



Cost-benefit analysis of mitigation and adaptation measures

Document authors:	Thijs Dekker (UoL), Jingyuan Di (UoL)
Document contributors:	Martin Dallimer (ICL), Julia Martin-Ortega (UoL), Lisette de Senerpont Domis (NIOO-KNAW)

Abstract

This deliverable relates to the economic assessment of adaptation and mitigation measures aimed at limiting the challenges posed by climate change in Drying River Networks (DRNs). Specifically, we present a lower bound estimate of the net present value of the benefits to society from achieving climate scenario SSP126 as opposed to SSP370 in three specific DRNs (Genal, Bükkosdi, and Lepsämäjoki). Due to limitations in available data and robust forecasting of how climate change affects delivery of relevant ecosystem services, this benefit assessment should be treated as illustrative and is restricted to the quantification of how a less severe climate scenario may result in reductions in i) the average number of drying days across reaches per year, ii) the duration of the drying period at the DRN level, and iii) changes in carbon emissions over the 2021-2050 period. The focus on articulating the monetary benefits of these alternative climate scenarios is driven by the lack of quantifiable dose-response relationships articulating how spatially targeted Nature-Based Solutions (NBS) may influence the delivery of ecosystem services and related attributes of DRNs, and accordingly how local populations may benefit from these Nature-Based Solutions specifically. From survey data, we do find that local populations would prefer NBS aimed at planting native trees and wider forest management, and that they show less support for NBS that would reintroducing meandering in rivers and streams.

Information Table

PROJECT INFORMATION	
PROJECT ID	869226
PROJECT FULL TITLE	Securing biodiversity, functional integrity and ecosystem services in DRYing riVER networks
PROJECT ACRONYM	DRYvER
FUNDING SCHEME	Horizon Europe
START DATE OF THE PROJECT	1st September 2020
DURATION	48 months
CALL IDENTIFIER	LC-CLA-06-2019

DELIVERABLE INFORMATION	
DELIVERABLE No AND TITLE	D5.3: Cost-benefit analysis of mitigation and adaptation measures
TYPE OF DELIVERABLE ¹	R
DISSEMINATION LEVEL ²	
BENEFICIARY NUMBER AND NAME	14. University of Leeds
AUTHORS	Thijs Dekker
CONTRIBUTORS	Jingyuan Di, Julia-Martin Ortega, Martin Dallimer, Lisette de Senerpont Domis
WORK PACKAGE No	WP5
WORK PACKAGE LEADER WP LEADER VALIDATION DATE	Thijs Dekker
COORDINATOR VALIDATION DATE	

¹ Use one of the following codes:

R=Document, report (excluding the periodic and final reports)
 DEM=Demonstrator, pilot, prototype, plan designs
 DEC=Websites, patents filing, press & media actions, videos, etc.
 OTHER=Software, technical diagram, etc.
 ORDP : Open Research Data Pilot

² Use one of the following codes:

PU=Public, fully open, e.g. web
 CO=Confidential, restricted under conditions set out in Model Grant Agreement
 CI=Classified, information as referred to in Commission Decision 2001/844/EC.

Table of Contents

Contents

Table of Contents	3
Table of Figures	4
Table of Tables	4
1. Introduction	5
2. Definition of the do-nothing scenario (SSP370)	6
3. Analysis of benefits of achieving SSP126	15
3.1 Changes in drying days, drying period and carbon emissions	16
3.1.1 Genal.....	16
3.1.2 Bökkosdi.....	17
3.1.3 Lepsämäjoki	18
3.2 Economic benefits over time and discounting	19
3.2.1 Changes in WTP for drying days and drying period over time	19
3.2.2 Forecasting the market price of carbon emissions over time	20
3.2.3 Discounting.....	20
3.3 Deriving the overall benefits of SSP126 relative to SSP370	21
4. Perceptions of Nature-Based Solutions	23
4.1 Identification of potential NBS measures	23
4.2 Preferences for the implementation of NBS.....	23
4.2.1 Genal.....	23
4.2.2 Bökkosdi.....	24
4.2.3 Lepsämäjoki	26
5. Reflections	26
6. References	28

Table of Figures

Figure 1: Presentation of the drying scenarios under climate change (SSP370) by 2050. Flow intermittence metric: ConD (additional number of drying days per year)	8
Figure 2: Average number of drying days (ConD) by reach by month between 1992-2021	10
Figure 3: Average number of drying days (ConD) by reach by month between 2041-2070 under SSP370	11
Figure 4: Increase in average number of drying days (ConD) by reach by month between 2041-2070 (SSP370) and present (1992-2021).....	12
Figure 5: Projections for ConD SSP126 in the Genal (left) and difference with SSP370 (right)	16
Figure 6: Projections for ConD SSP126 in the Bukkosdi (left) and difference with SSP370 (right)	18
Figure 7: Projections for ConD SSP126 in the Lepsämänjoki (left) and difference with SSP370 (right)	19
Figure 8: Assumed carbon price over the 2021-2050 period.....	20

Table of Tables

Table 1: Increase in the number of drying days per year until 20250 (SSP370)	9
Table 2: Cumulative carbon emissions (t C-CO ₂) during each of the selected hydrological phases for each DRN (total river length) considering both the emissions from flowing water (flow) and dry riverbed (dry) – Source: D3.9	14
Table 3: Cumulative carbon emissions (t C-CO ₂) during each of the selected hydrological phases for each DRN (total river length) considering both the emissions from flowing water (flow) and dry riverbed (dry) for SSP370 and averaged for period 2021–2060.	15
Table 4: Carbon emissions now vs SSP370 and SSP126 (avg over 2021-2060) in the Genal	17
Table 5: Carbon emissions now vs SSP370 and SSP126 (avg over 2021-2060) in the Bükösdi.....	18
Table 6: Net present value of monetary benefits of achieving SSP126 instead of SSP370.....	22
Table 7: Detailed NBS measurements of the three cases	24
Table 8: Preferences for NBS implementation in the Genal	25
Table 9: Preferences for NBS implementation in the Bükösdi	25
Table 10 Results of NBS preference of the Lepsämänjoki case.....	26

1. Introduction

This deliverable relates to the economic assessment of adaptation and mitigation measures aimed at limiting the challenges posed by climate change in Drying River Networks (DRNs). As per D4.3, climate change is forecasted to induce a welfare loss to society due to intensified drying. Some rivers are expected to shift from being fully perennial to having reaches experiencing flow intermittence, and drying patterns are expected to intensify, becoming longer, more frequent, and starting earlier in rivers already experiencing flow intermittence (e.g. Mimeau et al., 2024). Alongside this intensified drying, the increase in variability of weather patterns is also expected to amplify flood risks during periods of extreme rainfall (e.g. Madsen et al., 2014). Such fundamental changes to the state and functioning of DRNs inevitably influence the extent to which local populations and society interact with DRNs and thereby the extent to which they benefit from the delivery of Ecosystem Services (ES) and related attributes by DRNs (e.g. Datry et al., 2018, Pastor et al., 2022).

Even though changes in drying patterns may improve the delivery of certain existing ES or allow the delivery of new ES (e.g. new or increased recreational opportunities in dry riverbeds such as hiking), the overall expectation is that intensified drying will leave DRNs in a *'degraded state'*, where the overall annual flow of ES is lower than in the current state (e.g. Pérez-Silos et al., 2025). Accordingly, our working assumption is that climate change is associated with a welfare loss to society.

Building on this working assumption, a case can be made to implement adaptation and mitigation measures limiting the societal impacts of climate change. The economic benefits from implementing measures arise in the form of *'prevented climate damages'*, i.e. limiting the impacts of reductions in the delivery of ES and related attributes in DRNs. Since many benefits associated with adaptation and mitigation measures are not directly observable in markets, D4.3 implemented non-market valuation methods to express the benefits such measures bring to society in monetary terms (Ozdemiroglu and Hails, 2016).

From an economic point of view, a central question is the extent to which the benefits from implementing adaptation and mitigation measures outweigh the costs, and cost-benefit analysis (CBA) is a common tool to answer this question (Hurst, 2019, Glenk et al., 2014). In effect, CBA articulates whether implementing adaptation and mitigation measures can be considered as *'value for money'*. Additionally, CBA enables the contrasting of different policy scenarios, including the decision to take no action – labelled in Section 2 as the do-nothing scenario -, to decide on the best course of action. The comparability of the different policy scenarios rests on the assumption that all impacts of different policy interventions can be monetarily valued (Hanley and Barbier, 2009).

Despite having a general understanding of the challenges climate change poses to the functioning of DRNs, little is known about the effectiveness of spatially targeted interventions in limiting the impacts climate change has on the functioning of DRNs. DRYVER was by and large not designed to address this knowledge gap. Pengal (2025) provides a catalogue of nature-based solutions (NBS) which potentially have an adaptive and (or) mitigating capacity in relation to drying. A quantitative underpinning on the effectiveness of such solutions is, however, not provided because of the limited quantitative data available for establishing causal links between restoration measures, hydrological indicators, but also biodiversity metrics and flow intermittence indicators (see also Senerpont Domis et al., 2025).

The systematic literature review conducted by Senerpont Domis et al. (2025) underlines the articulated knowledge gap. Namely, the dose-response relationships of interest for their Bayesian Belief Network are either unstudied or based on limited and sometimes even conflicting evidence. Overall, the Bayesian Belief Network thereby illustrates the large amount of uncertainty associated with studying

the dose-response relationships of interest. In effect, this is a significant barrier to establishing credible ‘do something’ scenarios, i.e. alternative policy scenarios targeting different NBS, which can be evaluated and contrasted in CBA.

In the absence of quantifiable information regarding the effectiveness of NBS on the delivery of specific ecosystem services and related attributes, we have taken an alternative approach in this deliverable to describe an illustrative ‘do something’ scenario using information available in DRYvER. Namely, projections are available on how alternative climate scenarios affect drying patterns in the DRNs and subsequently a set of ecosystem services and related attributes. In this context, Section 2 defines climate scenario SSP370 as the ‘do-nothing’ scenario. Without larger climate action, this ‘regional rivalry’ scenario is probably the most likely scenario in which the world, and thus specific DRNs will end up in. If effective climate action is taken soon and persist over the next decades, i.e. very loosely interpreted as the ‘do something’ scenario here, then the DRNs maybe subject to a lesser extent of drying. Note that these reductions in emissions are not the result of locally implemented NBS, thus rendering a cost assessment of such measures somewhat obsolete.

Accordingly, we contrast the benefits for a restricted set of benefit categories where robust climate projections are available for that may arise at the DRN level from being able to restrict climate change to the more positive SSP126 scenario as opposed to the SSP370 scenario. These benefits are then used to identify ‘break-even’ points for the costs of potential interventions (i.e. the maximum costs that such interventions would have to be so that the interventions start generating net benefits to society). This is done for the three DRNs for which primary data on benefits from ES and related attributes have been gathered in DRYvER; namely: Genal in Spain, Bükkosdi in Hungary, and Lepsämäenjoki in Finland).

The deliverable is structured in the following way: Section 2 defines SSP370 as the do-nothing (i.e. business as usual) scenario where no interventions are implemented. Section 3 presents the benefit assessment associated with the more positive climate scenario SSP126, which can be interpreted a scenario where (local) adaptation and mitigation measures have been put in place and therefore the negative effects of climate change are lower. Section 4 reflects on the type of NBS considered to be relevant at the DRN level based on social perceptions by the local population. Finally, Section 5 reflects on the existing knowledge gaps.

2. Definition of the do-nothing scenario (SSP370)

Hurst (2019) highlights the importance of setting the baseline in CBA. The baseline, or the ‘do nothing’ scenario articulates what might happen if the intended policy intervention(s) do not go ahead. All potential policy solutions which are under consideration are generally contrasted against the ‘do nothing’ scenario, and the outcome of a CBA describes how well each policy solution performs relative to this scenario.

In the context of DRYvER, the ‘do nothing’ (DN) scenario corresponds to the projected degraded state of the DRN under climate change, as referred to in Section 1. It is important to associate the degradation of the functioning of DRNs with a notion of time, because the impacts of climate change are not happening overnight. Throughout DRYvER different climate scenarios have been considered (respectively SSP126, SSP370, and SSP585)³ over the 2015-2100 period. We consider it likely that some climate action will be taken soon, thereby ruling out SSP585 as the relevant DN scenarios. Similarly, it

³ <https://www.dkrz.de/en/communication/climate-simulations/cmip6-en/the-ssp-scenarios>

is unlikely that the SSP126 “green pathway” scenario is the most likely outcome to materialise. Accordingly, we treat SSP370 “regional rivalry” as the relevant scenario describing the DN scenario.

Inherently future projections are associated with a large degree of uncertainty and these uncertainties are becoming increasingly large the further projections are made into the future. The projections of changes in flow intermittence under alternative climate scenarios produced by WP1 (see Mimeau et al. (2023) and Mimeau et al. (2024)), are directly accessible through the interactive DRYvER Hydro application.⁴ WP1 thereby provides projections averaged over two distinct periods, respectively 2041-2070 and 2071-2100. The averaging of the intermittence scenarios over these time periods is advised due to the aforementioned uncertainties. Due to the propagation of uncertainty over time we select the 2041-2070 period and assume this scenario materialises by 2050. Moreover, the DRYvER hydro app describes the present situation over the period 1960-2021, and for consistency with the averaging period of 30 years, we describe the present flow intermittence conditions for 2021 by taking the average over the period 1992-2021. In other words, by examining the 2021-2050 period we adopt a 30-year time horizon during which the impacts of climate change, and benefits (and costs) of any policy interventions, on the functioning of DRNs materialise.

The emerging flow intermittence projections from WP1 articulate that the spatial extent and intensity of drying is increasing with the severity of the climate scenario evaluated. The severest impacts of climate change on flow intermittence are anticipated in the smaller tributaries of the DRNs, whereas many perennial reaches are likely to remain perennial. The maps presented in the Spanish and Hungarian non-market valuation surveys in D4.3 to elicit the benefits of the provisioning of ES and related attributes, articulate this spatial extent of increased drying under the SSP370 climate change scenario by 2050 (See Figure 1, and for more detail Figure 2 - Figure 4). Notably, the expected number of additional drying days is much higher in the Bükkosdi than in the Genal, but even in the Bükkosdi certain reaches of the river are predicted to remain perennial. For the third DRN, the Lepsämäjoki in Finland, the projected changes in drying patterns are much less severe, but Figure 1 again confirms that the largest impacts are anticipated in the smaller tributaries. It is these smaller tributaries where wet- and dry-phases that support an abundance of biodiversity, and changes in the length and intensity of these dry (and wet) phases may have significant impacts on the ecological system (e.g. Bunting et al., 2021, Sánchez-Montoya et al., 2022).

⁴ <https://dryver-hydro.sk8.inrae.fr/>

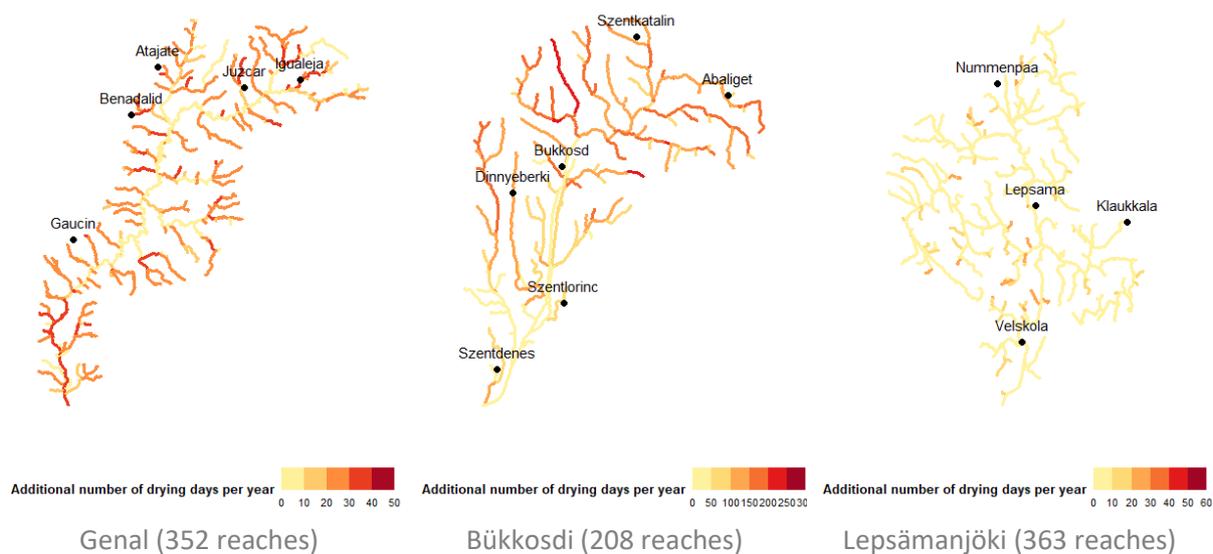


Figure 1: Presentation of the drying scenarios under climate change (SSP370) by 2050.
Flow intermittence metric: ConD (additional number of drying days per year)

Even though projections of flow intermittence are available at the reach level, the level of uncertainty associated with these future projections is substantive and the advice given by WP1 is not to focus on absolute changes in flow intermittence but on relative changes (i.e. the direction and categorical classification of, for example, weak and strong effects). For the purposes of CBA, it is however desirable to work with exact numbers where possible to quantify the impacts of climate change. We therefore acknowledge the described level of uncertainty in the flow intermittence projections at the reach level, and all the subsequent calculations should therefore be interpreted as illustrative.⁵ At the reach level, the number of projected drying (or flowing) days, respectively described by the variables *ConD* and *conF*, are available at the annual and monthly level (Mimeau et al., 2024). In this deliverable we work with *ConD* as our preferred measure of flow intermittence because this was also the unit of measurement in the non-market valuation surveys in D4.3 and the Bayesian Belief Network in D5.6.

Figure 2 describes the present number of drying days in the three primary DRN case study areas considered in WP4, respectively Genal, Bükkosdi, and Lepsämanjöki. At first sight, present drying patterns are remarkably different across the three DRNs. Where in the Genal, most reaches are dry for the whole months of July and August, current drying patterns are less severe in the Bükkosdi, and sporadic in Lepsämanjöki. The consistent pattern is, however, that the summer months are at present associated with the highest levels of drying in all three DRNs. Figure 3 shows that under the SSP370 DN scenario the number of drying days per reach increases, with the increase being most notable in the Bükkosdi and Lepsämanjöki DRNs.⁶ This is not surprising due to the high current levels of drying in the Genal. Figure 4 provides a clearer picture by looking into the additional number of drying days, where for the Genal it becomes evident that the drying period is extending beyond the summer months. That is months like May and October are now becoming increasingly dry. For the Bükkosdi, the average number of drying days increases drastically over the summer months and the height of the drying period can be experienced between June and October, perhaps even stretching into November. Table 1 presents the average number of drying days across the reaches per DRN by 2050

⁵ An alternative approach would have been to work at the DRN (i.e. network) level. The most relevant flow intermittence indicator available at the DRN level is the “Proportion of river length with intermittent conditions [%]” (*RelInt*). A downside of using a network indicator is that the spatial relation between NBS and their potential effects cannot be identified.

⁶ The climate scenarios are average across five global climate models.

under SSP370. Having defined the degree of flow intermittence at the start and the end of the 2021-2050 period, we need to make specific assumptions about the pace at which these changes will manifest themselves in the DRN. In the absence of reliable information over short time periods, we assume this relationship to be linear.

Table 1: Increase in the number of drying days per year until 20250 (SSP370)

DRN	Expected additional drying days averaged across reaches by 2050 (SSP370)
Genal	18.76 days
Bükkosdi	98.31 days
Lepsämäjoki	05.02 days

Since the spatial extent of drying differs, potential welfare losses due to increased drying will be experienced differently in different parts of the DRNs. Unfortunately, due to the small sample sizes and complexity of the nature of drying we haven't been able to identify a spatial relationship between willingness-to-pay (WTP) for reducing the number of drying days in given reaches of the river and the extent to which different parts of the population benefit from flowing (or drying) days in different reaches. As such, we can only assume that the local populations make equal use of each reach and therefore working with averages at the DRN level suffices for illustrative purposes in this deliverable. The spatial relationship between where respondents live and where they benefit from specific ES in DRNs remains an interesting topic for future research, whereas this has been studied in other contexts (e.g. Czajkowski et al., 2017, Toledo-Gallegos et al., 2021).

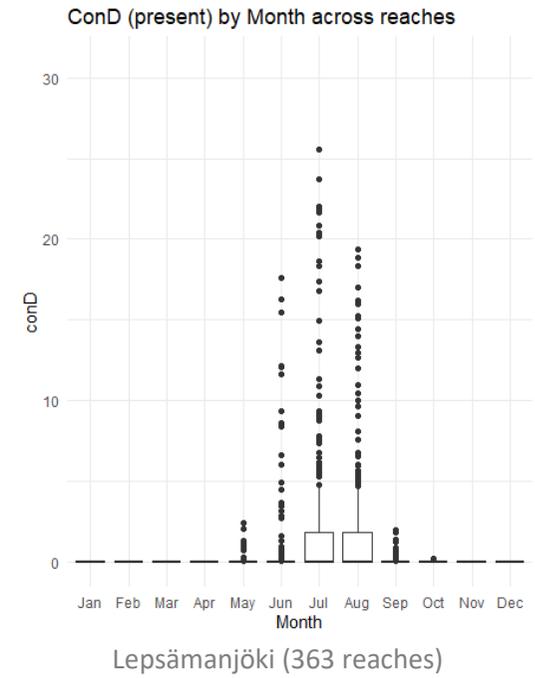
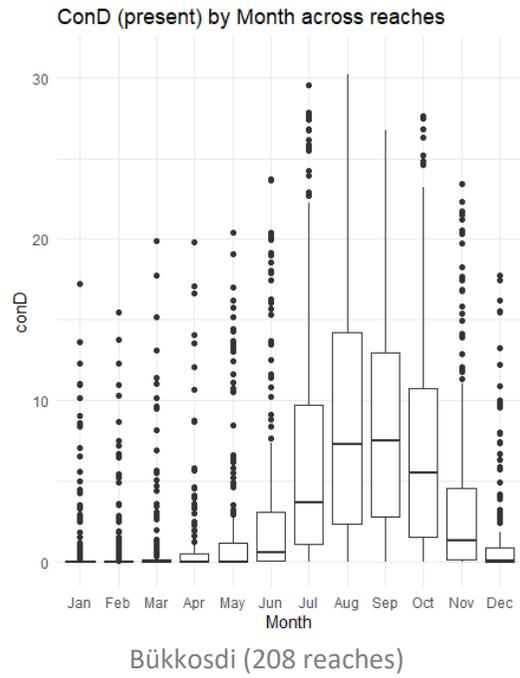
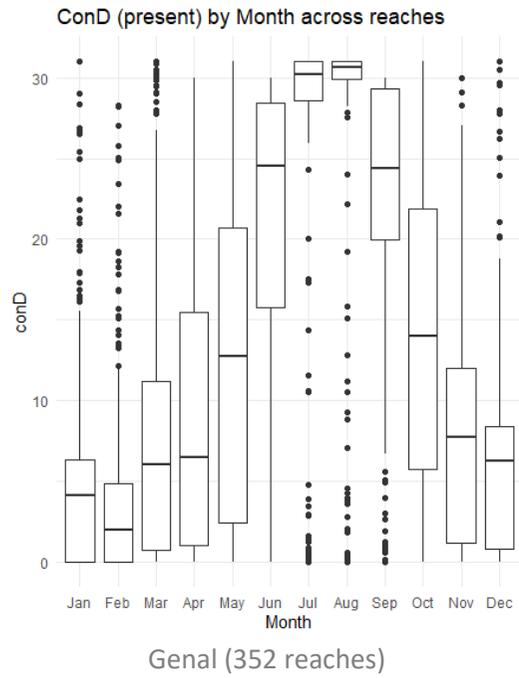
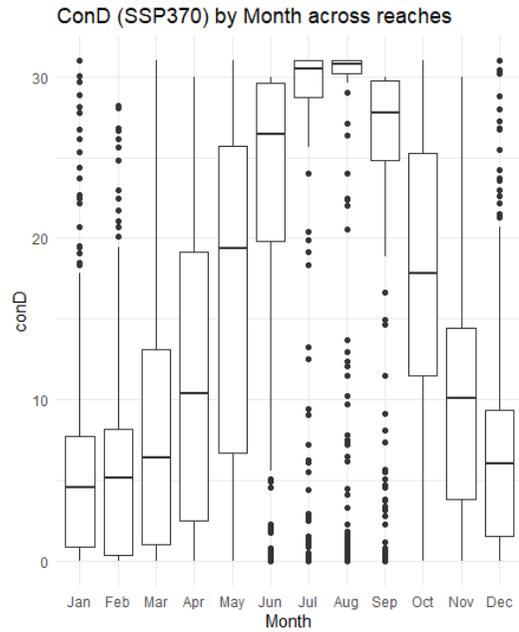
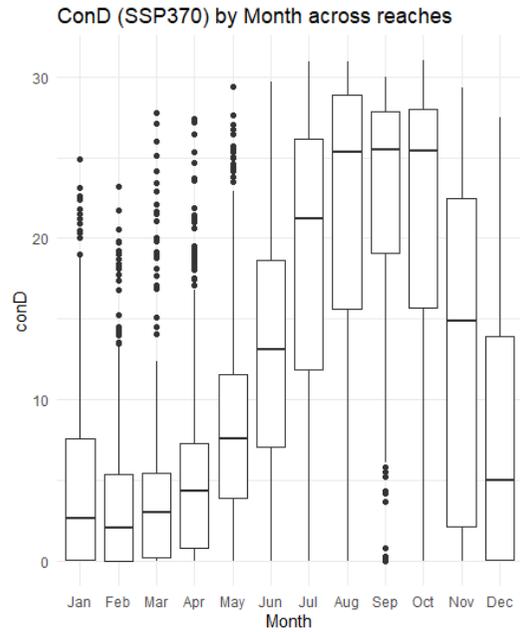


Figure 2: Average number of drying days (ConD) by reach by month between 1992-2021

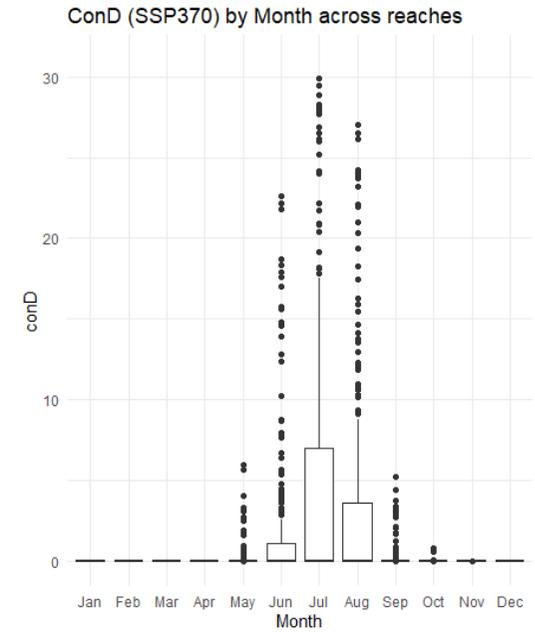




Genal (352 reaches)



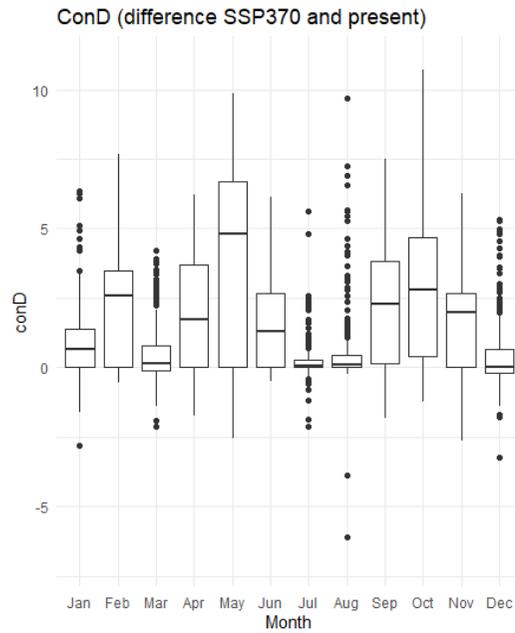
Bökkosdi (208 reaches)



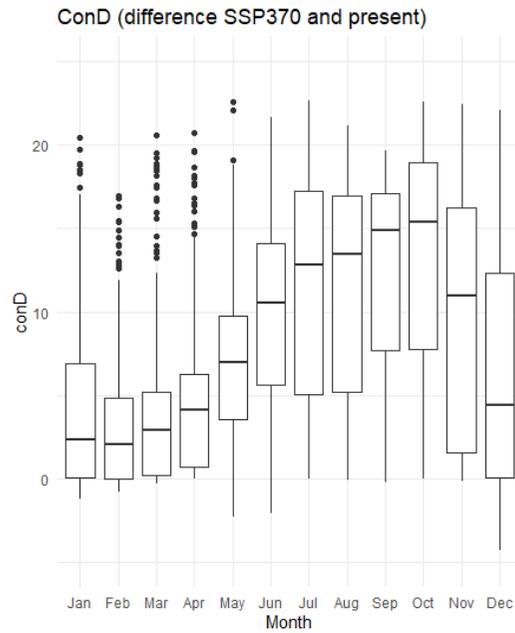
Lepsämanjöki (363 reaches)

Figure 3: Average number of drying days (ConD) by reach by month between 2041-2070 under SSP370

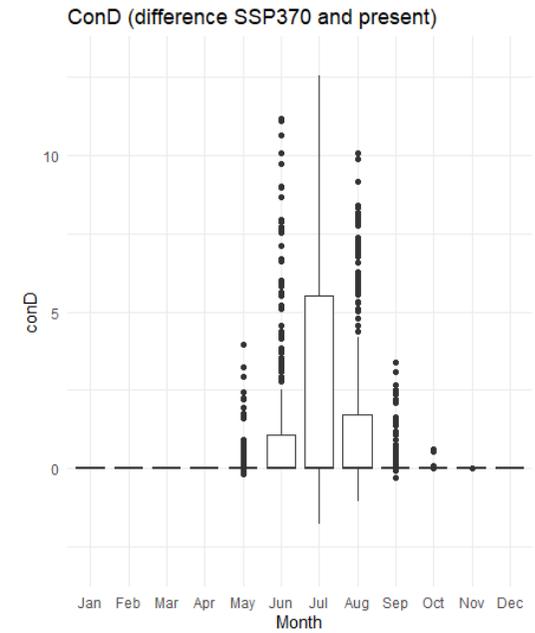




Genal (352 reaches)



Bökkosdi (208 reaches)



Lepsämanjöki (363 reaches)

Figure 4: Increase in average number of drying days (ConD) by reach by month between 2041-2070 (SSP370) and present (1992-2021).



In relation to biodiversity, Escobar-Camacho et al. (2025) established, using a dataset of 43 aquatic invertebrate metacommunities from drying river networks in Europe and South America, that in non-perennial reaches in Europe alpha-diversity (i.e. species richness and evenness) is lower than in perennial reaches, whereas beta-diversity (i.e. difference in species composition between different habitats) is higher in non-perennial than perennial reaches. The decline in alpha diversity with increased if further confirmed by Datry et al. (2014) who show that 1 family is lost for every 10% increase in flow intermittence, where flow intermittence is measured as the proportion of the year without surface water. Foulquier et al. (2024) furthermore, state that direct factors, such as nutrient and carbon availability, and indirect factors such as climate influence the local biodiversity of most taxa in non-perennial rivers. Specifically, limited resource availability and prolonged dry phases favour oligotrophic microbial taxa. Co-variation among taxa, particularly Bacteria, Fungi, Algae and Protozoa, explain more spatial variation in community composition than dispersal or environmental gradients. These finding suggests that biotic interactions or unmeasured ecological and evolutionary factors may strongly influence communities during dry phases, altering biodiversity responses to global changes. Jacquet et al. (2022) find that loss of patch connectivity decreases community recovery. Where local communities of flying organisms recovered more efficiently from drying events than organisms with strictly aquatic dispersal due to the capacity of the former group to overcome hydrological connectivity loss.

The evidence base for the biodiversity relationships established above largely relies on a space-for-time approach, where the intended relationships are based on geographical differences in biodiversity and flow intermittence hampering robust future projections as to how changes in intertemporal flow intermittence due to climate change affect biodiversity. Nevertheless, Chalmandrier and Munoz (2025) project biodiversity change for the six DRNs under future scenarios of changing environmental conditions. Macroinvertebrate and biofilm bacteria communities exhibit the most significant shifts under high and very high emission scenarios compared to low emission scenarios, and specifically the Bükkosdi is expected to experience the largest degree of biological community shifts. The main drivers of the decline in macroinvertebrate are increased drying frequency and decreased river discharge. Moreover, the modelling of Safe Operating Spaces (SOS) suggests that the Spanish and Hungarian DRN are particularly vulnerable to future climatic conditions. Due to the delay in developing these future projections, the impacts of increased flow intermittence under climate change could not be considered in this deliverable.

Rivers also play an important role in the processing of carbon and nitrogen, and associated fluxes of greenhouse gases (GHGs) both locally, and at the river network scale. Silverthorn et al. (2024), for example, find that positive temporal (time since rewetting) and spatial (presence of non-perennial reaches upstream) relationships exist between drying and particularly CO₂ and N₂O emissions. In a meta-analysis, Sepp et al. (2024a) identify that drying enhanced gross primary production (GPP) (under low flows) and CH₄ emissions, and decreased CO₂ and N₂O emissions but that desiccation (i.e. complete drying of streams) increased CO₂ emissions. However, the directional effect of drying was found to be inconsistent across climate zones, except for the Mediterranean climate zone where drying was showing a negative effect on both metabolism and GHG emissions. López-Rojo et al. (2024) find across the six DRNs considered in DRYvER that the annual contribution of dry riverbeds to total CO₂ emissions exceeded 50% in three of the six DRNs.

Broader evidence on the impact of (changes in) flow intermittence on ecosystem functioning has been identified in WP3, including the ability of streams to decompose leaf litter, have been identified, and ultimately these functions influence water quality and related metrics relevant to the Water Framework Directive (Sepp et al., 2024b). In this deliverable, our focus is restricted to changes in GHG

emission under climate changes as these are a direct measure of the regulating functions of a DRN and thereby represent an ecosystem service.

Sepp et al. (2024b) present patterns of carbon cycling-related ecosystem functions in the DRNs for present conditions and under climate change scenarios up to the year 2100. Consistent with the above evidence from the literature, the report highlights that with projected increases in drying intensity due to climate change, cumulative carbon emissions from DRNs are anticipated to increase as DRNs emit more during the drying phase – which according to WP1 are projected to increase in length and intensity over time. Consultations with the WP3 researchers deriving these estimates, again, indicate a low level of confidence in these projections due to the propagation of significant uncertainty in the WP1 drying projections.⁷ For illustrative purposes we make use of Tables 2 and 3 from Sepp et al. (2024b) describing total carbon emissions ($t-C-CO_2$) for the present conditions and averaged over the 2021-2060 period, respectively. The levels of emission are separated by the pre-drying, drying and post-drying phases and are studied at a smaller geographical resolution (see Figures 6-10 in the respective report), but to measure the impact of additional CO_2 emissions on society it does not matter when and where these emissions occur. Namely, carbon emissions are considered as a global externality where the negative impacts are experienced across the world irrespective of the location of emissions due to the cumulative nature of CO_2 in the atmosphere (Aldy et al., 2021). It should be noted that the CO_2 emissions associated with DRNs relative to anthropogenic emissions are very small and hence DRNs are only fractionally contributing to climate change.

Table 2 describes the current estimated carbon emissions per DRN ($t-C-CO_2$) and Table 3 summarises the same projections for the 2021-2060 period under the SSP370 scenario. The final column in Table 3 highlights that in the Genal and the Bükkösdi the annual emission levels are increasing by respectively 15.47 and 20.08 $t-C-CO_2$. For the Lepsämänjoki projections with respect to the impact of climate change on carbon emissions are unavailable. For reference, in 2021 total GHG emission, of which CO_2 accounts for roughly 80%, generated by economic activities of EU residents were a staggering 3.6 billion tonnes of CO_2 -equivalent again highlighting the minor role these emissions play in the greater scheme of things (Eurostat, 2021).

Table 2: Cumulative carbon emissions ($t-C-CO_2$) during each of the selected hydrological phases for each DRN (total river length) considering both the emissions from flowing water (flow) and dry riverbed (dry) – Source: D3.9

DRN	Pre-dry phase			Dry phase			Post dry phase			Overall Total
	Total	Flow	Dry	Total	Flow	Dry	Total	Flow	Dry	
Genal	123.04	69.37	53.67	120.35	17.46	102.89	56.54	32.83	23.7	299.93
Bükkösdi	58.82	23.56	35.26	107.82	13.17	94.65	52.68	14.77	37.91	219.32
Lepsämänjoki	162.3	151.38	10.92	143.48	96.26	47.23	210.47	192.64	17.83	516.25

⁷ The understanding of current GHG emissions from DRNs is considered to be highly accurate.

Table 3: Cumulative carbon emissions (t C-CO₂) during each of the selected hydrological phases for each DRN (total river length) considering both the emissions from flowing water (flow) and dry riverbed (dry) for SSP370 and averaged for period 2021–2060.

DRN	Pre-dry phase			Dry phase			Post dry phase			Overall	
	Total	Flow	Dry	Total	Flow	Dry	Total	Flow	Dry	Total	Difference
Genal	117.9	57.5	60.4	122.1	17.1	104.9	75.4	56.4	19	315.4	15.47
Bükkösdí	55.5	19.9	35.6	128.8	8.1	120.7	55.1	10.4	44.6	239.4	20.08
Lepsämánjoki	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

As part of this economic assessment, changes in carbon emissions will be converted into monetary values. To this end, we make use of the market price for carbon in the EU ETS (and its associated forecasts) – see Section 3.2.2.⁸ The market price for carbon emissions is measured in t/CO₂e and not in t/C-CO₂. To bring these metrics in the same unit of measurement, we multiply the amount of carbon (i.e. the final columns of Table 2 and Table 3) with 3.67. Again, we assume that the increases in carbon emissions over time will emerge at a constant rate.

We have covered the climate change projections for the number of additional drying days, the duration of the drying period, and the implications for biodiversity and climate change. Where relevant and possible, these projections are based on the WP1-WP3 projections. As alluded to by Senerpont Domis et al. (2025), the limitations of the harmonisation of data across work packages hampers the uptake of ecosystem functions from WP3, and ecosystem services from WP4. A further complication with the uptake of climate projections regarding ecosystem services from D4.1 in this economic assessment, is the focus on the main physical and ecological dynamics that structure the ES provision in river networks and their catchments. That is, the presented models describe how and where the DRNs provide specific ecosystem services (such as water provisioning, and flood regulation), but there is no translation between the service providing areas and service benefiting areas. Establishing these relationships is extremely difficult in the studied DRNs, because they are characterised by low population densities limiting the ability to establish meaningful spatial relationship between service providing areas and which parts of the population (and visitors) benefit where from these ecosystem services (Fezzi et al., 2023).

3. Analysis of benefits of achieving SSP126

In this section, the alternative climate scenario SSP126 is treated as the ‘do-nothing’ scenario as an illustrative example of the monetary benefits which may arise from preventing the focal DRNs from reaching the degraded state associated with the ‘do-nothing’ scenario SSP370. As articulated in Section 11, climate scenario SSP126 is the only available scenario where changes in flow intermittence are projected due to the lack of credible dose-response functions between NBS, flow intermittence and subsequent impacts on biodiversity, ecosystems functioning, ecosystem services and related attributes. These illustrative benefit calculations are done at the level of the three primary DRNs in the Genal, Bükkösdí, and Lepsämánjoki.

To avoid confusion, we only make use of projections made in the DRYvER project and connect those to values for which monetary estimates have been obtained in D4.3. These projections cover respectively, (i) changes in the number of drying days; (ii) changes in the drying period, and for which there is available benefit information (iii) changes in carbon emissions.

⁸ <https://www.enerdata.net/publications/executive-briefing/carbon-price-projections-eu-ets.html>

To establish the monetary benefits of achieving climate scenario SSP126 relative to SSP370 we need to make several assumptions over the 2021-2050 period in relation to the changes in the three attributes of interest, and their corresponding values. These are explained next.

3.1 Changes in drying days, drying period and carbon emissions

Under the assumption that climate scenario SSP126 is the relevant climate scenario as opposed to SSP370, we can revisit the WP1 projections as presented in Section 2.

3.1.1 Genal

Figure 5 highlights that even under this improved climate scenario, drying remains prominent in the Genal during the summer months and particularly between June and August the forecasted number of drying days (*ConD*) by month by reach remains high. The largest differences are observed in April and May where these spring months are projected to be less dry. On average, across the reaches and across the year, climate scenario is projected to increase the number of drying days relative to the present day by 11.60 days by 2050. Contrasting this with the SSP370 scenario, this implies that in the DRN the average number of additional drying days across the reaches per year is decreasing from 18.76 to 11.60, i.e. the improved climate scenario reduces the average number of drying days by 7.16 days by 2050, and we assume this happens at a constant rate of 0.247 days per year per reach between 2022 and 2050. In total that means that during this period on average 107.4 less drying days will occur.

Additionally, we can assume that by 2050 under SSP126 the drying period is 2 months shorter than under SSP370. This means that on an annual basis the drying period will be increasing 0.069 months (roughly 2 days) per year quicker under SSP370 than under SSP126 starting from 2021. Accordingly, over the 2022-2050 period SSP126 will have 30 months of drying less than SSP370.

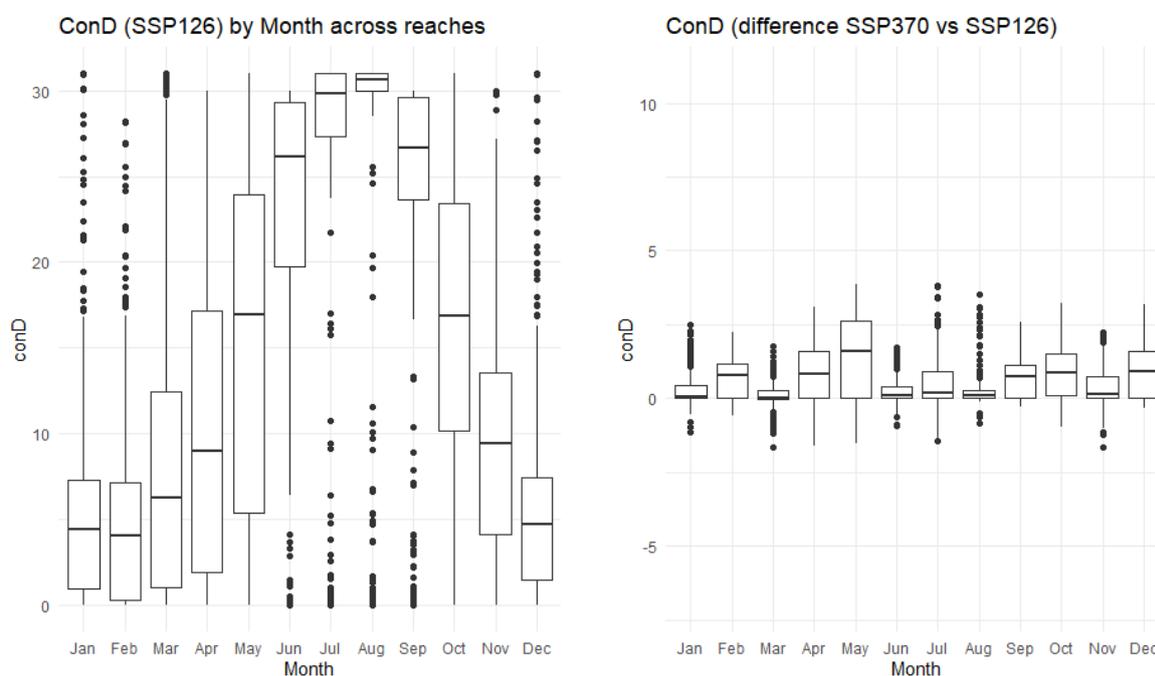


Figure 5: Projections for ConD SSP126 in the Genal (left) and difference with SSP370 (right)

For the difference in projections with respect to carbon emissions we make use of D3.9 projections where Table 4 below reveals that by 2050 carbon emissions under SSP126 will be higher relative to the current situation and relative to the SSP370. This is likely the result of uncertainty associated with the calculations arriving at these estimates for carbon emissions. The overall picture is that projected changes in carbon emissions will be relatively small in the grant scheme. Extrapolating these

relationships to the 2022-2050 period, this shows that carbon emissions grow annually by 0.886 t/CO₂ (or 0.24 t/C-CO₂) quicker under SSP126 than under SSP370. Overall, the extra emissions over the 2022-2050 period are therefore 385.35 t/CO₂ higher than under SSP370.

Table 4: Carbon emissions now vs SSP370 and SSP126 (avg over 2021-2060) in the Genal

	Pre-dry phase			Dry phase			Post dry phase			Total	Difference	
	Total	Flow	Dry	Total	Flow	Dry	Total	Flow	Dry	Total	Vs. current	Vs. SSP370
Now	123.04	69.37	53.67	120.35	17.46	102.89	56.54	32.83	23.7	299.93		
SSP370	117.9	57.5	60.4	122.1	17.1	104.9	75.4	56.4	19	315.4	15.47	
SSP126	119.7	62.5	57.2	122.7	18	104.7	80	62.6	17.5	322.4	22.47	7

3.1.2 Bökkosdi

Figure 6 highlights that even under this improved climate scenario, drying remains prominent in the Bökkosdi during the summer months and particularly between June and September the forecasted number of drying days (*Cond*) by month by reach remains high. The largest differences are observed between October and December where these autumn months are projected to be less dry. On average, across the reaches and across the year, the SSP126 climate scenario projects an increase in the number of drying days relative to the present day by 77.51 days by 2050. Contrasting this with the SSP370 scenario, this implies that in the DRN the average number of additional drying days across the reaches per year is decreasing from 98.31 to 77.51, i.e. the improved climate scenario reduces the average number of drying days by 20.80 days by 2050, and we assume this happens at a constant rate of 0.717 days per year per reach between 2022 and 2050. In total that means that during this period on average 312 less drying days will occur.

Additionally, we can assume that by 2050 under SSP126 the drying period is 3 months shorter than under SSP370. This means that on an annual basis the drying period will be increasing 0.103 months (roughly 3 days) per year quicker under SSP370 than under SSP126 starting from 2021. Accordingly, over the 2022-2050 period SSP126 will have 45 months of drying less than SSP370.

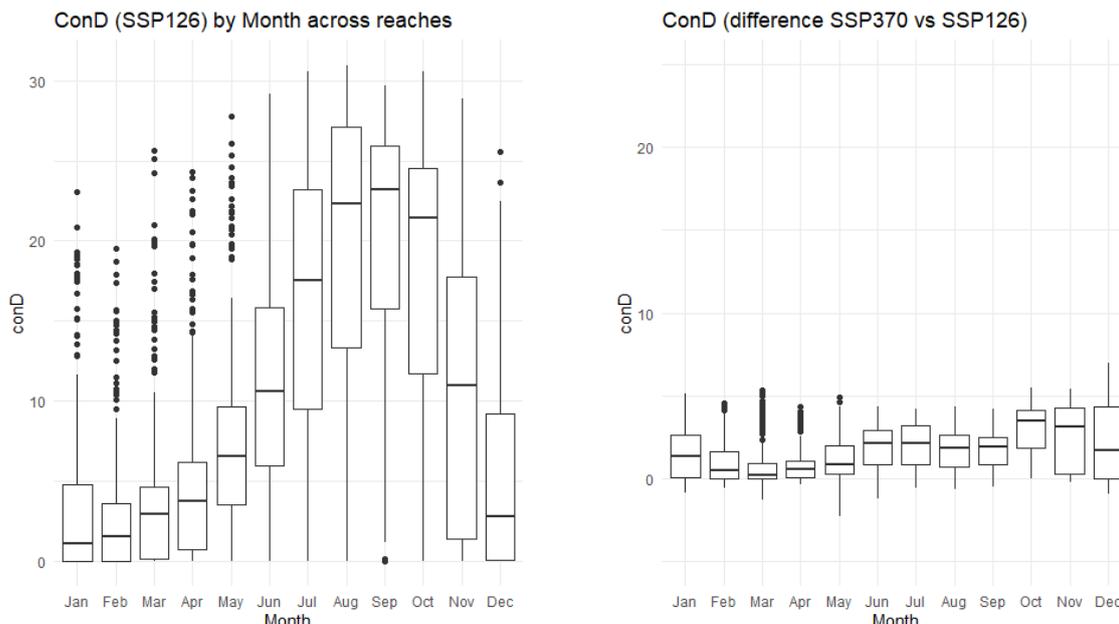


Figure 6: Projections for ConD SSP126 in the Bukkosdi (left) and difference with SSP370 (right)

For the difference in projections with respect to carbon emissions we make use of D3.9 projections where Table 5 below reveals that by 2050 carbon emissions under SSP126 will be higher relative to the current situation and relative lower to the SSP370. Again, the overall picture is that projected changes in carbon emissions will be relatively small in the grant scheme. Extrapolating these relationships to the 2022-2050 period, this shows that carbon emissions grow annually by 0.202 t/CO₂ (or 0.055 t/C-CO₂) quicker under SSP370 than under SSP126. Overall, the extra emissions over the 2022-2050 period are therefore 88.08 t/CO₂ higher than under SSP370.

Table 5: Carbon emissions now vs SSP370 and SSP126 (avg over 2021-2060) in the Bükösdi

	Pre-dry phase			Dry phase			Post dry phase			Total	Difference	
	Total	Flow	Dry	Total	Flow	Dry	Total	Flow	Dry		Vs. current	Vs. SSP370
Now	58.82	23.56	35.26	107.82	13.17	94.65	52.68	14.77	37.91	219.32		
SSP370	55.50	19.90	35.60	128.80	8.10	120.70	55.10	10.40	44.60	239.40	20.08	
SSP16	56.80	22.10	34.60	126.10	9.50	116.60	54.90	12.00	42.90	237.80	18.48	-1.60

3.1.3 Lepsämänjoki

Figure 7 highlights that also under this improved climate scenario, drying projections are not severe in the Lepsämänjoki during the summer months and drying – if any - is large taking place during June to August. The largest differences are observed in June and July where these summer months are projected to be less dry relative to SSP370. On average, across the reaches and across the year, the SSP126 climate scenario projects an increase in the number of drying days relative to the present day by 3.39 days by 2050. Contrasting this with the SSP370 scenario, this implies that in the DRN the average number of additional drying days across the reaches per year is decreasing from 5.02 to 3.39, i.e. the improved climate scenario reduces the average number of drying days by 1.63 days by 2050, and we assume this happens at a constant rate of 0.056 days per year per reach between 2022 and 2050. In total that means that during this period on average 24.45 less drying days will occur.

Additionally, we can assume that by 2050 under SSP126 the drying period is 1 month shorter than under SSP370. This means that on an annual basis the drying period will be increasing 0.034 months



(roughly 1 day) per year quicker under SSP370 than under SSP126 starting from 2021. Accordingly, over the 2022-2050 period SSP126 will have 15 months of drying less than SSP370.

No projections for changes in carbon emissions are available for Lepsämäenjoki under SSP126 nor under SSP370 and hence this is not considered in the remainder of this deliverable.

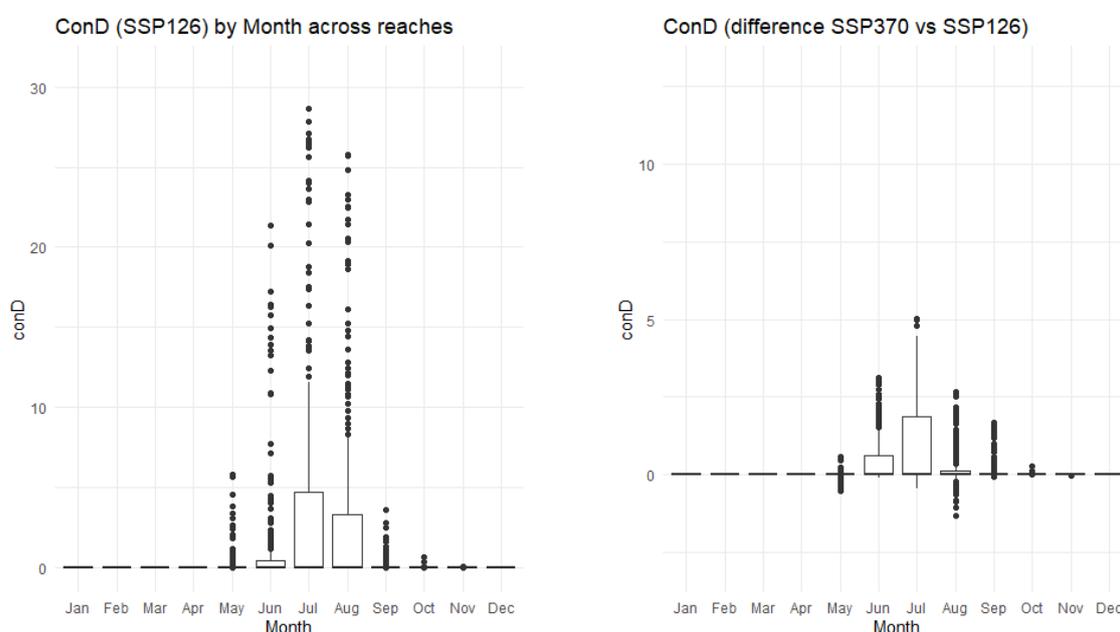


Figure 7: Projections for ConD SSP126 in the Lepsämäenjoki (left) and difference with SSP370 (right)

3.2 Economic benefits over time and discounting

We now shift our attention to connecting these changes in the average number of drying days, length of the drying period, and changes in carbon emissions with the extent to which local populations benefit from the changes in the functioning of the DRNs over time. As explained, for that we use the values calculated for the first two attributes (drying days and drying period) in D4.3 via willingness-to-pay (WTP) estimates for the public surveys, and carbon prices for carbon emissions.

3.2.1 Changes in WTP for drying days and drying period over time

For the monetary value of reducing the average number of drying days and the length of the drying period in the three DRNs, we refer to Table 23 in D4.3. The non-market valuation surveys conducted in these three DRNs reveals that in 2024 the local population is willing to pay €1.39 (Genal), €0.74 (Bükkosdi), and €2.75 (Lepsämäenjoki) per household per year for each drying day saved each year. Similarly, they are willing to pay respectively €7.28 (Genal), €3.91 (Bükkosdi), and €14,45 (Lepsämäenjoki) per household per year to reduce the length of the drying period by one month. These WTP estimates apply to 2024, but value estimates over the considered time horizon are required.

Economic theory establishes that WTP estimates increase as income increases. In D4.3 this same relationship is used in transferring WTP values across DRNs. Specifically, an income elasticity of WTP of 1.5 was used in that deliverable, also in the estimation of the joint model across the three case studies which resulted in the referred Table 23 above. Hence, we stick to that assumption in this deliverable. Moreover, we assume long term income growth rates of 2% per year, such that WTP grows

at a rate of 1.03 per year. We use this factor to re-calibrate WTP estimates to 2021, i.e. the start of our period of analysis.

3.2.2 Forecasting the market price of carbon emissions over time

For the value of changes in carbon emissions we refer to forecasts of the EU ETS market prices. For the period 2021-2024 we make use of observed EU ETS market prices obtained from the Worldbank⁹ and convert these from USD\$ to € using Eurostat's Euro/ECU annual exchange rates for the respective period.¹⁰ Beyond the 2024 period we make use of carbon price forecast by Enerdata¹¹, which predict the market price for carbon to be around €70 per t/CO_2 in 2030, and to rise to €130 per t/CO_2 in 2030 before quickly rising to €500 per t/CO_2 in 2044 due to the phasing out of permits in the EU ETS. Forecasts beyond that date are not available and hence we keep the price fixed at €500 per t/CO_2 until 2050. Figure 8 displays our approximations of the forecasts in the EU-ETS market price for carbon.

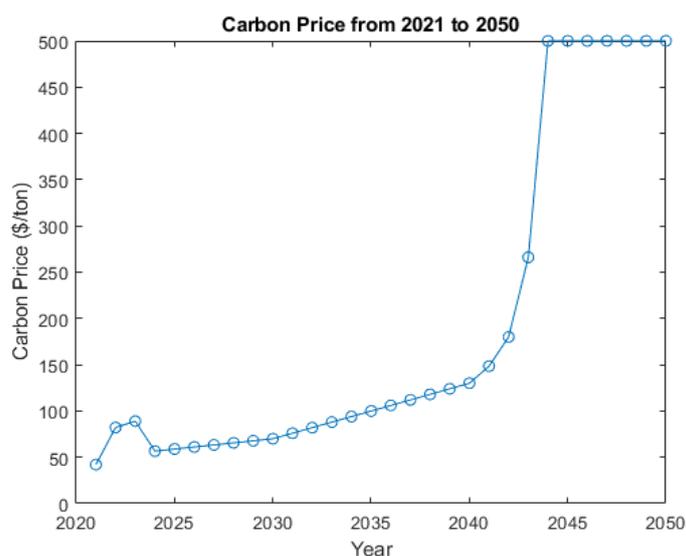


Figure 8: Assumed carbon price over the 2021-2050 period

3.2.3 Discounting

Whilst willingness to pay values and carbon prices are forecasted to increase over time, economic theory also dictates to express the value of future benefits (i.e. less days of drying, shorter drying periods, and lower carbon emissions) in terms of the value of today's money. That is, economists assume that it is worth having money today than in the future, because future generations are assumed to be richer, and people are impatient. In other words, we prefer benefits taking place today rather than next year because the same benefits next year are worth less this year. The process of transforming future benefits into today's money is also known as discounting (Groom et al., 2022). To arrive at our discount rate, we make use of the well-known Ramsey equation defining the discount rate by:

$$SDR = \delta + \eta \cdot g$$

⁹ <https://carbonpricingdashboard.worldbank.org/compliance/price>

¹⁰ https://ec.europa.eu/eurostat/databrowser/product/page/ERT_BIL_EUR_A_custom_822192

¹¹ <https://www.enerdata.net/publications/executive-briefing/carbon-price-forecast-under-eu-ets.pdf>

where δ defines the rate of impatience and we follow the value assumed for this in the UK (i.e. $\delta = 1.5$). η refers to the income elasticity which for the purposes of consistency we equate to the income elasticity of WTP ($\eta = 1.5$), and g refers to the rate of income (or consumption) growth which we again make consistent with Section 3.2.1, i.e. $g = 2$. Accordingly, an overall discount rate of 4.5% is used in our analysis. Since the discount factor grows at a quicker pace than the growth in WTP with income, the net present value of reducing the number of drying days and reducing the length of the drying period declines at a rate of $\frac{1.045}{1.03015} \approx 1.015$, such that effectively only our rate of time preferences is relevant in the changes in WTP over time. In other words, the assumptions imposed imply that on average reducing the number of drying days per year in the DRN by one year is value more than next year or in 2050.

3.3 Deriving the overall benefits of SSP126 relative to SSP370

To express the overall benefits of being able to restrict to climate scenario SSP126 as opposed to SSP370 requires to aggregate the intertemporal benefits by DRN. The equation below makes the net present value of these benefits explicit.

$$B_j = \sum_{t=2021}^{T=2025} \frac{Price_t^C \cdot \Delta Carbon_{jt} + N_{jt} \cdot \left(WTP_{jt}^{days} \cdot \Delta Days_{jt} + N_{jt} \cdot WTP_{jt}^{length} \cdot \Delta length_{jt} \right)}{\left(1 + \frac{SDR}{100} \right)^{t-2021}}$$

In the above,

- $Price_t^C$ describes the carbon price in year t in t/CO_2
- $\Delta Carbon_{jt}$ describes the amount of carbon saved in year t in DRN j
- N_{jt} describes the number of households living in DRN j in year t
- WTP_{jt}^{days} describes the marginal WTP for reducing the average number of drying days by one in DRN j in year t .
- $\Delta Days_{jt}$ describes the projected number of reduced drying days under SSP126 relative to SSP370 in year t in DRN j
- WTP_{jt}^{length} describes the marginal WTP for reducing the length of the drying period by one month in DRN j in year t .
- $\Delta length_{jt}$ describes the projected reduction in the length of the drying period under SSP126 relative to SSP370 in year t in DRN j
- SDR – refers to the social discount rate which is assumed to be 4.5%

An essential difference between the treatment of carbon and changes in the number of drying days is the multiplication by the number of households in each DRN, since the later have been estimated using WTP per household in the valuation surveys (see D4.3). For changes in the drying conditions this multiplication is appropriate because the benefits arise at the household level because interactions with the river and its related attributes changes. In contrast, carbon emissions are considered a global externality where the market price is assumed to reflect the negative impacts this has on the entire population (Aldy et al., 2021). In other words, the market price already reflects the benefits to society of reducing carbon emissions because it does not matter where these emissions occur.

To establish the relevant populations in the three DRNs we start off with the most recent estimates of the number of households in the three DRNs. In Genal, the population of the Genal Valley in 2024 is 7,091 (Spanish office for national statistics, 2024). In Bükkosdi, the population of the Szentlorinc district is reported in the 2022 census at 13,901, and in Lepsämäjoki D4.3 reports the population at 18,237 in 2023. Average household sizes are reported in D4.3 as respectively 2.61 (Genal), 2.2 (Bükkosdi) 2.49

(Lepsämänjoki). After rounding this provides us with an expectation of the number of households of respectively 2,717 (Genal), 6,319 (Bükkosdi), and 7324 (Lepsämänjoki). We then make use of the population growth statistics for 2023 from the Worldbank¹², which reveal the population in Spain is increasing at a rate of 1.2% per year, in Hungary declining by 0.5% per year, and in Finland increases by 0.5% per year. Assuming the average household size does not change over time allows us to have an estimate of the number of households per DRN over the considered period.

Table 6 presents the net present value of the benefits as per the above equation at the DRN level and splits these across the three benefit categories. Most of the benefits arise from the reduction in drying days and the changes in carbon emissions only account for a small portion of the benefits. It is not surprising that the overall benefits are highest in the Bükkosdi because the projected changes in drying patterns are largest.

These net present values are useful in terms of the economic assessments of potential interventions. These essentially represent ‘break-even’ points for the costs of NBS (e.g. Glenk and Martin-Ortega, 2018), that is: the maximum costs that any intervention or ensemble of interventions would have to be for them to be economically efficient, i.e. for the interventions start generating net benefits to society, in relation to these specific attributes (drying duration, drying period and carbon emissions).

Table 6: Net present value of monetary benefits of achieving SSP126 instead of SSP370

	Drying days saved		Shorter drying period		Lower carbon emissions	Total Benefits
Genal	€	354,077.31	€	98,904.28	€ - 38,945.16	€ 414,036.42
Bükkosdi	€	921,048.65	€	132,843.56	€ 8,901.75	€ 1,062,793.96
Lepsamanjoki	€	375,779.06	€	230,539.30	NA	€ 606,318.36

Note that the benefit estimates presented in Table 6 should be considered as a lower bound because only a limited amount of ecosystem services (e.g. carbon sequestration) and benefit generating attributes are considered. Indeed, the non-market valuation surveys in D4.3 indicate that other sources of benefit arise from changes in biodiversity, changes in flood risks and the risks of wildfires, and recreational services. We, however, have insufficient scientific evidence to project the developments of these ES and related attributes into the future and accordingly the benefits associated with limiting the challenges climate change poses to the functioning of the DRNs are not presented as explained in Section 2. In similar vein, we do not present benefit estimates for the other DRNs due to the significant errors that will emerge as part of the benefit transfer exercise as articulated by D4.3.

¹² <https://databank.worldbank.org/reports.aspx?source=2&series=SP.POP.GROW&country=>

4. Perceptions of Nature-Based Solutions

4.1 Identification of potential NBS measures

During the co-creating workshops in WP5 the Nature Futures Framework (NFF - Kim et al., 2023) was operationalised allowing stakeholders to express current pressures experienced in the DRNs and identify desirable future states, including potential solutions (not limited to NBS). Across the DRNs various key pressures were identified ranging from water abstraction, point and diffuse pollution, modification of the river channels causing challenges with flash floods, but also (lack of) forest management was mentioned, increasing the risk of wildfires.

Whilst in most DRNs the discussions settled on improving management structures to address a diverse range of pressures, as opposed to the identification of specific NBS solutions addressing specific challenges, some measures were nevertheless identified. These were used to inform the selection of a set of NBS included in the surveys in D4.3 with the aim of eliciting perceptions relating to their implementation. This initial list of NBS measures was subsequently revised based on comments and suggestions from the pilot surveys and local experts. Table 7 presents the final list of NBS, and in each DRN eight to ten NBS solutions were evaluated. For consistency with D5.6 the final column in Table 7 links the NBS to the three potential categories of NBS included in the BBN, respectively drainage wing, river reach, and riparian buffer restoration measures.

4.2 Preferences for the implementation of NBS

Preferences for the implementation of distinct NBS were elicited by means of the following questions. In the Genal and Bükkosdi, respondents were asked to rank their preferred NBS from most preferred (value = 1) to least preferred (value = 8 (Genal); 10 (Bükkosdi)), and they were also asked to identify which NBS were considered as unacceptable (binary variable). In Lepsämäjoki respondents were asked to identify their (up to) three most preferred NBS. Additionally, in Lepsämäjoki a Likert scale question was also included inquiring the extent to which respondents would like to see an increase in the implementation of each NBS (1 – Current level is enough; 3 – this needs to be implemented a lot more). Finally, in the Genal and Bükkosdi respondents were asked to identify the extent to which they believed each NBS to be effective on a five-point Likert scale (1- not effective at all; 5 – very effective).

4.2.1 Genal

The ranking exercise indicates that the top three most preferred NBS measures are the planting of native tree species; replacing current crops with other requiring less water; and forest management (see Table 8). In other words, they prefer measures taking place in the drainage wing. Improving water infiltration, for example, by recovering ancient agricultural practices such as leaking dams comes in as a close fourth, whereas planting trees along the riverbank to increase shade. is on average the lowest ranked option. Moreover, the most preferred measure is interpreted by most respondents (93.9%). Overall, levels of acceptability are high, but more controversial NBS such as replacing existing crops and restoring natural flows through dam management are associated with the lowest levels of acceptability. In terms of effectiveness, all NBS score high with an average just over four, with five denoting very effective.

Table 7: Detailed NBS measurements of the three cases

NBS Measures	Genal	Bükkösi	Lepsämäenjoki	Classification
Avoiding drainage of commercial forests			x	Drainage wing
Avoiding over-fertilization on fields			x	Drainage wing
Floodplain channels along agricultural watercourses			x	Drainage wing
Forest management	x	x		Drainage wing
Improve vegetation on the margins of crop fields.	x	x		Drainage wing
Improve water infiltration, for example, by recovering ancient agricultural practices such as leaking dams	x	x		River reach
Plant trees along the riverbank to increase shade.	x	x		Riparian buffer
Planting native tree species	x	x		Riparian buffer
Reintroduce river meandering to allow the river to curve with a low speed of flow		x	x	River reach
Reintroduction of ecosystem engineer species that promote water retention (e.g. Eurasian beaver).		x		River reach
Removing migration barriers from watercourses			x	River reach
Replace some current crops (mangos, avocados) with others that require less water	x	x		Drainage wing
Restoration of natural flows through dam management	x	x		River reach
Restoring small wet reservoirs, such as ponds	x	x		Riparian buffer
Wetlands for retaining water, nutrients, and sediments			x	Riparian buffer
Wider and more wooded buffer zones along watercourses			x	Riparian buffer
Winter cover and/or reduced tillage on fields			x	Drainage wing
Total	8	10	8	

Note: 'x' marks inclusion of the NBS in the respective non-market valuation survey

4.2.2 Bükkösi

In the Bükkösi the planting of native tree species also comes out as the highest ranked NBS, with forest management, and the restoration of small wet reservoirs, lakes and wetlands coming respectively as second and third ranked NBS (see Table 9). At the other end of the ranking, the reintroduction of beavers and other ecosystem engineers, and reintroducing the meandering of the river are ranked as the least preferred options by respondents. This picture is thus overall, consistent with the Genal. Levels of acceptability are high across all ten NBS with the reintroduction of beavers being ranked lowest at 89.8% acceptability. This is also considered the least effective option to address drying, whereas the restoration of small wet reservoirs, lakes and wetlands is considered most effective.

Table 8: Preferences for NBS implementation in the Genál

NBS	Ranking		Acceptability		Effectiveness	
	Avg. rank	Std.	Ranking	% of sample	Mean	Std.
Planting native tree species	3.72	2.28	1	93.94%	4.16	0.78
Replace some current crops (mangos, avocados) with others that require less water	4.06	2.54	2	72.53%	4.1	0.97
Forest management	4.44	2.4	3	88%	4.26	0.75
Improve water infiltration, for example, by recovering ancient agricultural practices such as leaking dams	4.47	2.21	4	85.66%	4.15	0.86
Restoring small wet reservoirs, such as ponds	4.72	2.07	5	85.45%	4.18	0.77
Improve vegetation on the margins of crop fields.	4.74	2.16	6	87.07%	4.16	0.8
Restoration of natural flows through dam management	4.76	2.25	7	79.19%	4.14	0.82
Plant trees along the riverbank to increase shade.	5.09	2.13	8	83.03%	4.08	0.86

Table 9: Preferences for NBS implementation in the Bükkosdi

NBS	Ranking		Acceptability		Effectiveness	
	Avg. rank	Std.	Ranking	% of sample	Mean	Std.
Planting native tree species	4.63	2.92	1	96.9%	4.16	0.93
Forest management	4.73	3.21	2	96.6%	4.29	0.84
Restoring small wet reservoirs, lakes and wetlands.	5.22	2.84	3	92.5%	4.41	0.80
Replace some current crops with others that require less water	5.25	2.89	4	93.0%	4.18	1.01
Restoration of natural flows through dam management	5.37	2.64	5	95.2%	4.2	0.96
Improve vegetation on the margins of crop fields	5.65	2.85	6	92.9%	4.1	1.03
Plant trees along the riverbank to increase shade	5.72	2.74	7	93.7%	4.13	0.96
Improve water infiltration, for example, by recovering ancient agricultural practices such as leaking dams or artificial beaver dams.	5.79	2.88	8	92.7%	4.18	0.89
Reintroduction of ecosystem engineer species that promote water retention (e.g. Eurasian beaver).	6.29	2.72	9	89.8%	3.74	1.33
Reintroduce river meandering to allow the river to curve with a low speed of flow	6.34	2.47	10	92.9%	4.01	1.06

4.2.3 Lepsämäjoki

In the case of Lepsämäjoki, ‘Avoiding over-fertilization on fields’ and ‘Wetlands for retaining water, nutrients, and sediment’ are most frequently (63%, and 47%) included in the most preferred set of NBS. ‘Avoiding the drainage of commercial forest’ comes in as the third most preferred option. Also, in the case of Lepsämäjoki there appears to be an aversion to the increasing the meandering of streams, which is only included in the set of most preferred NBS 8% of the times (see Table 10). The responses to the alternative question where respondents are asked to indicate if they wish to see each measure implemented more often (1- no; 2-yes; 3- a lot more) provides a consistent picture with the emerging ranking of the NBS. Respondents prefer to see the most preferred options to be implemented more often than those they rank lowest. Note that the mean of the Likert scale cannot be contrasted against the other two case studies because it is only measured here on a three-point as opposed to a five-point Likert scale in the other two case studies.

Table 10 Results of NBS preference of the Lepsämäjoki case

	Frequency of implementation		Included in preferred NBS		Rank
	Mean	St.D.	Mean	St.D.	
Avoiding over-fertilization on fields	2.5	0.75	0.63	0.48	1
Wetlands for retaining water, nutrients, and sediments	2.32	0.66	0.47	0.50	2
Avoiding drainage of commercial forests	2.26	0.84	0.32	0.47	3
Wider and more wooded buffer zones along watercourses	2.27	0.74	0.29	0.45	4
Removing migration barriers from watercourses	2.32	0.75	0.25	0.43	5
Floodplain channels along agricultural watercourses	2.15	0.67	0.23	0.42	6
Winter cover and/or reduced tillage on fields	2.16	0.75	0.20	0.40	7
Increasing the meandering of streams	1.93	0.79	0.08	0.28	8

The results reveal a consistent focus on forest management across both the Genal and Bükködsi case studies, establishing it as a common solution to the drying. Additionally, both the Bükködsi and Lepsämäjoki cases reveal a shared concern for the management of small wet reservoirs. Across the three case studies there is, however, a consistent aversion to reintroducing natural flows (i.e. meandering) of streams and rivers.

5. Reflections

We set out this deliverable with the intention of conducting cost-benefit analyses (CBA) contrasting the extent to which the benefits generated by the implementation of spatially targeted NBS outweigh their implementation costs. We have been able to identify through non-market valuation surveys the kind of NBS preferred by local populations. Not unsurprisingly, the preferred measures are specific to the local DRNs, but some consistent patterns emerge. A clear preference is expressed across the case studies for making changes in the drainage wing through planting native tree species, and forest management, whereas the reintroduction of meandering streams is considered amongst the least preferred NBS.

Ideally, we would have evaluated the effectiveness and impacts of implementing such measures on flow intermittence, biodiversity, and the wider functioning of the ecosystems in DRNs, ultimately affecting the way in which local populations benefit from interacting with their local DRN – also known as ecosystem services. CBA is an ideal tool for bringing all these benefits together and expressing them in a common unit (i.e. money), allowing the comparison of alternative policy solutions mitigating the effects of climate change in DRNs against each other, and against the ‘do nothing’ scenario.

For CBA exercises to be meaningful in these kinds of contexts many things need to come together. To make this more explicit, the modelling components developed in large scale projects like DRYvER need to be integrated such that all the generated transdisciplinary insights can be brought together. This challenge is not new, and Martin-Ortega et al. (2015) already flag that *“research agendas should be driven by attempts to address the challenges of the integrated approach, rather than (or rather than only) on improving the sophistication of the individual methods that might end up bringing them further apart”*. Whilst cross-work package consultations have taken place throughout the DRYvER project aiming to ensure knowledge integration where possible, the desired level of integration has not been established.

This deliverable has articulated major knowledge gaps regarding key aspects, specifically in the form of robust dose-response functions, still exist and thereby limit the ability of undertaking comprehensive CBA tailored to specific NBS at the DRN level. Without dose-response functions capturing the effectiveness of spatially targeted adaptation and mitigation measures in the form of NBS on flow intermittence and subsequent changes in the provisioning of ecosystem services proved challenging. Namely, it is that extent of the intervention (e.g. size, coverage, locations) that determines the costs of interventions *and* the potential for generating benefits to society. We therefore had to resort to a second-best strategy evaluating alternative climate scenarios and interpreting this ‘as if’ a bundle of NBS could be equally effective.

This presented analysis illustrates, for the limited set of attributes for which information was available in a way that could be in-putted into an economic assessment, how ‘break-even’ points for the costs of NBS can be identified. While limited, this can serve as first stepping stone in guiding policy makers as per the maximum costs that the NBS would have to be so that net benefits to society are generated from NBS implementation.

The evidence generated by DRYvER, although not (yet) perfectly aligning with the informational needs of a full-fledged CBA to support a business case to implement adaptation and mitigation measures, postulates that the impacts of climate change on flow intermittence can be significant, especially in the Hungarian DRN. Subsequent impacts on local biodiversity can be substantive and may put certain macroinvertebrates at risk due to conditions falling beyond Safe Operating Spaces. With such drastic changes in the functioning of ecosystems in DRNs and the corresponding risk posed on the delivery of ecosystem services, there is a clear need to rapidly develop evidence as to how relevant NBS may effectively limit such welfare losses to society.

Future research should look into reducing the uncertainty in the future projections of drying patterns and the modelling of related ES and attributes, and the modelling of specific NBS in given territories, so these can be connected with the outputs that are possible to obtain from monetary valuation techniques.

6. References

- ALDY, J. E., KOTCHEN, M. J., STAVINS, R. N. & STOCK, J. H. 2021. Keep climate policy focused on the social cost of carbon. *Science*, 373, 850-852.
- BUNTING, G., ENGLAND, J., GETHING, K., SYKES, T., WEBB, J. & STUBBINGTON, R. 2021. Aquatic and terrestrial invertebrate community responses to drying in chalk streams. *Water and Environment Journal*, 35, 229-241.
- CHALMANDRIER, L. & MUNOZ, F. 2025. A report on the biodiversity scenarios, mapping safe operational spaces for freshwater biodiversity at focal DRN and European scales.
- CZAJKOWSKI, M., BUDZIŃSKI, W., CAMPBELL, D., GIERGICZNY, M. & HANLEY, N. 2017. Spatial Heterogeneity of Willingness to Pay for Forest Management. *Environmental and Resource Economics*, 68, 705-727.
- DATRY, T., BOULTON, A. J., BONADA, N., FRITZ, K., LEIGH, C., SAUQUET, E., TOCKNER, K., HUGUENY, B. & DAHM, C. N. 2018. Flow intermittence and ecosystem services in rivers of the Anthropocene. *Journal of Applied Ecology*, 55, 353-364.
- DATRY, T., LARNED, S. T., FRITZ, K. M., BOGAN, M. T., WOOD, P. J., MEYER, E. I. & SANTOS, A. N. 2014. Broad-scale patterns of invertebrate richness and community composition in temporary rivers: effects of flow intermittence. *Ecography*, 37, 94-104.
- ESCOBAR-CAMACHO, D., CRABOT, J., STUBBINGTON, R., ENGLAND, J., SARREMEJANE, R., BONADA, N., FERNÁNDEZ-CALERO, J. M., CAÑEDO-ARGÜELLES, M., REZENDE, C. F., CHANUT, P., CSABAI, Z., ENCALADA, A. C., LAINI, A., MYKRÄ, H., MOYA, N., PAŘIL, P., ROSERO-LÓPEZ, D. & DATRY, T. 2025. River Drying Causes Local Losses and Regional Gains in Aquatic Invertebrate Metacommunity Diversity: A Cross-Continental Comparison. *Global Change Biology*, 31, e70068.
- EUROSTAT 2021. EU economy emissions in 2021: -22% since 2008.
- FEZZI, C., FORD, D. J. & OLESON, K. L. L. 2023. The economic value of coral reefs: Climate change impacts and spatial targeting of restoration measures. *Ecological Economics*, 203, 107628.
- FOULQUIER, A., DATRY, T., CORTI, R., VON SCHILLER, D., TOCKNER, K., STUBBINGTON, R., GESSNER, M. O., BOYER, F., OHLMANN, M., THUILLER, W., RIOUX, D., MIQUEL, C., ALBARIÑO, R., ALLEN, D. C., ALTERMATT, F., ARCE, M. I., ARNON, S., BANAS, D., BANEGAS-MEDINA, A., BELLER, E., BLANCHETTE, M. L., BLESSING, J., BOËCHAT, I. G., BOERSMA, K., BOGAN, M., BONADA, N., BOND, N., BRINTRUP, K., BRUDER, A., BURROWS, R., CANCELLARIO, T., CANHOTO, C., CARLSON, S., CID, N., CORNUT, J., DANGER, M., DE FREITAS TERRA, B., DE GIROLAMO, A. M., DEL CAMPO, R., DÍAZ VILLANUEVA, V., DYER, F., ELOSEGI, A., FEBRIA, C., FIGUEROA JARA, R., FOUR, B., GAFNY, S., GÓMEZ, R., GÓMEZ-GENER, L., GUARESCHI, S., GÜCKER, B., HWAN, J., JONES, J. I., KUBHEKA, P. S., LAINI, A., LANGHANS, S. D., LAUNAY, B., LE GOFF, G., LEIGH, C., LITTLE, C., LORENZ, S., MARSHALL, J., MARTIN SANZ, E. J., MCINTOSH, A., MENDOZA-LERA, C., MEYER, E. I., MILIŠA, M., MLAMBO, M. C., MORAIS, M., MOYA, N., NEGUS, P., NIYOGI, D., PAGÁN, I., PAPTAEODOULOU, A., PAPPAGALLO, G., PARDO, I., PAŘIL, P., PAULS, S. U., POLÁŠEK, M., RODRÍGUEZ-LOZANO, P., ROLLS, R. J., SÁNCHEZ-MONTOYA, M. M., SAVIĆ, A., SHUMILOVA, O., SRIDHAR, K. R., STEWARD, A., TALEB, A., UZAN, A., VALLADARES, Y., VANDER VORSTE, R., WALTHAM, N. J., ZAK, D. H. & ZOPPINI, A. 2024. Unravelling large-scale patterns and drivers of biodiversity in dry rivers. *Nature Communications*, 15, 7233.
- GLENK, K. & MARTIN-ORTEGA, J. 2018. The economics of peatland restoration. *Journal of Environmental Economics and Policy*, 7, 345-362.
- GLENK, K., SCHAAF SMA, M., MOXEY, A., MARTIN-ORTEGA, J. & HANLEY, N. 2014. A framework for valuing spatially targeted peatland restoration. *Ecosystem Services*, 9, 20-33.
- GROOM, B., DRUPP, M. A., FREEMAN, M. C. & NESJE, F. 2022. The Future, Now: A Review of Social Discounting. *Annual Review of Resource Economics*, 14, 467-491.
- HANLEY, N. & BARBIER, E. 2009. *Pricing nature : cost-benefit analysis and environmental policy*, Cheltenham, UK ;, Edward Elgar.

- HURST, M. 2019. Demystifying cost benefit analysis.
- JACQUET, C., MUNOZ, F., BONADA, N., DATRY, T., HEINO, J. & JABOT, F. 2022. Disturbance-driven alteration of patch connectivity determines local biodiversity recovery within metacommunities. *Ecography*, 2022, e06199.
- KIM, H., PETERSON, G. D., CHEUNG, W. W. L., FERRIER, S., ALKEMADE, R., ARNETH, A., KUIPER, J. J., OKAYASU, S., PEREIRA, L., ACOSTA, L. A., CHAPLIN-KRAMER, R., DEN BELDER, E., EDDY, T. D., JOHNSON, J. A., KARLSSON-VINKHUYZEN, S., KOK, M. T. J., LEADLEY, P., LECLÈRE, D., LUNDQUIST, C. J., RONDININI, C., SCHOLES, R. J., SCHOOLENBERG, M. A., SHIN, Y.-J., STEHFEST, E., STEPHENSON, F., VISCONTI, P., VAN VUUREN, D., WABNITZ, C. C. C., JOSÉ ALAVA, J., CUADROS-CASANOVA, I., DAVIES, K. K., GASALLA, M. A., HALOUJANI, G., HARFOOT, M., HASHIMOTO, S., HICKLER, T., HIRSCH, T., KOLOMYTSEV, G., MILLER, B. W., OHASHI, H., GABRIELA PALOMO, M., POPP, A., PACO REMME, R., SAITO, O., RASHID SUMALIA, U., WILLCOCK, S. & PEREIRA, H. M. 2023. Towards a better future for biodiversity and people: Modelling Nature Futures. *Global Environmental Change*, 82, 102681.
- LÓPEZ-ROJO, N., DATRY, T., PEÑAS, F. J., SINGER, G., LAMOUROUX, N., BARQUÍN, J., RODELES, A. A., SILVERTHORN, T., SARREMEJANE, R., DEL CAMPO, R., ESTÉVEZ, E., MIMÉAU, L., BOYER, F., KÜNNE, A., DALVAI RAGNOLI, M. & FOULQUIER, A. 2024. Carbon emissions from inland waters may be underestimated: Evidence from European river networks fragmented by drying. *Limnology and Oceanography Letters*, 9, 553-562.
- MADSEN, H., LAWRENCE, D., LANG, M., MARTINKOVA, M. & KJELDSEN, T. R. 2014. Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *Journal of Hydrology*, 519, 3634-3650.
- MARTIN-ORTEGA, J., PERNI, A., JACKSON-BLAKE, L., BALANA, B. B., MCKEE, A., DUNN, S., HELLIWELL, R., PSALTOPOULOS, D., SKURAS, D., COOKSLEY, S. & SLEE, B. 2015. A transdisciplinary approach to the economic analysis of the European Water Framework Directive. *Ecological Economics*, 116, 34-45.
- MIMÉAU, L., KÜNNE, A., BRANGER, F., KRALISCH, S., DEVERS, A. & VIDAL, J. P. 2023. Flow intermittence prediction using a hybrid hydrological modelling approach: influence of observed intermittence data on the training of a random forest model. *EGUsphere*, 2023, 1-30.
- MIMÉAU, L., KÜNNE, A., DEVERS, A., BRANGER, F., KRALISCH, S., LAUVERNET, C., VIDAL, J. P., BONADA, N., CSABAI, Z., MYKRÄ, H., PAŘIL, P., POLOVIĆ, L. & DATRY, T. 2024. Projections of streamflow intermittence under climate change in European drying river networks. *Hydrol. Earth Syst. Sci. Discuss.*, 2024, 1-34.
- OZDEMIROGLU, E. & HAILS, R. 2016. Demystifying Economic Valuation.
- PASTOR, A. V., TZORAKI, O., BRUNO, D., KALETOVÁ, T., MENDOZA-LERA, C., ALAMANOS, A., BRUMMER, M., DATRY, T., DE GIROLAMO, A. M., JAKUBÍNSKÝ, J., LOGAR, I., LOURES, L., ILHÉU, M., KOUNDOURI, P., NUNES, J. P., QUINTAS-SORIANO, C., SYKES, T., TRUCHY, A., TSANI, S. & JORDA-CAPDEVILA, D. 2022. Rethinking ecosystem service indicators for their application to intermittent rivers. *Ecological Indicators*, 137, 108693.
- PENGAL, P. 2025. A catalogue of NBS measures for drying river networks. Zenodo.
- PÉREZ-SILOS, I., BARQUÍN, J. & DATRY, T. 2025. Ecosystem Services in Drying River Networks: A Meta-Ecosystem Conceptual Model. *WIREs Water*, 12, e70002.
- SÁNCHEZ-MONTOYA, M. M., GÓMEZ, R., CALVO, J. F., BARTONIČKA, T., DATRY, T. & PARIL, P. 2022. Ecological values of intermittent rivers for terrestrial vertebrate fauna. *Science of The Total Environment*, 806, 151308.
- SENERPONT DOMIS, L., DULLEMOND, F., ZHAN, Q. & TEURLINCX, S. 2025. Decision support system based on Bayesian Belief Network modelling.
- SEPP, M., GONZÁLEZ-TRUJILLO, J. D., R., M. & SABATER, S. 2024a. Synthesis reveals heterogeneous changes in the metabolism and emission of greenhouse gases of drying rivers. *Environmental Research Letters*, 19.
- SEPP, M., LÓPEZ-ROJO, N., RODELES, A. A. & DEL CAMPO, R. 2024b. A report on ecosystem functioning in DRNs under climate change scenarios.

- SILVERTHORN, T., LÓPEZ-ROJO, N., SARREMEJANE, R., FOULQUIER, A., CHANUDET, V., AZOUGUI, A., DEL CAMPO, R., SINGER, G. & DATRY, T. 2024. River network-scale drying impacts the spatiotemporal dynamics of greenhouse gas fluxes. *Limnology and Oceanography*, 69, 861-873.
- TOLEDO-GALLEGOS, V. M., LONG, J., CAMPBELL, D., BÖRGER, T. & HANLEY, N. 2021. Spatial clustering of willingness to pay for ecosystem services. *Journal of Agricultural Economics*, 72, 673-697.