Supplementary Materials

All the indicators included in the MCA decisional tree in Aosta Valley have a common description form, which contains all the information characterizing the indicator. The main sections of the description form are: the name and the acronym of the indicator, its aim, a description including the algorithm which allows the indicator score calculation, the measurement unit, the procedure for the indicator elaboration, monitoring methods and standards, the utility function associated to the indicator; in addition, literature and normative references are indicated and, in the final part, possible limits and comments. Tables from S1 to S6 summarize the main features of the indicators considered in the final decisional tree in Aosta Valley (except the Index of river Habitat integrity – IH, which is fully described in the paper): reference criterion, aim, algorithm, unit, and utility function [1,2].

Furthermore, Tables from S7 to S11 show the assessment of stakeholders' feedbacks (collected during the TAB meetings of the Graines experimentation and of previous and ongoing case studies), for the five features described in the paper (subsection 2.5). For each feature, all the indicators considered in the MCA decisional tree have been evaluated, comparing initial and revised indicators, by means of one of the following judgements: bad, poor, moderate, good, or high. Besides, in the "Comments" column, a short summary of the reasons leading to the assignment of each judgement is reported.

Table S1. Main features of the "Energy Index" indicator

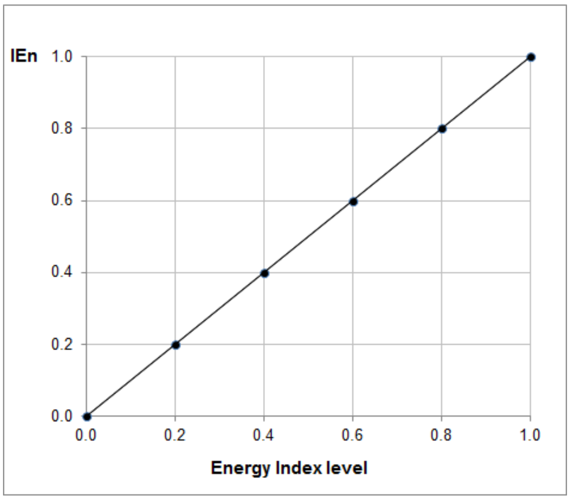
INDICATOR NAME	Energy Index
ACRONYM	IEn
REFERNCE CRITERION	Energy
AIM	Assessing the HP energy losses due to water flow releases
ALGORITHM	$IEn = E_i \;/\; E_0$ where IEn is the Energy Index [-], E_i is the energy [kWh] produced by applying the i-th alternative, and E_0 is the energy production according to the average annual nominal power of the HP plant [kWh]
UNIT	Dimensionless
UTILITY FUNCTION	

Table S2. Main features of the "Landscape Protection level" indicator

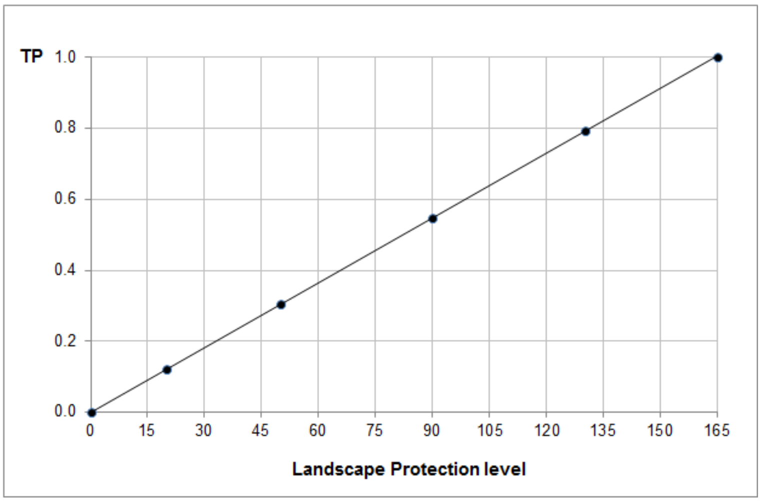
INDICATOR NAME	**Landscape Protection level**
ACRONYM	TP
REFERNCE CRITERION	Landscape
AIM	Assessing how the landscape perception changes according to the water flow releases
ALGORITHM	$TP = CF + RF + VEF$ where CF [-] is the Constraint Factor, calculated on the basis of national and regional landscape protection constraints and of the watercourse stream visibility, RF is the Release Factor, based on water flow releases downstream of the HP dam, and VEF is the Visual Elements Factor, calculated by landscape experts by visualizing a set of photos of the downstream stretch and identifying the flow alteration due to HP withdrawal [1].
UNIT	Dimensionless
UTILITY FUNCTION	

Table S3. Main features of the "Economic income including incentives" indicator

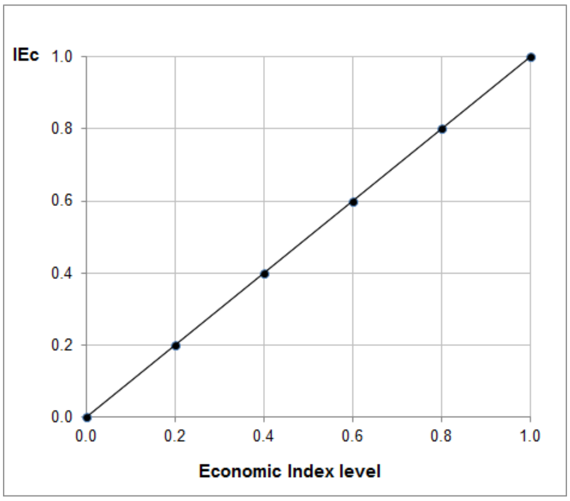
INDICATOR NAME	Economic income including incentives
ACRONYM	IEc – 1
REFERNCE CRITERION	Economy (HP producer income)
AIM	Assessing the economic losses (linked to HP energy losses) due to water flow releases, during the incentive period
ALGORITHM	The indicator is based on the "Economic Index" (IEc), considering the energy price during the incentive period (i.e. national incentives given to plants producing energy from renewable sources for the first 15 years of operation): $$IEc = \frac{E_i \cdot €_{en} - C_i}{E_0 \cdot €_{en} - C_0}$$ where E_i is the energy produced by applying the i-th alternative [kWh], $€_{en}$ is the energy sale price [€/kWh], C_i is the HP plant management and maintenance costs related to the i-th alternative [€], E_0 is the energy production according to the average power output of the HP plant [kWh], and C_0 is the HP plant management and maintenance costs related to E_0 [€].
UNIT	Dimensionless
UTILITY FUNCTION	

Table S4. Main features of the "Economic income without incentives" indicator

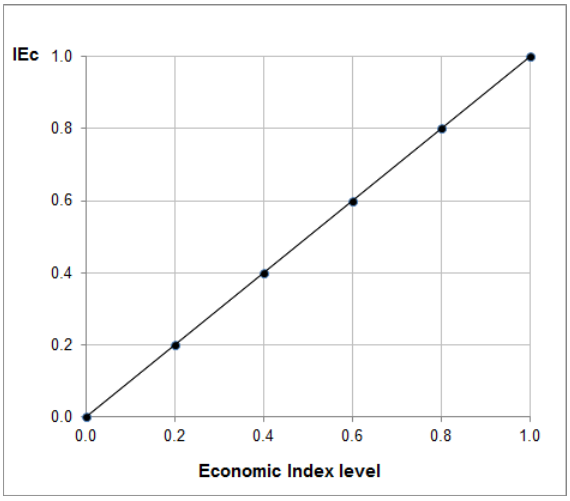
INDICATOR NAME	**Economic income without incentives**
ACRONYM	IEc – 2
REFERNCE CRITERION	Economy (HP producer income)
AIM	Assessing the economic losses (linked to HP energy losses) due to water flow releases, during the non-incentive period
ALGORITHM	The indicator, as IEc – 1, is based on the "Economic Index" (IEc) (see Table S3), but in this case the energy price is considered during the non-incentive period: $IEc = \frac{E_i \cdot €_{en} - C_i}{E_0 \cdot €_{en} - C_0}$
UNIT	Dimensionless
UTILITY FUNCTION	

Table S5. Main features of the "Services for the community" indicator

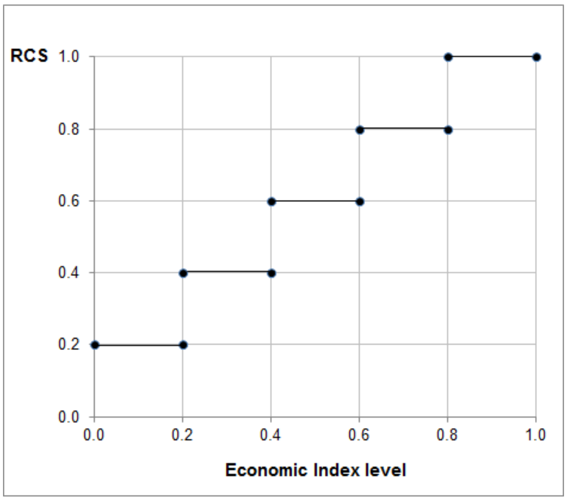
INDICATOR NAME	Services for the community
ACRONYM	RCS
REFERNCE CRITERION	Economy (Community income)
AIM	Assessing the services offered by the HP company to the community, according to flow releases
ALGORITHM	The indicator score is calculated on the basis of the "Economic Index" (IEc) (see Table S3) through the transformation given by the utility function: $RCS = f(IEc)$ It is based on the fact that a higher income for the HP company is directly associated to a larger income for the community living in the area, in terms of services and works which can be offered by the HP producer.
UNIT	Dimensionless
UTILITY FUNCTION	

Table S6. Main features of the "Financial income for the community" indicator

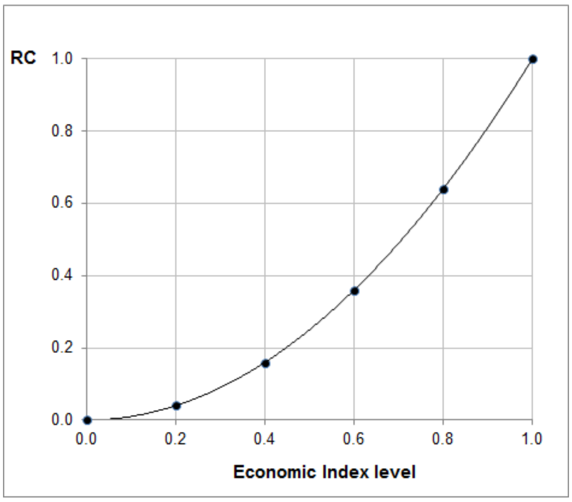
INDICATOR NAME	Financial income for the community
ACRONYM	RCS
REFERNCE CRITERION	Economy (Community income)
AIM	Assessing the financial income for the community due to fees paid by the HP producer, according to flow releases
ALGORITHM	The indicator score is calculated on the basis of the "Economic Index" (IEc) (see Table A3) through the following formula: $RC = IEc^2$ It is based on the assumption that a higher income for the HP company (due to a higher HP energy production) is directly associated to a larger financial return for the community living in the area
UNIT	Dimensionless
UTILITY FUNCTION	

Table S7. Stakeholders' feedbacks for the feature "Reactiveness to flow releases variation"

INDICATOR(S)	JUDGEMENT FOR THE PREVIOUS INDICATOR(S)	JUDGEMENT FOR THE REVISED INDICATOR(S)	COMMENTS
Energy indicator	good	high	The previous indicator was defined to identify flow releases effects mainly on medium and large HP plants (mostly public plants), while the new indicator has been conceived explicitly by the small HP producers involved in the TAB, taking into account specific plant characteristics (e.g. turbine typology, cut-off flows, absence of water intake, etc.).
Environmental indicator(s)	bad	high	The previous "WFD derived" indicators were not reactive to variations of flow release, while the IH indicator is directly related to watercourse discharge alterations.
Fishing indicator	moderate	high	The previous indicator was a hydromorphological proxy indicator, essentially based on expert judgement and not directly based on flow releases quantification, while IH is directly related to watercourse discharge alterations.
Landscape indicator	poor	high	The previous indicator did not vary significantly with flow releases, because it assigned a higher weight to regional landscape protection constraints, while visual effects of flow releases amounts were not quantified. On the contrary, the revised indicator assesses in a reliable way and step-by-step flow releases effects on the landscape.
Economic indicators	good	good	No relevant changes have been noticed.

Table S8. Stakeholders' feedbacks for the feature "Compliance with the legislative framework"

INDICATOR(S)	JUDGEMENT FOR THE PREVIOUS INDICATOR(S)	JUDGEMENT FOR THE REVISED INDICATOR(S)	COMMENTS
Energy indicator	moderate	moderate	Both the indicators quantify the outcomes at single-plant level. An indicator assessing the contribution of each plant to regional, national and European strategy for CO_2 emissions reduction would be very useful, but it is still missing
Environmental indicator(s)	good	high	The previous "WFD derived" indicators were required by the regional environmental regulations, based on the European Water Framework Directive. On the contrary, the IH index fully complies with a more recent national set of laws, i.e. DD 29/2017 [3] and DD 30/2017 [4], which define new methodological guidelines for water withdrawals planning, monitoring and assessment.
Fishing indicator	poor	high	The previous indicator was essentially based on expert judgement, while, at present, the IH index refers to a recent national set of laws.
Landscape indicator	good	good	No relevant changes have been noticed, because the same regional landscape protection constraints are considered for both the indicators elaboration.
Economic indicators	good	good	No relevant changes have been noticed.

Table S9. Stakeholders' feedbacks for the feature "Compliance with stakeholders' needs"

INDICATOR(S)	JUDGEMENT FOR THE PREVIOUS INDICATOR(S)	JUDGEMENT FOR THE REVISED INDICATOR(S)	COMMENTS
Energy indicator	good	high	Both the indicators generally well represent the HP producers' needs. However the revised indicator better quantifies the outputs of energy production for small HP plants.
Environmental indicator(s)	bad	high	The previous "WFD derived" indicators did not respond reliably to variations of flow releases and they also overestimated the ecological status, thus not allowing to properly quantify the effects of withdrawals on river ecosystem. On the contrary, the IH index assesses in a reliable and predictable way flow releases effects on the environment. It also allows to define, step-by-step, the effects of releases, even if limited in time and in amount (e.g. slightly increasing flow releases during low water periods to support river ecological functions).
Fishing indicator	good	high	The previous expert-based indicator usually well represented fishermen needs. However its compliance with the legislative framework was poor, while the IH index holds a clear reference to recent national normative, thus strengthening the related stakeholders' requests. Moreover, again, IH allows to define, step-by-step, the effects of releases, even if limited in time and in amount: for example, a slight increase of flow releases during low water periods can support fish population maintenance by enhancing available wet area for juveniles.
Landscape indicator	poor	high	In the previous indicator, neither visual effects of flow releases amounts nor the bypassed stretch visibility were quantified. On the contrary, the new indicator assesses in a reliable way and step-by-step flow releases effects on the landscape, including effects on landscape perception.
Economic indicators	good	good	Both the indicators generally well represent economic outcomes for HP producer and local community.

Table S10. Stakeholders' feedbacks for the feature "Transferability to different river contexts"

INDICATOR(S)	JUDGEMENT FOR THE PREVIOUS INDICATOR(S)	JUDGEMENT FOR THE REVISED INDICATOR(S)	COMMENTS
Energy indicator	moderate	good	The previous indicator had been defined to identify flow releases effects mainly on medium and large HP plants (mostly public plants). On the contrary, the new indicator better quantifies the outputs of energy production for small HP plants, which are more frequently concerned by sustainability assessments in Aosta Valley and in Italy.
Environmental indicator(s)	high	high	Both the indicators can be used in different river contexts and for different types of water withdrawals.
Fishing indicator	high	high	Both the indicators can be used in different river contexts and for different types of water withdrawals.
Landscape indicator	moderate	moderate	The landscape protection constraints considered for the elaboration of both the indicators are typically referred to the regional conditions and set of laws. To adapt the indicator to another regional river context, regulations and landscape features of the area should be taken into account.
Economic indicators	good	good	Economic and financial indicators can be easily reused in other river contexts in Italy.

Table S11. Stakeholders' feedbacks for the feature "Available dataset"

INDICATOR(S)	JUDGEMENT FOR THE PREVIOUS INDICATOR(S)	JUDGEMENT FOR THE REVISED INDICATOR(S)	COMMENTS
Energy indicator	moderate	moderate	Energy production datasets are easily available in case of existing HP plants, while for new HP plants this information can be obtained only by referring to reliable instream discharge data. Therefore, to implement such indicators, significant streamflow time series are compulsorily needed, thus requiring significant time extension, not only for data collection, but also for processing and validation.
Environmental indicator(s)	good	moderate	The previous "WFD derived" indicators were based on datasets that can be quite easily collected and elaborated. On the contrary, for IH, morphological data can be collected using a common gear (laptop and rangefinder) and an available software, while hydrological data collection requires several years of monitoring, increasing the time extension to obtain a reliable flow dataset.
Fishing indicator	high	moderate	The previous indicator was essentially based on expert judgement and thus data collection was not regular and organized. On the contrary, for IH, morphological data can be collected using common gear (pc and rangefinder) and available software, while hydrological data collection requires several years of monitoring, increasing the time extension to obtain a reliable flow dataset.
Landscape indicator	good	moderate	The previous indicator did not quantify visual effects of water withdrawals and it required less time to be implemented. On the contrary, the revised indicator assesses, in a reliable way and step-by-step, flow releases effects on landscape perception: therefore, the collection of pictures of the bypassed stretch, aligned with discharge data, is compulsorily require, thus increasing the time extension to obtain a reliable visual dataset.
Economic indicators	moderate	moderate	Economic datasets are available for HP producer in case of existing HP plants, while for new HP plants this information is reliable only if instream discharge data have been collected. Moreover, it may be possible that, for some financial data, trade secret can be applied. In addition, the quantification of economic outcomes at local community level could be difficult due to the lack of clear methodological references.

References

1. ARPA Valle d'Aosta. Analisi Multicriterio: schede tecniche indicatori (Multicriteria analysis: indicators description sheets), WPT3 – Pilot Case Study Dora Baltea river. Deliverable 3.2.1 of SPARE (Strategic Planning for Alpine Rivers Ecosystems), a cooperation project within the Alpine Space Program 2014-2020 (http://www.alpine-space.eu/projects/spare/it/home); September 2017.
2. Vassoney, E.; Mammoliti Mochet, A.; Comoglio, C. Multicriteria analysis for the assessment of flow release scenarios from a hydropower plant in the Alpine region. *Water Resour. Manag. Under review*.
3. Ministero dell'Ambiente e della Tutela del Territorio e del Mare. Decreto n. 29/STA del 13.02.2017 (di approvazione delle Linee Guida per le valutazioni ambientali ex ante delle derivazioni idriche, in relazione agli obiettivi di qualità ambientale dei corpi idrici definiti ai sensi della Direttiva 2000/60/CE), 2017.
4. Ministero dell'Ambiente e della Tutela del Territorio e del Mare. Decreto n. 30/STA del 13.02.2017 (di approvazione delle Linee Guida per l'aggiornamento dei metodi di determinazione del deflusso minimo vitale al fine di garantire il mantenimento, nei corsi d'acqua, del deflusso ecologico a sostegno del raggiungimento degli obiettivi di qualità ambientale dei corpi idrici definiti ai sensi della Direttiva 2000/60/CE), 2017.