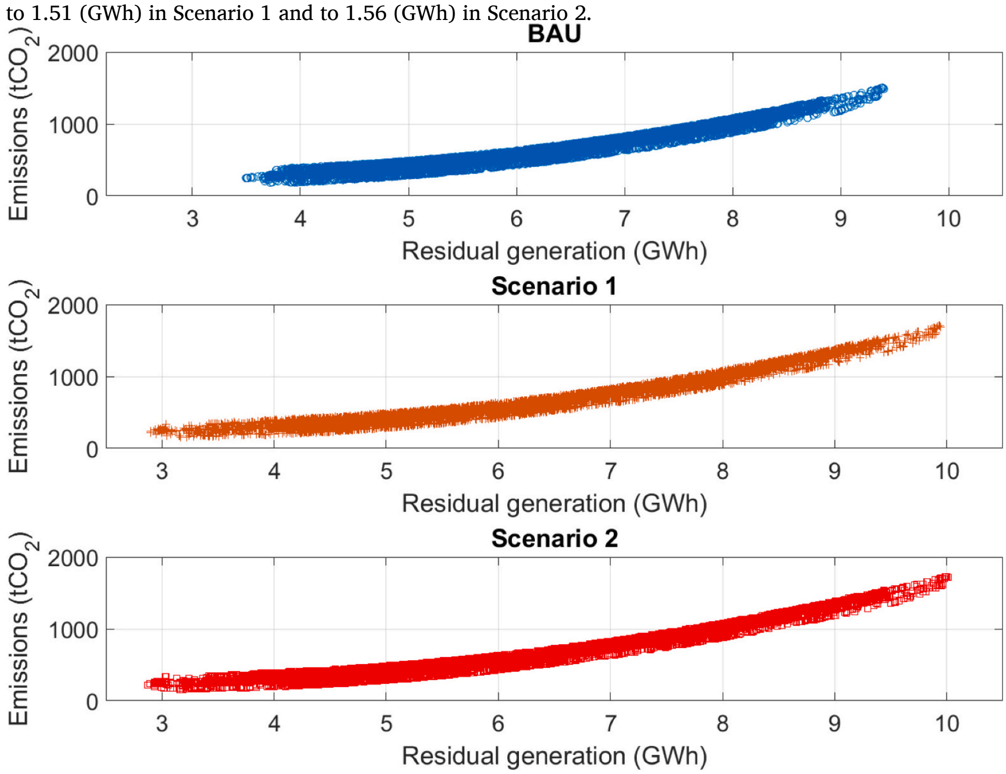


Fig. B2. Simulated hourly residual generation (GWh) and system emissions (tCO_2) for BAU scenario with no hydropeaking restrictions, Scenario 1 with moderate restriction on hydropeaking and Scenario 2 with strong restriction on hydropeaking.

As a result, system-wide CO_2 emissions are increased when the volatility of residual generation becomes higher (Table B2). In Scenario 1 the increase in total emissions is 2.08% relative to BAU scenario, and 2.73% in Scenario 2.

Table B2
Mean and standard deviation of residual generation over simulated hydropeaking scenarios.

	Average hourly emissions (tCO_2)	Total emissions ($MtCO_2$)	Change in total emissions (%)
BAU	623.1	5.459	–
Scenario 1	636.0	5.572	2.08
Scenario 2	640.2	5.608	2.73

In general, the increase in total emissions is caused by the mean-preserving spread [59] of residual generation q due to reduced hydropeaking. Consider residual generation q distributed according to $F(\bullet)$. Then, consider that the generation q is randomized further to $q + z$, where z has a distribution function $H_q(z)$ with a mean of zero, i.e., the mean of $q + z$ is q. Denote the second distribution by $G(\bullet)$. For a concave function $u(\bullet)$, it can be concluded that

$$\int u(q)dG(q) = \int\left(\int u(q+z)dH_q(z)\right)dF(q) \le \int u\left(\int (q+z)dH_q(z)\right)dF(q)$$

$$= \int u(q)dF(q). \tag{B.11}$$

Given that the system emissions with respect to residual generation $Em(\bullet)$ in convex (see Eq. (B.10)), it can be stated that

$$\int Em(q)dG(q) \ge \int u(q)dF(q), \tag{B.12}$$

where $G(\bullet)$ is a mean-reserving spread of $dF(q)$.

B.2. Costs

Price effects from restricting hydropower generation were examined in two markets – the day-ahead and balancing power markets. The residual generation profiles in Scenarios 1 and 2 are used to calculate the price effect in the day-ahead market arising from restricting hydropower generation. Similarly, as in calculating the emission impacts, other conventional dispatchable generation sources were used to fill in for the "missing" hydropower generation in the day-ahead market.

As more fuel is used, additional generation costs incur. The added fuel usage is calculated backwards from the estimated added CO_2 emissions as follows:

$$\text{Additional primary energy} = \frac{\left(\sum_{t=1}^{8760} Em_t^{SCE} - \sum_{t=1}^{8760} Em_t^{BAU}\right)}{\left(S_{peat} \times EF_{peat} + S_{coal} \times EF_{coal} + S_{gas} \times EF_{gas}\right)} \tag{B.13}$$

where fuel specific CO_2 emission factors (EF) are 381.2 gCO_2/kWh for peat, 340.6 gCO_2/kWh for hard coal and 198.1 gCO_2/kWh for natural gas. The shares (S) of fuels in fuel mix were 25% peat, 37.5% hard coal and 37.5% natural gas [58]. The resulting mean emission factor was 297.3 gCO_2/kWh. After determining the additional primary energy, we calculated the added cost from using it as:

$$\text{Added fuel cost} = \text{Additional primary energy} \times \left(S_{peat} \times P_{peat} + S_{coal} \times P_{coal} + S_{gas} \times P_{gas}\right), \tag{B.14}$$

where prices (P) for peat was 13.2 €/MWh, hard coal 14.7 €/MWh and natural gas 42.0 €/MWh [60]. The mean price was 24.6 €/MWh.

Additional cost from higher emissions compared to BAU scenario were calculated as:

$$\text{Additional emissions permit cost} = \left(\sum_{t=1}^{8760} Em_t^{SCE} - \sum_{t=1}^{8760} Em_t^{BAU}\right) \times P_{ETS}, \tag{B.15}$$

where EU ETS emissions allowance price P_{ETS} was set at 50 €/tCO_2.

In total the additional costs for a representative household with 20,000 kWh yearly electricity consumption would be 3.5 € in Scenario 1 and 4.6 € in Scenario 2.

Appendix C. Additional results

Table C1
Results of the MXL models in the WTP space without correlations.

		Means				Standard Deviations			
Variable	Dist.	Coeff.		St. Err.	P value	Coeff.		St. Err.	P value
ASC	normal	−0.3675	**	0.1670	0.0278	2.3433	***	0.2495	0.0000
REGUL_H	normal	−0.0802		0.0624	0.1985	0.4915	***	0.0955	0.0000
RECREA_M	normal	0.4089	***	0.0517	0.0000	0.0814		0.2359	0.7302
RECREA_H	normal	0.5624	***	0.0628	0.0000	0.4577	***	0.0762	0.0000
ECOL_M	normal	0.3903	***	0.0527	0.0000	0.0185		0.5949	0.9752
ECOL_H	normal	0.5091	***	0.0591	0.0000	0.3730	***	0.0916	0.0000
FISH_M	normal	0.5099	***	0.0432	0.0000	0.3627	***	0.0670	0.0000
EMIS_2	normal	−0.3163	***	0.0590	0.0000	0.2558	*	0.1434	0.0744
EMIS_4	normal	−0.6249	***	0.0758	0.0000	0.7022	***	0.1107	0.0000
EBILL/−100 EUR)	log-normal	1.1480	***	0.1467	0.0000	0.7159	***	0.1938	0.0002
Model diagnostics									
LL at convergence	−1720.85								
LL at constant(s) only	−2472.66								
McFadden's pseudo-R^2	0.30								
Ben-Akiva-Lerman's pseudo-R^2	0.49								
AIC/n	1.54								
BIC/n	1.59								
n (observations)	2256								
r (respondents)	376								
k (parameters)	20								

Table C2
Correlation matrix of random parameters in Model 1.

	ASC	REGUL_H	RECREA_M	RECREA_H	ECOL_M	ECOL_H	FISH_M	EMIS_2	EMIS_4	EBILL/−100 EUR
ASC	1.0000	0.1939	−0.5153	−0.5120	−0.5535	−0.5654	−0.6675	0.3427	0.5091	0.4756
REGUL_H	0.1939	1.0000	0.2337	0.0315	0.1193	0.0321	−0.0176	0.2767	0.3483	−0.1680
RECREA_M	−0.5153	0.2337	1.0000	0.6770	0.7053	0.7752	0.8457	−0.4327	−0.3763	−0.1967
RECREA_H	−0.5120	0.0315	0.6770	1.0000	0.8194	0.6982	0.7874	−0.7881	−0.7607	−0.4637
ECOL_M	−0.5535	0.1193	0.7053	0.8194	1.0000	0.9312	0.7620	−0.5211	−0.6969	−0.5720
ECOL_H	−0.5654	0.0321	0.7752	0.6982	0.9312	1.0000	0.7618	−0.4451	−0.6085	−0.4948
FISH_M	−0.6675	−0.0176	0.8457	0.7874	0.7620	0.7618	1.0000	−0.7582	−0.7342	−0.2794
EMIS_2	0.3427	0.2767	−0.4327	−0.7881	−0.5211	−0.4451	−0.7582	1.0000	0.8095	0.1169
EMIS_4	0.5091	0.3483	−0.3763	−0.7607	−0.6969	−0.6085	−0.7342	0.8095	1.0000	0.5477
EBILL/−100 EUR	0.4756	−0.1680	−0.1967	−0.4637	−0.5720	−0.4948	−0.2794	0.1169	0.5477	1.0000

Table C3
Correlation matrix of random parameters in Model 2.

	ASC	REGUL_H	RECREA_M	RECREA_H	ECOL_M	ECOL_H	FISH_M	EMIS_2	EMIS_4	EBILL/−100 EUR
ASC	1.0000	0.0328	−0.5910	−0.5892	−0.4994	−0.5418	−0.6573	0.3986	0.4986	0.5048
REGUL_H	0.0328	1.0000	0.1643	0.1533	0.2544	0.1500	0.0794	0.2668	0.2236	−0.2449
RECREA_M	−0.5910	0.1643	1.0000	0.7317	0.7054	0.7706	0.8704	−0.5187	−0.4779	−0.1940
RECREA_H	−0.5892	0.1533	0.7317	1.0000	0.8056	0.7464	0.8242	−0.7975	−0.8002	−0.5609
ECOL_M	−0.4994	0.2544	0.7054	0.8056	1.0000	0.9656	0.7824	−0.5352	−0.7140	−0.5262
ECOL_H	−0.5418	0.1500	0.7706	0.7464	0.9656	1.0000	0.7965	−0.5268	−0.6699	−0.4561
FISH_M	−0.6573	0.0794	0.8704	0.8242	0.7824	0.7965	1.0000	−0.7697	−0.7693	−0.3891
EMIS_2	0.3986	0.2668	−0.5187	−0.7975	−0.5352	−0.5268	−0.7697	1.0000	0.8543	0.3286
EMIS_4	0.4986	0.2236	−0.4779	−0.8002	−0.7140	−0.6699	−0.7693	0.8543	1.0000	0.6459
EBILL/−100 EUR	0.5048	−0.2449	−0.1940	−0.5609	−0.5262	−0.4561	−0.3891	0.3286	0.6459	1.0000

Table C4
Results of the LC model.

	Group 1			Group 2			Group 3			Group 4		
Variable	Coeff.	St. Err.	P value	Coeff.	St. Err.	P value	Coeff.	St. Err.	P value	Coeff.	St. Err.	P value
ASC	2.1864***	0.6245	0.0005	−2.1925***	0.3509	0.0000	−0.8431***	0.3221	0.0088	−3.7564**	1.5632	0.0163
REGUL_H	0.2382	0.3890	0.5403	0.1177	0.2728	0.6662	−0.4275*	0.2241	0.0565	0.1375	0.2196	0.5313
RECREA_M	−0.3218	0.5195	0.5356	1.4786***	0.3441	0.0000	0.7853***	0.2775	0.0047	0.5947**	0.2390	0.0128
RECREA_H	0.5999	0.4865	0.2175	1.4956***	0.3511	0.0000	0.9729***	0.3036	0.0014	1.0007***	0.2987	0.0008
ECOL_M	0.7047*	0.4240	0.0965	−0.4633	0.3916	0.2368	0.8417***	0.2932	0.0041	1.0001***	0.2591	0.0001
ECOL_H	−0.4785	0.6612	0.4693	−0.1158	0.3396	0.7331	1.4375***	0.3432	0.0000	1.1236***	0.2904	0.0001
FISH_M	−0.0119	0.4302	0.9779	0.2641	0.2146	0.2185	1.0230***	0.2111	0.0000	1.2250***	0.1641	0.0000
EMIS_2	−0.3725	0.4728	0.4308	−0.3031	0.2913	0.2981	−1.4901***	0.2443	0.0000	−0.0114	0.2058	0.9557
EMIS_4	−0.4698	0.5455	0.3891	0.1108	0.4698	0.8136	−3.2162***	0.4156	0.0000	−0.5739*	0.3481	0.0992
EBILL/100	−4.7485***	1.0815	0.0000	−5.1185***	0.6028	0.0000	−2.1738***	0.3937	0.0000	−0.3177	0.3215	0.3229
Class probability	0.2998***	0.0246	0.0000	0.2065***	0.0277	0.0000	0.1680***	0.0250	0.0000	0.3257***	0.0283	0.0000
Model diagnostics												
LL at convergence	−1656.00											
LL at constant(s) only	−2472.66											
McFadden’s pseudo-R^2	0.33											
AIC/n	1.51											
n (observations)	2256											
r (respondents)	376											
k (parameters)	43											

Table C5
Results of the MXL models in the preference space.

		Model 1 (signs unchanged)									Model 2 (signs reversed)							
		Means				Standard deviations					Means				Standard deviations			
Variable		Coeff.		St. Err.	P value	Coeff.		St. Err.	P value		Coeff.		St. Err.	P value	Coeff.		St. Err.	P value
ASC	n	−2.1617	***	0.5211	0.0000	5.1170	***	0.9033	0.0000	ASC (s. rev.)	2.0423	***	0.5063	0.0001	4.9290	***	0.8613	0.0000
REGUL_H	n	−0.1778		0.2653	0.5028	1.8809	***	0.3790	0.0000	REGUL_H (s. rev.)	0.2363		0.2561	0.3562	1.7588	***	0.3799	0.0000
RECREA_M	n	1.2459	***	0.2856	0.0000	1.6463	***	0.4578	0.0000	RECREA_M	1.2577	***	0.2992	0.0000	1.6269	***	0.4402	0.0000
RECREA_H	n	1.8584	***	0.3481	0.0000	2.0928	***	0.4902	0.0000	RECREA_H	1.7893	***	0.3563	0.0000	2.0394	***	0.4474	0.0000
ECOL_M	n	0.8910	***	0.3059	0.0036	1.8423	***	0.3968	0.0000	ECOL_M	0.8637	***	0.3085	0.0051	1.8693	***	0.3848	0.0000
ECOL_H	n	1.1071	***	0.3417	0.0012	2.4839	***	0.4496	0.0000	ECOL_H	1.1079	***	0.3432	0.0012	2.4914	***	0.4624	0.0000
FISH_M	n	1.2800	***	0.2901	0.0000	3.0456	***	1.1967	0.0000	FISH_M	1.2747	***	0.2910	0.0000	2.6696	***	0.8618	0.0000
EMIS_2	n	−1.1641	***	0.3214	0.0003	5.2035	**	2.1500	0.0173	EMIS_2 (s. rev.)	1.1328	***	0.3168	0.0003	3.9481	***	1.3426	0.0002
EMIS_4	n	−1.9391	***	0.4169	0.0000	6.6620	**	2.4953	0.0403	EMIS_4 (s. rev.)	1.9438	***	0.4095	0.0000	6.8061	**	2.4762	0.0465
EBILL/−100 EUR)	l	1.1336	***	0.2293	0.0000	2.9083	***	0.6627	0.0000	EBILL/−100 EUR)	1.1920	***	0.2193	0.0000	2.8793	***	0.6318	0.0000
Model diagnostics																		
LL at convergence	−1608.25										−1607.95							
LL at constant(s) only	−2472.66										−2472.66							
McFadden's pseudo-R^2	0.35										0.35							
Ben-Akiva-Lerman's pseudo-R^2	0.52										0.52							
AIC/n	1.48										1.48							
BIC/n	1.65										1.65							
n (observations)	2256										2256							
r (respondents)	376										376							
k (parameters)	65										65							

References

[1] Gaudard L, Romerio F. The future of hydropower in Europe: interconnecting climate, markets and policies. Environ Sci Policy 2014;37:172–81. https://doi.org/10.1016/j.envsci.2013.09.008.
[2] Vardanyan Y, Hesamzadeh MR. The coordinated bidding of a hydropower producer in three-settlement markets with time-dependent risk measure. Electr Pow Syst Res 2017;151:40–58. https://doi.org/10.1016/j.epsr.2017.05.007.
[3] Carolli M, Zolezzi G, Geneletti D, Siviglia A, Carolli F, Cainelli O. Modelling white-water rafting suitability in a hydropower regulated Alpine River. Sci Total Environ 2017;579:1035–49. https://doi.org/10.1007/s00027-015-0408-5.
[4] Hase B, Seidel C. Balancing services by run-of-river-hydropower at low reservoir amplitudes: potentials, revenues and emission impacts. Appl Energy 2021;294: 116988. https://doi.org/10.1016/j.apenergy.2021.116988.
[5] Ashraf FB, Haghighi AT, Riml J, Alfredsen K, Koskela JJ, Kløve B, et al. Changes in short term river flow regulation and hydropeaking in Nordic rivers. Sci Rep 2018;8 (1):17232. https://doi.org/10.1038/s41598-018-35406-3.
[6] Haghighi AT, Ashraf FB, Riml J, Koskela J, Kløve B, Marttila H. A power market-based operation support model for sub-daily hydropower regulation practices. Appl Energy 2019;255:113905. https://doi.org/10.1016/j.apenergy.2019.113905.
[7] Mattmann M, Logar I, Brouwer R. Hydropower externalities: a meta-analysis. Energy Econ 2016;57:66–77. https://doi.org/10.1016/j.eneco.2016.04.016.
[8] Bruno MC, Maiolini B, Carolli M, Silveri L. Short time-scale impacts of hydropeaking on benthic invertebrates in an alpine stream (Trentino, Italy). Limnologica 2010;40(4):281–90. https://doi.org/10.1016/j.limno.2009.11.012.
[9] Bartoň D, Brabec M, Sajdlová Z, Souza AT, Duras J, Kortan D, et al. Hydropeaking causes spatial shifts in a reproducing rheophilic fish. Sci Total Environ 2022;806(Pt 2):150649. https://doi.org/10.1016/j.scitotenv.2021.150649.
[10] Casas-Mulet R, Saltveit SJ, Alfredsen KT. Hydrological and thermal effects of hydropeaking on early life stages of salmonids: a modelling approach for implementing mitigation strategies. Sci Total Environ 2016;573:1660–72. https://doi.org/10.1016/j.scitotenv.2016.09.208.
[11] Moreira M, Hayes DS, Boavida I, Schletterer M, Schmutz S, Pinheiro A. Ecologically-based criteria for hydropeaking mitigation: a review. Sci Total Environ 2019;657:1508–22. https://doi.org/10.1016/j.scitotenv.2018.12.107.
[12] Hynes S, Hanley N. Preservation versus development on Irish rivers: whitewater kayaking and hydro-power in Ireland. Land Use Policy 2006;23(2):170–80. https://doi.org/10.1016/j.landusepol.2004.08.013.
[13] Håkansson C. Costs and benefits of improving wild salmon passage in a regulated river. Journal of Environmental Planning and Management 2009;52(3):345–63. https://doi.org/10.1080/09640560802703249.
[14] Getzner M. Importance of free-flowing Rivers for recreation: case study of the river Mur in Styria, Austria. Journal of Water Resources Planning and Management 2015;141(2):04014050. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000442.
[15] Weisser D. A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. Energy 2007;32(9):1543–59. https://doi.org/10.1016/j.energy.2007.01.008.
[16] Han SY, Kwak SJ, Yoo SH. Valuing environmental impacts of large dam construction in Korea: an application of choice experiments. Environmental Impact Assessment Review 2008;28(4):256–66. https://doi.org/10.1016/j.eiar.2007.07.001.
[17] Botelho A, Lina LG, Lígia MCP, Patrícia S, Sara S, Marieta V, et al. Using choice experiments to assess environmental impacts of dams in Portugal. AIMS Energy 2015;2(3):316–25. https://doi.org/10.3934/energy.2015.3.316.
[18] Tabi A, Wüstenhagen R. Keep it local and fish-friendly: social acceptance of hydropower projects in Switzerland. Renew Sustain Energy Rev 2017;68:763–73. https://doi.org/10.1016/j.rser.2016.10.006.
[19] Loomis JB. Measuring the economic benefits of removing dams and restoring the Elwha River: results of a contingent valuation survey. Water Resour Res 1996;32 (2):441–7. https://doi.org/10.1029/95WR03243.
[20] Loomis J. Quantifying recreation use values from removing dams and restoring free-flowing rivers: a contingent behavior travel cost demand model for the lower Snake River. Water Resour Res 2002;38(6):2. -1-2–8, https://doi.org/10.1029/2000WR000136.
[21] Robbins JL, Lewis LY. Demolish it and they will come: estimating the economic impacts of restoring a recreational fishery. JAWRA Journal of the American Water Resources Association 2008;44(6):1488–99. https://doi.org/10.1111/j.1752-1688.2008.00253.x.
[22] Kataria M. Willingness to pay for environmental improvements in hydropower regulated rivers. Energy Econ 2009;31(1):69–76. https://doi.org/10.1016/j.eneco.2008.07.005.
[23] Jones BA, Berrens RP, Jenkins-Smith HC, Silva CL, Carlson DE, Ripberger JT, et al. Valuation in the Anthropocene: exploring options for alternative operations of the Glen canyon dam. Water Resources and Economics 2016;14:13–30. https://doi.org/10.1016/j.wre.2016.02.003.
[24] Mariel P, Artabe A. Interpreting correlated random parameters in choice experiments. Journal of Environmental Economics and Management 2020;103: 102363. https://doi.org/10.1016/j.jeem.2020.102363.
[25] Räinä P, Ylikörkkö J, Puro-Tahvanainen A, Lindholm A, Karjalainen N, Pasanen J. Kemijoen vesienhoitoalueen vesienhoitosuunnitelma vuosille 2022–2027: Osa 1. Vesienhoitoaluekohtaiset tiedot [Internet] 2022 [cited 2022 May 12]. Available from: https://www.doria.fi/handle/10024/185060.
[26] Ashraf FB, Torabi Haghighi A, Marttila H, Kløve B. Assessing impacts of climate change and river regulation on flow regimes in cold climate: a study of a pristine and a regulated river in the sub-arctic setting of northern Europe. J Hydrol 2016; 542:410–22. https://doi.org/10.1016/j.jhydrol.2016.09.016.
[27] Bergmann A, Hanley N, Wright R. Valuing the attributes of renewable energy investments. Energy Policy 2006;34(9):1004–14. https://doi.org/10.1016/j.enpol.2004.08.035.
[28] Klinglmair A, Bliem MG, Brouwer R. Exploring the public value of increased hydropower use: a choice experiment study for Austria. J Environ Econ Policy 2015;4(3):315–36. https://doi.org/10.1080/21606544.2015.1018956.
[29] Brouwer R, Bliem M, Getzner M, Kerekes S, Milton S, Palarie T, et al. Valuation and transferability of the non-market benefits of river restoration in the Danube river basin using a choice experiment. Ecol Eng 2016;87:20–9. https://doi.org/10.1016/j.ecoleng.2015.11.018.
[30] Official Statistics of Finland. Educational structure of population - Statistics Finland [Internet] [cited 2023 Sep 13]. Available from: https://stat.fi/en/statistics/vkour; 2022.
[31] Official Statistics of Finland Statistics Finland - Education - Educational structure of population [Internet] [cited 2023 Sep 13]. Available from:. https://www.stat.fi/til/vkour/index_en.html; 2021.
[32] Train KE. Discrete choice methods with simulation. Cambridge University Press; 2009.
[33] Train K, Weeks M. In: Scarpa R, Alberini A, editors. Discrete choice models in preference space and willingness-to-pay space. Dordrecht: Springer; 2005. p. 1–16 (Applications of Simulation Methods in Environmental and Resource Economics). Available from: https://doi.org/10.1007/1-4020-3684-1_1.
[34] Daly A, Hess S, Train K. Assuring finite moments for willingness to pay in random coefficient models. Transportation 2012;39(1):19–31. https://doi.org/10.1007/s11116-011-9331-3.
[35] Hess S, Train K. Correlation and scale in mixed logit models. Journal of Choice Modelling 2017;23:1–8. https://doi.org/10.1016/j.jocm.2017.03.001.
[36] Hess S, Rose J. Can scale and coefficient heterogeneity be separated in random coefficients models? Transportation 2012;39(6):1225–39. https://doi.org/10.1007/s11116-012-9394-9.
[37] Hanemann WM. Applied Welfare Analysis with Qualitative Response Models [cited 2022 Jul 7]; Available from: https://escholarship.org/uc/item/7982f0k8; 1982.
[38] Boxall PC, Adamowicz WL. Understanding heterogeneous preferences in random utility models: a latent class approach. Environ Resource Econ 2002;23(4):421–46. https://doi.org/10.1023/A:1021351721619.
[39] Håkansson C. A new valuation question: analysis of and insights from interval open-ended data in contingent valuation. Environ Resource Econ 2008;39(2): 175–88. https://doi.org/10.1007/s10640-007-9102-y.
[40] Immerzeel B, Vermaat JE, Riise G, Juutinen A, Futter M. Estimating societal benefits from Nordic catchments: an integrative approach using a final ecosystem services framework. PloS One 2021;16(6):e0252352. https://doi.org/10.1371/journal.pone.0252352.
[41] Venus TE, Sauer J. Certainty pays off: the public's value of environmental monitoring. Ecol Econ 2022;191:107220. https://doi.org/10.1016/j.ecolecon.2021.107220.
[42] Hanley N, Wright RE, Alvarez-Farizo B. Estimating the economic value of improvements in river ecology using choice experiments: an application to the water framework directive. J Environ Manage 2006;78(2):183–93. https://doi.org/10.1016/j.jenvman.2005.05.001.
[43] Andreopoulos D, Damigos D, Comiti F, Fischer C. Estimating the non-market benefits of climate change adaptation of river ecosystem services: a choice experiment application in the Aoos basin, Greece. Environ Sci Policy 2015;45: 92–103. https://doi.org/10.1016/j.envsci.2014.10.003.
[44] Jones BA, Ripberger J, Jenkins-Smith H, Silva C. Estimating willingness to pay for greenhouse gas emission reductions provided by hydropower using the contingent valuation method. Energy Policy 2017;111:362–70. https://doi.org/10.1016/j.enpol.2017.09.004.
[45] Kahneman D, Tversky A. Prospect theory: an analysis of decision under risk. Econometrica 1979;47(2):263–91.
[46] Tversky A, Kahneman D. Loss aversion in riskless choice: a reference-dependent model. The Quarterly Journal of Economics 1991;106(4):1039–61.
[47] Ahtiainen H, Pouta E, Artell J. Modelling asymmetric preferences for water quality in choice experiments with individual-specific status quo alternatives. Water Resources and Economics 2015;12:1–13. https://doi.org/10.1016/j.wre.2015.10.003.
[48] Juutinen A, Kurttila M, Pohjanmies T, Tolvanen A, Kuhlmey K, Skudnik M, et al. Forest owners' preferences for contract-based management to enhance environmental values versus timber production. Forest Policy Econ 2021;132: 102587. https://doi.org/10.1016/j.forpol.2021.102587.
[49] Kosenius AK, Ollikainen M. Valuation of environmental and societal trade-offs of renewable energy sources. Energy Policy 2013;62:1148–56. https://doi.org/10.1016/j.enpol.2013.07.020.
[50] Mäntymaa E, Artell J, Forsman JT, Juutinen A. Is it more important to increase carbon sequestration, biodiversity, or jobs? A case study of citizens' preferences for forest policy in Finland. Forest Policy and Economics 2023;154:103023. https://doi.org/10.1016/j.forpol.2023.103023.
[51] Frings O, Abildtrup J, Montagné-Huck C, Gorel S, Stenger A. Do individual PES buyers care about additionality and free-riding? A choice experiment. Ecological Economics 2023;213:107944. https://doi.org/10.1016/j.ecolecon.2023.107944.
[52] ENTSO-E Transparency Platform [Internet] [cited 2023 Sep 13]. Available from: https://transparency.entsoe.eu/; 2023.
[53] Finnish Environment Institute. Waterpower situation: Reservoir content and inflow energy. www.ymparisto.fi [Internet]. [cited 2023 Sep 13]. Available from: http://wwwi2.ymparisto.fi/i2/finergy/indexe.html; 2023.
[54] Pöyry. Demand and supply of flexibility. Final report. Demand and Supply of Flexibility. Available from: https://www.fingrid.fi/globalassets/dokumentit/fi/

sahkomarkkinat/kehityshankkeet/dalyve-fingrid_flexibility-study_final-report_v300-id-151641.pdf; 2018.

[55] Fingrid. Dataset - Fingridin avoin data [Internet] [cited 2023 Sep 15]. Available from: https://data.fingrid.fi/en/dataset/; 2023.

[56] Energy Authority. Data on hourly emissions from electricity generation in 2019. Data is not publicly available. Energy Authority Finland. 2019.

[57] Huuki H, Karhinen S, Böök H, Ding C, Ruokamo E. Residential solar power profitability with thermal energy storage and carbon-corrected electricity prices. Utilities Policy 2021;68:101157. https://doi.org/10.1016/j.jup.2020.101157.

[58] Electricity Production and Consumption - Energiateollisuus [Internet] [cited 2023 Sep 13]. Available from: https://energia.fi/en/statistics/electricity_statistics/electricity_production_and_consumption; 2023.

[59] Mas-Colell A, Whinston MD, Green JR. Microeconomic theory. New York: Oxford University Press; 1995.

[60] Official Statistics of Finland. Energy prices - Statistics Finland [Internet] [cited 2023 Sep 13]. Available from: https://www.stat.fi/en/statistics/ehi; 2023.