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DOWNSTREAM FISH MIGRATION ALONG THE LOW MEUSE RIVER

Action D3

Assessment of the socio-economic impacts

Report on the assessment of the socioeconomic impacts of the LIFE4FISH project

LIFE16 NAT/BE/000807 LIFE4FISH

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Summary

Conducted in 2017-2023, the LIFE4FISH project has aimed to demonstrate the effectiveness of solutions reducing the impact of six hydropower plants on the downstream migration of European eels and Atlantic salmons in the Low Meuse in Wallonia. For decades, both species have been facing a severe population decline globally due to anthropogenic pressures, and are regionally protected through important preservation and reintroduction programmes.

Man-made obstacles on rivers can interrupt the reproductive and development cycle of diadromous species such as salmon and eels, and be a significant factor of mortality. Downstream migration from freshwater to saltwater is a particularly sensitive period for these fishes, and is influenced by river hydromorphology which largely determines their escapement. The LIFE4FISH project has aimed at reducing the negative impacts of hydropower plants during these periods while minimising power production losses.

Key findings of the assessment of the socioeconomic impacts of the project are as follows:

- The project has included biology research to analyse fish-infrastructure interactions, complementing the hydrology approaches traditionally associated with hydropower. This has contributed to the consolidation of the knowledge base on local population statuses and on the technical solutions tested by the project, as well as to the development of fish migration models. These innovations have been conceived and implemented by a highly skilled workforce.
- Hydropower plants are part of a river regulation system involving multiple water uses. At the project location, the Meuse is a heavily modified water body, largely artificialized for inland navigation (dams, locks, weirs etc.). Water level and water flow management remain primary concerns of water infrastructure operators. Other river regulation objectives, such as fish migration, represent an additional operational constraint requiring a coordination between water infrastructure operators.
- The Atlantic salmon and the European eel are “flagship species” that symbolise an overall improvement of water quality and limitation of further biodiversity losses. Their preservation in Wallonia is motivated by a decades-long programme to recreate a “Meuse salmon” subtype and by the need to comply with the European Eel Regulation. Their protection is not directly guided by utilitarian concerns, as these species are not used locally (i.e. they are not fished, neither commercially nor recreationally). Despite the limited size of endemic populations, salmon and eels as protected species make a relatively high contribution to societal welfare in the region, as their existence contributes to the ecosystem services of the Meuse river, with a mainly cultural and symbolic role.

Caution is required when comparing the benefits and costs of the project, as it would consist of a comparison between renewable power production, a well-known contribution to climate change prevention, and biodiversity restoration objectives, which are subject to the complex functioning of ecosystems as well as to uncertainty. Additionally, the project has been conducted on an international river, at a location over 300 km from the sea, with river continuity challenges and benefits spreading across Belgium, France and the Netherlands.

The restoration of river continuity in heavily modified water bodies such as the Low Meuse requires large-scale investments and changes in infrastructure design and operation. In this perspective, the LIFE4FISH project has initiated a novel approach for limiting the negative impacts of existing installations, with lessons learnt for other contexts.

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1 Policy background

River continuity refers to the free movement of water, sediment, fish and other organisms as part of the functioning of river ecosystems and of the lifecycle of aquatic species. It contributes to the quality of aquatic environments as defined by the Water Framework Directive (2000/60/EC). River continuity and hydromorphology can be negatively affected by water infrastructure, with longitudinal alternations such as weirs and dams, and lateral alterations such as dikes. Alterations of hydromorphology, interrupted migration routes and fragmented habitats can cause a decline in freshwater biodiversity, and particularly affect migrating fish populations.

Diadromous fishes i.e., fish species with a lifecycle involving migrations between freshwater and marine habitats, such as salmon and eels, are particularly exposed to alterations of river continuity. Downstream migration is a critical moment in their development and reproduction cycle. As they leave their freshwater habitat, river obstacles, modifications of river flows and other anthropogenic pressures can interrupt or delay their journey and cause population declines.

Other pressures affecting river biodiversity and water quality include pollutants (e.g. effluents), temperature increases, infectious diseases, predation, invasive species and habitat losses.

Species	IUCN status	Migration type	Downstream migration stage	Downstream migration season
European eel (*Anguilla anguilla*)	Critically endangered	Catadromous	Silver eel	Autumn/Winter (Aug.-Feb.)
Atlantic salmon (*Salmo salar*)	Least concern	Anadromous	Smolt	Spring (March-May)

Table 1 Fish species targeted by the LIFE4FISH project

1.1 The European eel, a critically endangered species

Eels spawn in the Sargasso Sea in the Atlantic Ocean, before reaching the continental coast as glass eels and migrating up freshwaters as elvers. During up to twenty years or more, they develop as yellow eels until they start becoming reproductively mature. At the silver eel stage, they migrate back to the Sargasso Sea to reproduce. The reproduction cycle of eels remains largely undocumented, and captive breeding attempts have had limited results so far.

The global population of European eels has experienced an overall collapse since the 1980s, with a number of explanatory factors including overexploitation, pollution, parasites, diseases, migratory barriers and other habitat loss, and oceanic factors affecting migrations[1]. The European eel is listed as “critically endangered” under the Red List of the International Union for Conservation of Nature (IUCN), and is listed under Appendix II of the Convention of Migratory Species of Wild Animals (CMS). Eel trade is restricted under Appendix II of the Convention on International Trade in Endangered Species (CITES). The International Council for the Exploration of the Sea (ICES) recommends that all anthropogenic mortality of European eels should be kept to “zero or as close to zero as possible”[2].

The European “Eel Regulation” (Regulation (EC) 1100/2007)[3] aims to “reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock”, with national objectives laid down in Eel Management Plans (EMPs).

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[1] ICES, Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL) 2019
[2] ICES Advice on fishing opportunities, catch and effort (2016)
[3] Regulation (EC) No. 1100/2007 establishing measures for the recovery of the stock of European eel

The project location is part of the Belgian Meuse (BE_Meus) Eel Management Unit (EMU) with an EMP since 2008[4]. Stock indicators reflect a high lifetime mortality and low spawner escapement, respectively higher and lower than in most other EMUs, and a free-fall of ascending yellow eels. At Lixhe, the number of ascending yellow eels has declined by 4% per year since 1992, bringing it in 2018 to 1.2% of the 1992 level. The silver eel production represents 0.54% in numbers and 0.64% in biomass of the ascending yellow eel stock[5].

There is no commercial fishing of eels in Wallonia. Recreational fishing of eels is forbidden in the region since 2017[6] and eel poaching is negligible[7].

1.2 The Atlantic salmon, a declining population globally

The Atlantic salmon spawns in the gravel of rivers and streams. Its initial freshwater phase lasts one to four years, with the alevin evolving as fry and then as parr. At this stage, it begins to adapt to life in seawater with physiological changes known as smoltification, and starts migrating to the ocean. Salmon smolts can complete their growth in estuaries, before spending one to four years in the ocean as adults and migrating back to their river of origin to spawn. This reproductive cycle can be repeated.

The global stock of Atlantic salmon has significantly decreased globally in the last decades, due to overfishing, pollution, climate change, deterioration of freshwater habitats and other factors. The European Union is part of the North Atlantic Salmon Conservation Organization (NASCO) since 1983. Under the Common Fisheries Policy (CFP), total allowable catch (TAC) quotas for Atlantic salmon are fixed annually by the European Council. Most of salmon production in Europe today comes from aquaculture, and 1-2% of salmon consumed in the EU is produced internally.

The decline of the Atlantic salmon in the Belgian Meuse started in 1840 with the construction of needle dams for inland navigation, and the species has been extinct in the Belgian Meuse since 1935, after the construction of larger dam and lock complexes in the Netherlands and in Belgium[8]. The Meuse and the Rhine have been the first rivers of Europe where the salmon has disappeared.

In 1983, the discovery of sea trouts in the Berwinne stream, a tributary of the Meuse, initiated the idea of a salmon restoration programme: the “Meuse Saumon 2000” programme was launched in 1987 by the Wallonia region with the universities of Liège and Namur. It included restocking based on populations from Scotland, Ireland and France, bred[9] and released in estuaries of the Meuse. Fish passes were constructed in the Netherlands, in Belgium and in France to restore upstream migration. Fishing of Atlantic salmons is forbidden in Wallonia since 1993[10] and the first returning salmon has been captured in 2002.

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4 Eel Management Plan for Belgium (2008)
5 ICES-WGEEL, “Eel Country Report Belgium” (2020)
6 Arrêté du Gouvernement wallon du 8 décembre 2016 relatif aux conditions d’ouverture et aux modalités d’exercice de la pêche
7 ICES-WGEEL, Eel Country Report Belgium (2020)
8 International Meuse Commission, « Les poissons migrateurs dans la Meuse » (2011)
9 The breeding and restocking of the “Meuse salmon” at the Erezée fish farm is now based on a salmon subtype originating from the Loire-Allier river basin in France.
10 Arrêté de l’Exécutif régional wallon du 11 mars 1993 portant exécution de la loi du 1er juillet 1954 sur la pêche fluviale

2 Water infrastructure on the Meuse

Water infrastructure reflects the variety of human activities involving water use. On the Belgian Meuse, the built environment is historically linked to the development of inland navigation, which has supported the development of one of the first industrial areas of the continent. River flow management on the Low Meuse aims at reconciling several water uses including waterborne transport, public water supply, industrial uses of water, energy production and flood and drought prevention.

2.1 The Meuse, an international river

Figure 1 Hydropower plants of the project on the Meuse

The Meuse is a 925-km river that flows through France, Belgium and the Netherlands. It rises on the Langres plateau and ends in the Rhine-Meuse delta. Its total catchment area is 33,629 km^2 with around nine million inhabitants. In Belgium, three river sections can be broadly distinguished: the Upper Meuse between the French border and Namur, the Low Meuse between Namur and the Dutch border, and its bordering section between the Flemish Limburg and the Dutch Limburg.

Country/Region	Area (km²)	Population 2018
France	7,812	471,066
Luxembourg	69	68,819
Belgium – Wallonia	12,283	2,340,241
Belgium – Flanders	1,591	497,617
Netherlands	7,876	3,695,341
Germany	3,997	1,974,209
Total	**33,629**	**9,047,293**

Table 2 The international river basin district Meuse (based on WISE and JRC-GEOSTAT data)

The largest part of the international river basin district Meuse is in Wallonia, where the Walloon Government (SPW “Service Public de Wallonie”) is the competent authority for the enforcement of the Water Framework Directive (WFD), with two relevant directorate-generals: the Directorate General of Mobility and Waterways (DGO2) and the Directorate General for Agriculture, Natural Resources and the Environment (DGO3).

Fish migration measures on the Meuse are also coordinated at the levels of the International Meuse Commission[11] and of the Benelux[12].

The project is part of the Belgian Low Meuse from Namur to the Dutch border (a linear distance of approximately 75 km) and includes all six hydropower plants in this river section: Grands-Malades, Andenne, Ampsin-Neuville, Ivoz-Ramet, Monsin and Lixhe. The project area starts 527 km from the source at Grands-Malades and ends 323 km from the sea at Lixhe.

2.2 The Low Meuse, a heavily modified water body

The Low Meuse is a heavily modified water body (HMWB) under the WFD[13]. The current hydromorphology of the Low Meuse between Namur and Liège results from a series of hydraulic works since the 1840s to develop inland navigation and flood protection, as the river historically presents high variations in drought and discharge due to its pluvial regime: dam, weir and lock constructions, deepening and widening of navigation channels, stabilisation and diking of river banks.

Large bridge-dams with hydropower plants have been constructed at Monsin (1930) downstream Liège and at Ivoz-Ramet (1938), and reconstructed after the Second World War. Between Namur and Liège, needle dams have been replaced by larger dam and lock complexes at Ampsin-Neuville (1958[14]), Andenne (1974) and Grands-Malades (1983). Lastly, the Lixhe dam (1980) has replaced needle dams downstream Liège. The Low Meuse now is a wide-gauge waterway axis[15] towards the North Sea through the Netherlands and connected to the Scheldt and the Port of Antwerp by the Albert Canal, built in 1930-1939. The construction of run-of-river hydropower plants on the Low Meuse has accompanied these dam constructions providing a head of 4 to 8 meters. They are either located on the inland waterway (Grands-Malades, Andenne, Ampsin-Neuville and Ivoz-Ramet) or parallel to the Albert canal (Monsin and Lixhe).

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[11] Commission Internationale de la Meuse, « Plan directeur pour les poissons migrateurs de la Meuse » (2011)
[12] Décision (M(2009)1) du Comité des Ministres de l’Union Economique Benelux abrogeant et remplaçant la Décision M(96)5 du 26 avril 1996 relative à la libre circulation des poissons dans les réseaux hydrographiques du Benelux
[13] Water body reference MV35Ra. Natura 2000 sites along the Low Meuse are limited to a few riparian areas and small islands (Île Dossay, Île de Belgrade, Île des Chanoines, Île du Bosquet).
[14] The Ampsin-Neuville lock complex has been considerably upgraded in 2022 for wide-gauge navigation. Works include the construction of an artificial river circumventing the locks and hydropower plant.
[15] The Low Meuse waterway is part of the North Sea – Alpine corridor of the trans-European transport network (TEN-T)

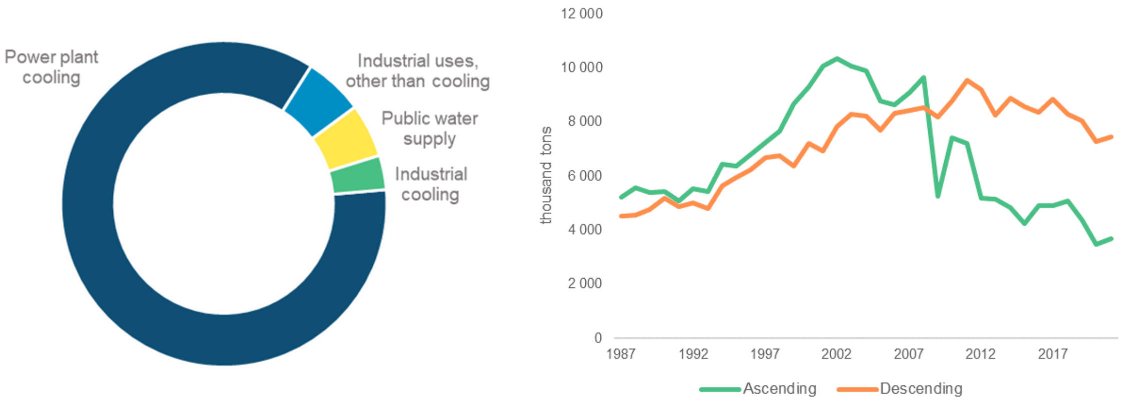

Figure 2 Surface water withdrawals in Wallonia (average 2009-2018) and transported tonnage on the Meuse, upstream of the Albert Canal (data sources: SPW)

River dams on the Low Meuse are operated by SPW-DGO2 and equipped with sluices and fusegates, to regulate water flows and water levels. River regulation aims to ensure the availability of water for multiple uses:

- Inland navigation;
- Public water distribution;
- Cooling and process water supply to industry;
- Cooling water supply to nuclear and gas power plants;
- Hydropower production;
- Water supply to other regions (Flanders, the Netherlands, the Senne and Scheldt river basins).

In addition to regulating water quantities, river regulation also aims to prevent river flow fluctuations, as they can expand while propagating downstream and affect water supply. This requires a coordination of river dams, based on the continuous monitoring of water inflows and with a control of flow allocations. Water inflow monitoring and prevision notably plays a critical role for the management of extreme flow rates, either during low-water periods or for flood control.

2.3 Hydropower in Belgium

The installed hydropower capacity in Belgium is for the most part located in Wallonia and delivers around 1,430 GWh annually in the country[16]. It consists of multiple run-of-river power plants on the Meuse, small-scale hydropower plants on Meuse tributaries and on the Albert Canal, and of two large pumped-storage hydropower plants. Hydropower represents around 200 direct and indirect jobs, an annual €40m turnover and an annual €10m direct gross value added in Belgium[17]. The potential for additional run-of-river hydropower capacity is limited to small units of around 1 MW or lower. Recent projects include removable plants on the Meuse and its tributaries based on concessions by SOFICO "Société wallonne de financement complémentaire des infrastructures".

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[16] Average gross electricity production 2012-2021 (Statbel). Pumped hydro: 1,100 GWh/year; run-of-river hydro: 330 GWh/year.

[17] EurObserv'ER, "The State of Renewable Energies in Europe, Edition 2021" (2022)

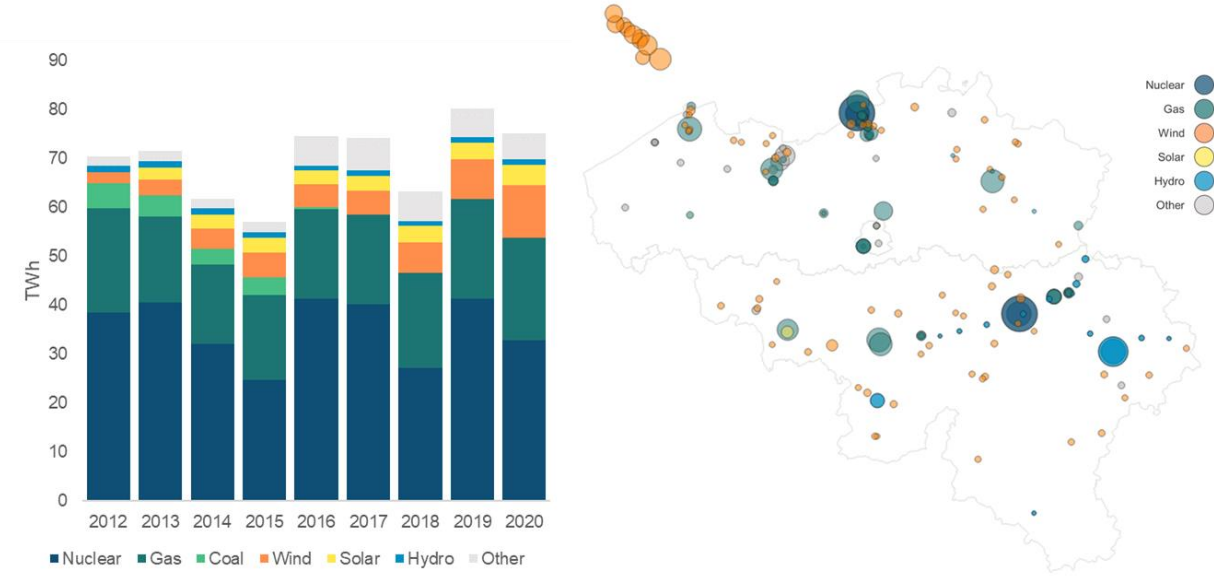

Figure 3 Power production in Belgium (data source: CREG) and power production units over 1 MW (data sources: ELIA, Global Energy Monitor)

The six hydropower plants of the project are the largest run-of-river installations in Belgium, representing a combined 67 MW. They have entered in operation between 1954 and 1988, and have been successively built and operated by SOCOLIE “Société Coopérative Liégeoise d’Electricité”, a public entity created in 1949, and SPE “Société Productrice d’Electricité” which regrouped in 1978 several public electricity producers from Wallonia and Flanders. In 2000, SPE was privatised and it merged in 2005 with the then Flemish electricity retailer LUMINUS to become an energy production, retail and services company[18].

HPP characteristics	Unit	Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Commissioning	Year	1988	1980	1965	1954	1954	1980
Flow rate	m^3/s	160	167	220	270	450	280
Turbine type	-	Straflo	Bulb, Straflo	Bulb	Kaplan	Kaplan	Bulb
Number of turbines	-	4	3	4	3	3	4
Nominal power	MW	5.00	7.05	9.00	10.35	19.50	16.10
Other water infrastructure	-	Dam, lock	Dam, lock	Dam, two locks	Dam, two locks	Dam	Dam

Table 3 Project HPP characteristics (sources: LUMINUS, EMP Belgium)

2.4 Hydropower and water flow management on the Low Meuse

Hydropower generation is physically determined by three key factors: the head, which is the difference between the upper and lower water levels, the flow rate, or hydroelectric discharge, which corresponds to the volume of water passing through the hydropower plant per unit of time, and the overall system efficiency. The water flow rate is an essential variable for hydropower production, and thereby for the commercial viability of the power plant. Estimates for the average annual flow rate and power output are based on decennial hydrological projections.

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[18] EDF “Electricité de France S.A.” is a majority shareholder of LUMINUS since 2009.

In addition to natural factors affecting the availability of water for hydropower production, such as pluviometry, the volume of water redirected by the dam to the water turbine also depends on other river regulation functions:

- Water level and flow requirements for navigability, other water uses and safety including flood prevention;
- Minimum instream flow for the functioning of water ecosystems, and resulting in a minimal water level on the dam spillway.

As a result, the power that can be delivered by run-of-river hydropower plants on the Low Meuse depends on river regulation requirements affecting the flow rate, including measures to ensure ecological continuity. The broader constraints of river flow management therefore need to be taken into account when considering the trade-off between renewable power production and ecological continuity restoration, as the operating conditions for run-of-river hydropower plants on the Low Meuse are also largely dependent on multi-purpose, multi-stakeholder water management objectives.

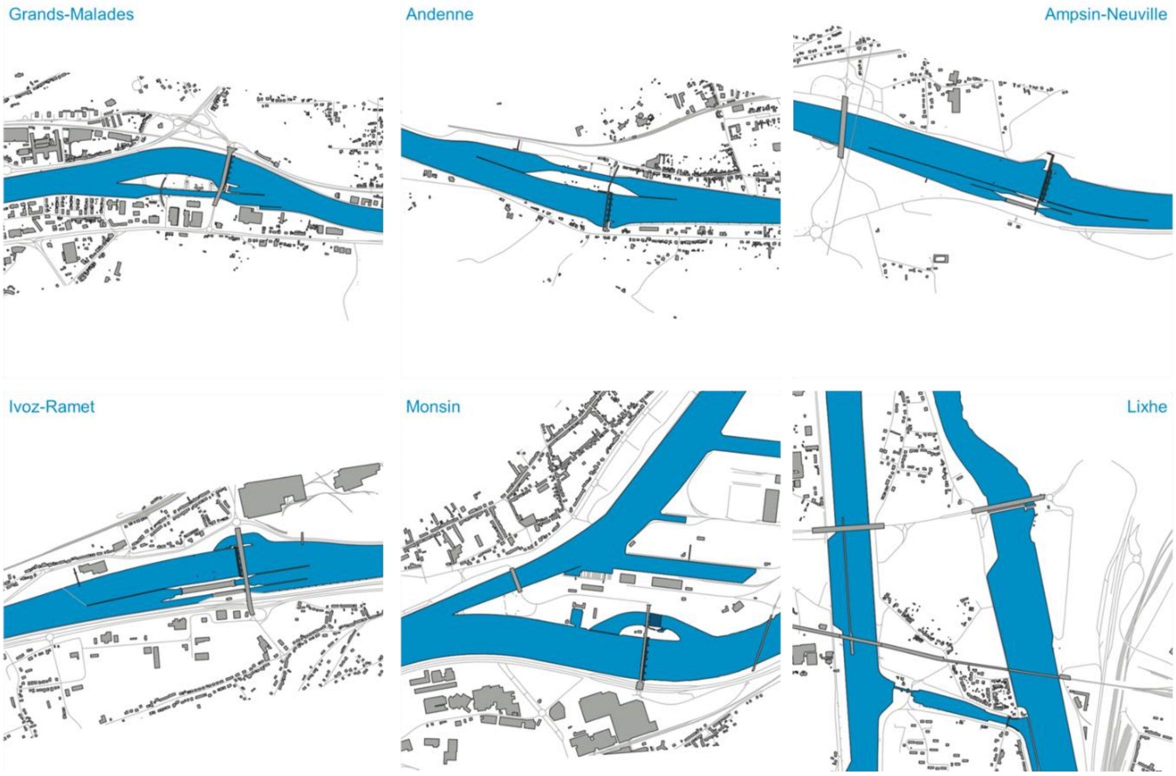

Figure 4 Dams, locks and hydropower plants at the project locations

2.5 Permitting for hydropower plants on the Low Meuse

The starting point of the LIFE4FISH project has been the renewal of operating permits for the Lixhe, Monsin and Ivoz-Ramet hydropower plants since 2008. For the first time, they laid down maximum residual mortality rates for European eels and Atlantic salmons[19]. These maximum mortality rates either reflect European objectives laid down in the Eel Regulation or salmon preservation objectives in Wallonia[20].

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[19] Permits for hydropower plant operation have a twenty-year duration.

[20] Whereas hydropower plants on non-navigable rivers in Wallonia are required to include equipment for the preservation of upstream migrations (fish passes, branch rivers…) and downstream migrations ("ichthyocompatible" turbines and water intakes), these requirements do not apply to installations on the Low Meuse which are subject to obligations on results, and not on means.

In order to prevent hydropower production losses due to migrations in critical periods, which would negatively affect the commercial viability of power plants, LUMINUS initiated the LIFE4FISH project. The approach developed by LUMINUS consisted of apprehending all six hydropower plants on the Low Meuse in order to determine the size of the fish population potentially impacted by them, the cumulated impact of hydropower plants and to develop strategies reducing the mortality of silver eels and salmon smolts.

3 Direct impacts of the project

Indicator	Baseline	Interim result	Project end result	Post-project result (f)	Target
Silver eel mortality	25.8%	20.5%	12.2%	9.9%	<20.0%
Salmon smolt mortality	56.0%	53.8%	17.7%	14.4%	<10.0%
Power production losses	0.0%	1.3%	5.2%	3.7%	<5.0%

Table 4 Key project result indicators – (f): forecast (data source: LUMINUS, May 2022)

3.1 Towards coordinated water infrastructure management

In simplified terms, the downstream migration of salmon and eels largely depends on water flow conditions, at the level of the river system, in specific river sections and around the water infrastructure[21]. The minimisation of power production losses and impacts on fish populations takes into account the following interdependences between water flow conditions, downstream migration and water infrastructure management:

- Migration events: the start of downstream migrations can be related to phenological conditions where increases of water flows play a key role (amongst other factors such as temperature or seasonality) as demonstrated by the migration models developed by the LIFE4FISH project to anticipate them. As a higher flow rate can correspond to a favourable operating range for hydropower production, delineating migration events enables to minimise renewable power losses;
- Migration seasons: as downstream migrations occur at different periods of the year (autumn/winter for eels, spring for salmon) with different water levels, they will correspond to different dam and hydropower plant operating conditions. The availability of water for hydropower production, the amount of water redirected to the turbine or evacuated by dam openings depends on the river regulation functions described above;
- Behavioural aspects: fish locomotion differs between smolts (that swim closer to the surface) and eels (anguilliform propulsion and less predictable itineraries), and is differently affected by the current. As a result, the LIFE4FISH project has combined water flow management and behavioural barriers to direct fishes to a favourable passage. Additionally, the significant decrease of water velocity between upstream tributaries and the Low Meuse, a considerably larger and dammed river section, also affects migration as the interrupted flow can have a disorientating role;

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[21] Interviews with LIFE4FISH project partners

- Impact of different water infrastructure components (turbine, dam, downstream fish pass, but also canalised river sections, other ecological continuity installations) on fish passage, health and mortality.

The definition of less impactful passages for salmon smolts and silver eels in the project has relied on testing and population monitoring (behaviour around the infrastructure, crossing, health effects, mortality) bringing together physical and biological expertise. It has resulted in a range of operational rules for water flow transfers:

- To the dam, with turbine stoppages and dam openings (“migration/compensation” mode);
- To the turbine, which can be specifically designed to reduce impacts;
- To the downstream fish pass, which also represents a flow rate reduction.

As the management of water flow involves different infrastructure operators, flow transfers to enable fish migrations have been coordinated between LUMINUS, hydropower plant operator and coordinator of the LIFE4FISH project, and SPW, the operator of dams and inland waterways. Automated flow transfers have been tested in July 2022 and are being developed, although they remain technically challenging. If successfully implemented in the future, the automation of flow transfers to preserve downstream migration may contribute to a wider integration of command-and-control systems for water infrastructure on the Meuse[22] and more generally to the integration of biodiversity preservation objectives in river regulation functions.

3.2 Scientific knowledge: contributions from/to research in physics and biology

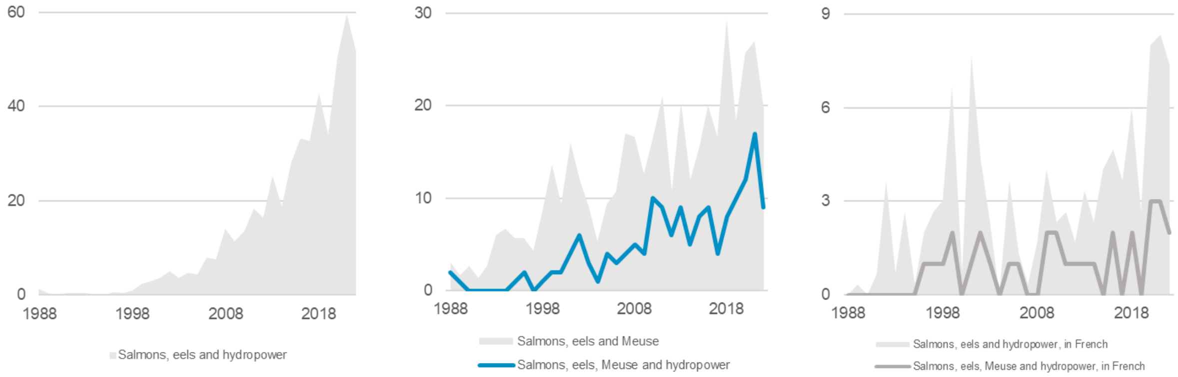

Figure 5 Scientific publications related to salmon, eels, hydropower and the Meuse (data source: Dimensions.ai)

A key contribution of the LIFE4FISH project has been the improvement of the understanding of physical and biological phenomena affecting fish migration[23]. These analyses have enabled to validate:

- The prediction of eel and salmon migration events;
- Less impactful fish passage routes (over the spillway, through the downstream fish pass, through the turbine).

The monitoring of fish populations by the project has also enabled to reassess the size of local eel and salmon populations, as well as to identify the potential impact of other water infrastructure elements on

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[22] With links to the “PEREX 4.0” initiative of the Wallonia government for the operational management of road, inland waterway and broadband network management based on real-time, integrated information systems.

[23] Interviews with project partners. As one respondent puts it, “the challenge was to make different worlds talk to one another”.

fish migration. The in-situ testing of solutions has quantified the impact of the water infrastructure on fish mortality. The implementation of the LIFE4FISH project has thus been accompanied by scientific publications, contributing to a spike in English-language scientific publications on salmon, eels, hydropower and the Meuse river in 2020-2021. These scientific results have been presented by project partners attending conferences, with two key audiences:

- The scientific community (hydrology, fish biology);
- Hydropower plant operators, other water infrastructure operators and their service providers.

Dissemination has been conducted via a scientific committee and local stakeholder committee, including with a local event on biodiversity and renewables in May 2022. The involvement of LIFE4FISH partners in complementary projects (e.g. “Walloneel”) has further contributed to the diffusion of project results.

Scientific publications of the LIFE4FISH project

Imen Ben Ammar, Sébastien Baeklandt, Valérie Cornet, Sascha Antipine, Damien Sonny, Syaghalirwa N. M. Mandiki and Patrick Kestemont, “Passage through a hydropower plant affects the physiological and health status of Atlantic salmon smolts”, *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, Volume 247, September 2020

Imen Ben Ammar, Valérie Cornet, Alexis Houndji, Sébastien Baeklandt, Sascha Antipine, Damien Sonny, Syaghalirwa N. M. Mandiki and Patrick Kestemont, “Impact of downstream passage through hydropower plants on the physiological and health status of a critically endangered species: The European eel Anguilla anguilla", *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, Volume 254, April 2021

Sébastien Erpicum, Vasileios Kitsikoudis, Pierre Archambeau, Benjamin Dewals and Michel Pirotton, “Experimental Assessment of the Influence of Fish Passage Geometry Parameters on Downstream Migrating Atlantic Salmon (Salmo salar) Smolts Behavior”, *Water*, 14 (4), 616, February 2022

Séverine Renardy, Abderrahmane Takriet, Jean-Philippe Benitez, Arnaud Dierckx, Raf Bayens, Johan Coeck, Ine S. Pauwels, Ans Mouton, Pierre Archambeau, Benjamin Dewals, Michel Pirotton, Sébastien Erpicum and Michaël Ovidio, “Trying to choose the less bad route: Individual migratory behaviour of Atlantic salmon smolts (Salmo salar L.) approaching a bifurcation between a hydropower station and a navigation canal”, *Ecological Engineering*, 169, June 2021

Nils Teichert, Jean-Philippe Benitez, Arnaud Dierckx, Stéphane Tétard, Eric de Oliveira, Thomas Trancart, Eric Feunteun, Michaël Ovidio, “Development of an accurate model to predict the phenology of Atlantic salmon smolt spring migration”, *Aquatic Conservation*, Volume 30, Issue 8, August 2020

Nils Teichert, Stéphane Tétard, Thomas Trancart, Eric de Oliveira, Anthony Acou, Alexandre Carpentier, Bastien Bourillon and Eric Feunteun, “Towards transferability in fish migration models: A generic operational tool for predicting silver eel migration in rivers”, *Science of The Total Environment*, Volume 739, October 2020

Nils Teichert, Stéphane Tétard, Thomas Trancart, Eric Feunteun, Anthony Acou, Eric De Oliveira, “Resolving the trade-off between silver eel escapement and hydropower generation with simple decision rules for turbine shutdown”, *Journal of Environmental Management*, Volume 261, May 2020

3.3 Replicable technical innovations

The development of solutions for the reduction of hydropower impact on fish migrations by the LIFE4FISH project has consisted of a combination of modelling, testing and monitoring. The validation of these technical innovations has enabled their reuse in other contexts.

Technical innovation	Description	Replication potential
Downstream fish migration models	The LIFE4FISH project has developed downstream migration models based on phenological indicators (duration of migration, water temperature, and hydrological conditions). They relate the downstream migration of silver eels to water discharge and gradient, and the downstream migration of salmon smolts to discharge and temperature. The prevision of migration events depends on the complexity of hydrological systems, as larger river basins with multiple tributaries complexify the identification of relevant environmental conditions. The models have been validated by acoustic telemetry monitoring.	Since its development by the project, the downstream eel migration model has been reused by other public and private stakeholders on other rivers: Rhine, Loire, Seine and Var[24].

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[24] Interviews with project partners

Technical innovation	Description	Replication potential
Acoustic telemetry	Acoustic telemetry is a method used to investigate the ecology and behaviour of aquatic species in relation to their environment, and to improve the understanding of ecosystem functioning and dynamics. Acoustic telemetry notably enables to conduct three-dimensional monitoring of fish populations, and thereby precisely map out their interactions with the infrastructure. Project data has been made available to the European Tracking Network (ETN), a European biotelemetry network aiming to integrate regional telemetry initiatives.	The acoustic telemetry approach of the LIFE4FISH project has been since then replicated on other rivers (Seine, Allier, Saar) and for other projects on the Meuse[25].
Behavioural barriers	Behavioural barriers aim to alter fish migration routes and direct them to a favourable passage. Two types of behavioural barriers have been tested by the project: › Electrical barriers: the system tested by the project has demonstrated its effectiveness and compliance with operational requirements (notably in terms of protection from river debris); › Bubble barriers: the system tested by the project has not proved effective.	Behavioural barriers are not commonly installed on hydropower plants in Europe. The project may provide return on experience to other hydropower plant operators.
Downstream fish pass ("by-pass")	Downstream fish passes have been designed, tested in lab and installed by LUMINUS and Université de Liège. They build on the analysis of hydrodynamic conditions around the power plants and provide an exit close to the surface for salmon smolts. Their operation requires debris management as natural and man-made debris accumulates on the protective grids and clogs the fish pass.	Further hydrology and fish migration analysis by project partners.
"Eco-sustainable" turbines	Complementary to the LIFE4FISH project, LUMINUS is installing lower-impact turbines on certain hydropower plants, as part of mid-life replacements. The development of lower-impact turbines (for low heads and high flow rates) is based on specifications and scientific reviews jointly conducted by LUMINUS and EDF R&D. Two "eco-sustainable" Kaplan turbines have been installed by LUMINUS in Monsin. Their replication is being studied for the Grands-Malades and Ivoz-Ramet hydropower plants.	Such requirements are encouraging turbine manufacturers to develop designs lowering the impact of the equipment on fish passage.

Table 5 Technical innovations of the LIFE4FISH project

3.4 Reductions in renewable power production

Policy targets and scenarios for achieving climate neutrality by 2050 require an ambitious reduction of greenhouse gas (GHG) emissions by the power sector. Projections at federal level by ELIA (2017) place it in the 93-99% range. As a renewable energy source, hydropower does not emit direct GHG emissions and therefore makes an important contribution to climate and energy policies. In Wallonia, electricity production represents 9% of GHG emissions, and the region aims at 23.5% renewables in final energy consumption by 2030. Regional targets laid down in the National Energy and Climate Plan (NECP) 2021-2030 are based on stable hydropower production assumptions.

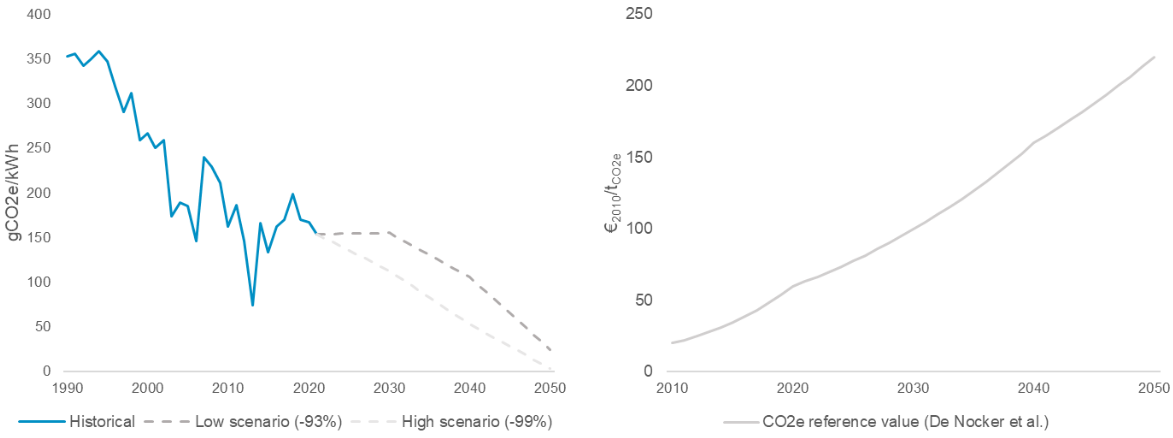

Figure 6 Emissions factor in Belgium (historical data: EEA; 2050 scenarios: ELIA) and CO_2e reference value

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[25] Interviews with project partners

Assuming a conservative 93% reduction of the GHG emissions trajectory in Belgium, the 5% reduction in hydropower production caused by the project (from 250.0 to 237.5 GWh per year[26]) represents an average 1,660 t_{CO2e}/year in 2023-2043 with a climate cost of the reduction in renewable power output having an economic value of €226,303/year[27] and optimised by the minimisation of hydropower production stoppages.

3.5 Investment

The minimisation of turbine stoppages and power production losses plays a key role in maintaining the commercial viability of the power plants. Hydropower investments are characterised by long asset lifetimes, high capital expenditure costs (initial investment and replacement costs) and low operation and maintenance costs. Expenditure by the LIFE4FISH project has consisted of research and development costs entailing the following:

- Studies and development (personnel) costs, resulting in new power plant operation rules and an assessment of the effectiveness of solutions;
- Installation of innovative equipment to facilitate fish passage (behavioural barriers, downstream fish passes involving civil works).

They have been complemented by the installation of lower-impact turbines, as part of mid-life equipment replacements.

3.6 Employment

The development of technical innovations for the project has been conducted over a five-year period by a staff of project partners and service providers with advanced qualifications, contributing to the emergence of high value-added solutions for ecological continuity improvement – and notably the development of acoustic telemetry. These activities contribute to the lifetime extension of the hydropower plants of the project, and to the preservation of the related employment which represents up to 25 direct jobs[28].

Partner	Total FTE	Qualification level
LUMINUS	<1.0	Master's/Engineering Ma, other
PROFISH	1.1	Master's/Engineering Ma, PhD
EDF R&D	<1.0	PhD
Université de Liège	<1.0	PhD, other
Université de Namur	<1.0	PhD, other

Table 6 Indicative full-time equivalent and qualification levels of staff involved in the LIFE4FISH project

4 Biodiversity benefits

The European eel and the Atlantic salmons are protected species in Wallonia, and are not being used for fishing or other purposes. Their existence however delivers socioeconomic benefits, as they contribute to the overall functioning of river ecosystems and are culturally significant. Regional efforts to restore local populations and stated preferences provide an indication of their importance for regional well-being.

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[26] Based on project baseline and target, not actual production.
[27] In EUR_{2021}, value not discounted
[28] Figure provided by LUMINUS. Each hydropower plant includes a site coordinator and technician for operation & maintenance, and all sites involve a centralised management and control system as well as support functions.

4.1 The value of ecosystem services in general

Ecosystem services refer to the dependence of human societies on the effective functioning of natural systems. They consist of outputs, conditions or processes that benefit humans or enhance social welfare. Different categories of ecosystem services can be identified[29]:

- Provisioning services, such as drinking water, process water, food and other products;
- Regulating services, such as water quality, flood protection, regional climate regulation;
- Cultural services, such as landscapes, emblematic entities, quality living environments, artistic inspiration, mental health, sciences and education.

These categories also include supporting services that contribute to the provision of other services (e.g. habitat and nutrient provision). The concept of ecosystem services enables to describe the variety of interactions supporting human existence within the environment. The socioeconomic benefits of ecosystem services can be created by their use, either directly or indirectly, but also by their mere existence. In economic terms, the total economic value (TEV)[30] of an environmental good is the sum of all its benefits for individuals, i.e. its contribution to welfare according to individual preferences. It largely depends on cultural factors.

Use/Non-use	Value	Description
Use value	Use value	Actual or planned use
	Option value	Conservation in existence for a possible future use
Non-use value	Altruism value	Conservation in existence for others
	Bequest value	Conservation in existence for future generations
	Existence value	Conservation in existence with no use to anyone

Table 7 The total economic value, based on OECD (2006)

Lastly, it should be noted that biodiversity also has an intrinsic value which is non-instrumental and independent from human values attached to it; although essential to apprehend the variety of interrelations in ecosystems beyond anthropogenic perspectives, intrinsic values have limited relevance to decision-making, and thus to the present socioeconomic assessment.

Improvements of river ecosystems can benefit a range of stakeholders including the local population, water suppliers and consumers, recreational users, and society in general. Based on a meta-analysis of studies in other countries (benefit transfer method), ICEDD (2014) estimates that the total value of provisioning, regulating and cultural services of freshwater ecosystems in Belgium amounts to €144,509/ha/year[31]. This includes the value derived from the supply of water and related products, recreational activities, flood prevention, water quality and biodiversity by rivers, lakes and wetlands.

4.2 The value of salmon and eels as protected species

The Atlantic salmon and European eels have been respectively extinct and quasi-extinct in the Low Meuse for several decades. As protected species in Wallonia, they cannot be commercially or recreationally fished. The current population of salmon results from an extensive reintroduction programme, and both species have benefitted from important regional investments in ecological continuity, water quality improvement, habitat restoration and research.

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[29] Examples are from DENDONCKER and RAQUEZ (2013) for freshwater ecosystems in Wallonia

[30] OECD (2006)

[31] In EUR_{2021}, value not discounted. ICEDD (2014) refers to the methodology used by CARRARO et al. in “Impacts of Climate Change and Biodiversity Effects, Final Report to the European Investment Bank” (2009), however this publication is not publicly available.

The two species play a highly symbolic role for the quality of river ecosystems and regional biodiversity in general:

- They are culturally significant, although with differences between salmon (with a generally positive image and with historical efforts to restore its migratory cycle through the "Meuse Saumon 2000" programme suggesting its contribution to the regional natural heritage) and eels (with a less emblematic role);
- Their conservation symbolises a prevention of further biodiversity losses: they are referred to as "flagship" or "umbrella" species whose protection delivers benefits to other species[32] (and noting that the outstanding swimming abilities of the salmon are key for demonstrating the feasibility of restoring the migration cycle of diadromous species);
- Their existence can imply an overall improvement of water quality;
- Their conservation is part of regulatory requirements (the Eel Regulation) and international commitments to maintain populations above reasonable biological limits;
- The local protection of migrating species delivers benefits to other areas along their migration route.

As a result, emblematic species such as salmon and eels largely contribute to river ecosystem services through their existence, as a sign of water quality and a contribution to natural heritage. Conservation costs provide an indication of their regional importance, while their contribution to welfare can be assessed by a stated preferences approach (willingness-to-pay).

4.2.1 Indirect approach: conservation efforts

The restoration of ecological continuity in Wallonia has mobilised important regional efforts since the 1990s, consisting of infrastructure works to remove obstacles, habitat restorations and research. These actions are not exclusively designed for salmon and eels, and are generally protective of the fish population and biodiversity.

Infrastructure adaptations to overcome obstacles on the Low Meuse consist of the following:

- Upgrade of fish passes for upstream migration at dam and lock complexes;
- Downstream migration works and equipment on hydropower plants, including as part of the LIFE4FISH project at Grands-Malades.

Location	**Upstream migration**		**Downstream migration (hydropower plant)**
	Original fish pass	Upgrade	
Lixhe	Pool ladder	Pool ladder with lateral slots (1998)	Downstream fish pass (1999)
Monsin	"Denil" baffle fishway	Pool ladder with vertical slots (2000)	'Eco-sustainable' turbine (2020)
Ivoz-Ramet	"Denil" baffle fishway	Pool ladder with vertical slots (2001)	'Eco-sustainable' turbine (2023)
Ampsin-Neuville	"Denil" baffle fishway	Artificial river (2023)	-
Andenne	Pool ladder	Planned (-)	-
Grands-Malades	Pool ladder	Planned (-)	Downstream fish pass (2020) and 'eco-sustainable' turbine (planned for 2026)

Table 8 Upstream and downstream migration equipment on obstacles on the Low Meuse

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[32] Other diadromous species of the Meuse ichthyofauna are the sea trout (*Salmo trutta trutta*), the allis shad (*Alosa alosa*), the twait shad (*Alosa fallax*), the houting (*Coregonus oxyrhynchus*), the European sea sturgeon (*Acipenser sturio*), the sea lamprey (*Petromyzon marinus*), the European river lamprey (*Lampetra fluviatilis*), the European flounder (*Platichthys flesus*) and the European smelt (*Osmerus eperlanus*) – International Meuse Commission (1999)

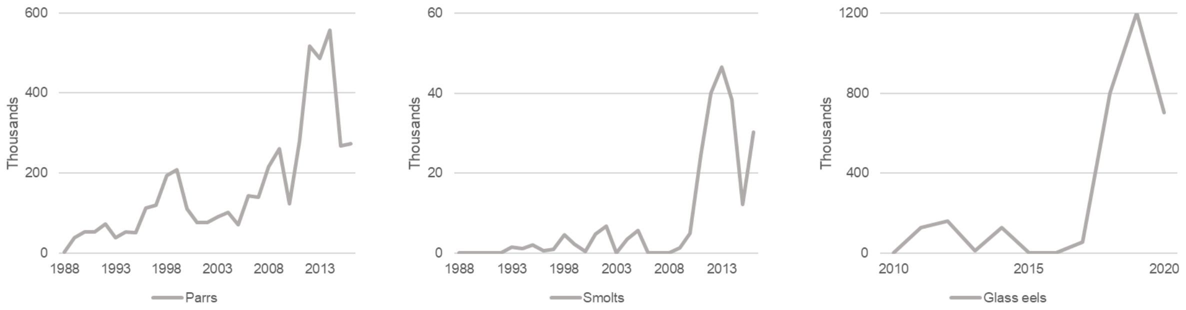

Figure 7 Number of restocked parrs, smolts (data source: SPW) and glass eels (data source: WGEEL) in Wallonia

The reintroduction of salmon and eels is specifically pursued by restocking programmes managed by the Wallonia region, either to redevelop (in the case of the Atlantic salmon) or to compensate the decline (in the case of European eels) of endemic populations.

Releases of young Atlantic salmons have been conducted by SPW since 1988 in the Ourthe and its tributaries Amblève and Vesdre, as well as in the Lesse (upstream of the project area) and its tributary Lomme. A public fish farm ("Pisciculture domaniale d'Erezée"[33]) is since 2015 dedicated to the breeding of Atlantic salmon, with a conservatory attached to it ("Conservatoire du Saumon Mosan") for heritage and educational purposes.

Restocking of European eels has existed in Wallonia throughout the 20th century (notably in support of fishing) and has considerably increased since 2018 in the framework of the regional EMP. Releases of glass eels and elvers purchased in the United Kingdom and in France are conducted in the Meuse tributaries Méhaigne and Oxhe and in the Ry de Mosbeux in the Vesdre river basin.

As a longer-term perspective, the Wallonia region steers river restoration programmes, either on the navigable network or on Meuse tributaries. Habitat creations have accompanied recent upgrades of inland waterways (Lanaye, Ampsin-Neuville). Some ground areas along the Low Meuse have been designated as protected (classification of some river islands as natural reserves, inclusion of riparian areas in the Natura 2000 network). In the river itself, vegetated rafts have been installed to provide spawning grounds that had disappeared with the construction of artificial banks. Ecological restoration measures are conducted in Meuse tributaries[34] and coordinated by "Contrats de Rivières" with local stakeholders. In the short to medium term however, river restoration does not have a direct effect on salmon as the population exclusively comes from artificial breeding.

Financial resources for these measures come from regional ("Fonds Piscicole et Halieutique de Wallonie", other), European (European Maritime and Fisheries Fund) and environmental compensation ("Fonds de protection de la Biodiversité") programmes.

4.2.2 Direct approach: stated preferences

Stated preferences methods using experiments, focus groups or surveys can be used to assess the demand for non-market resources and describe preferences[35]. They often include a measurement of

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[33] Three public fish farms ("piscicultures domaniales") are managed by SPW in Erezée, Florenville and Emptine

[34] Guidelines for ecological restoration have notably been developed by the LIFE WALPHY project (LIFE07 ENV/B/000038) in the Upper Meuse in 2009-2013, and hydromorphological restorations of the Ourthe, Amblève, Vesdre and Our river basins with the LIFE VALLEES ARDENNAISES project (LIFE19 NAT/BE/000054) in 2020-2028.

[35] Many, if not most environmental goods are not tradable in an organised market. As the measurement of socioeconomic benefits will usually require a conversion in monetary terms to reflect arbitrations between different objectives, various methods can be adopted to elicit their value. These can be indirect methods (measuring the costs of environmental damages, of protection measures, hedonist pricing, travel costs) or direct methods assessing the willingness-to-pay for environmental goods through surveys or experiments. These methods are subject to important limitations, as they do not necessarily reflect fully the reality of ecosystem services provided, or as they aim to derive individual preferences that are subject to biases. Qualitative approaches are therefore essential to describe ecosystem services and their perceptions.

the willingness-to-pay for an environmental change (or willingness-to-accept it) which translates in monetary terms the benefits of an ecosystem service.

In order to collect locally relevant information for this socioeconomic assessment, a small-scale field survey was conducted in the project area[36]. The first objective of the survey was to obtain information on general attitudes and motivations towards environmental protection, water quality and protected fish species such as salmon and eels.

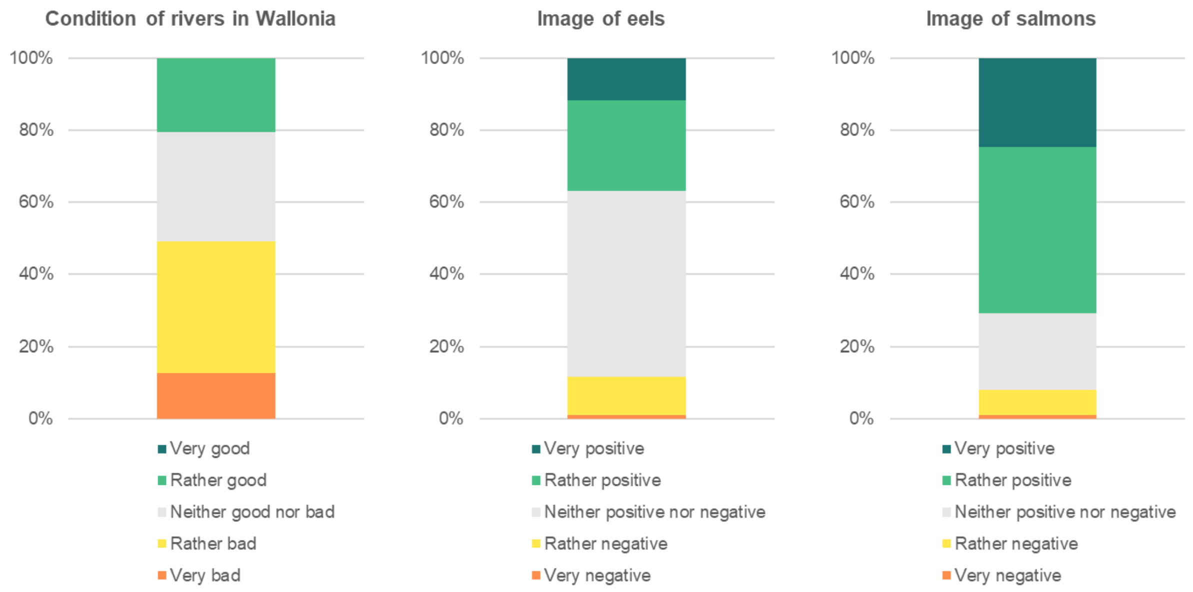

Figure 8 Perceptions of river condition, eels and salmon in Wallonia

It also provided qualitative information on perceptions of water quality, salmon and eels, as well as on motivations for biodiversity conservation:

- General opinions on the quality of rivers in Wallonia: statements on the "good" or "bad" condition of rivers were nuanced by differentiations between rivers, by statements on its general improvement, and in some cases by a comparison with the Netherlands;
- Unclarity on the actual existence of salmon and eels in the Meuse: some respondents recollected memories of salmon and eel fishing by previous generations, others mentioned their visits to fish passes;
- General opinions on salmon and eels: "positive" and "negative" perceptions of fish species can be affected by culinary or aesthetic considerations or by representations in popular culture, while "neutral" perceptions can either reflect disinterest in fish or a reluctance to rank species (notably by anglers or people involved in river restoration activities, stating for instance that "all species are important"). Negative perceptions can also be caused by eco-toxicity concerns, as these fish species can accumulate harmful substances;
- Types of benefits: the improvement of water quality and biodiversity is not spontaneously perceived as bearing benefits for the respondents themselves, although they can regard it as very important. This rationale of protecting biodiversity "for itself" is coherent with the relatively high existence value of protected species.

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[36] Survey conducted along the Meuse in the areas of Namur and Liège in 2023 (N=113)

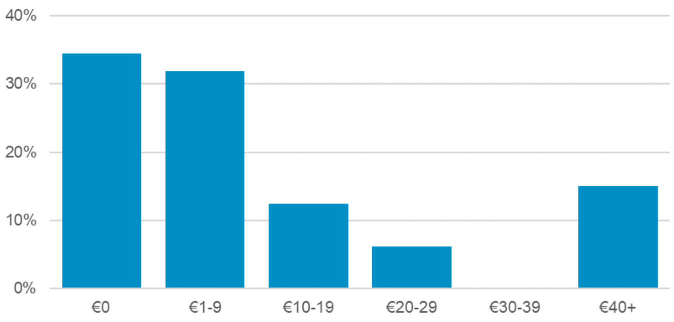

Figure 9 Range of responses in the assessment of willingness-to-pay for an increased preservation of protected species such as salmon and eels in Wallonia

The second objective of the survey was to obtain an order of magnitude of the willingness-to-pay for an increased protection of fish species such as salmon and eels, irrespective of their population size. Its results indicate that it could amount to €10.9 per person, which would represent a total €5.7 million benefits in the communes along the Meuse in the project area[37] and a total €25.6 million at the level of the Meuse river basin in Wallonia.

This estimate is subject to important limitations stemming from:

- The limited size of the sample;
- The absence of correction for income effects;
- The hypothetical nature of the question, which is subject to biases (enrolment bias, anchoring, “warm glow” effect) and rejections (“individuals are not supposed to contribute directly to environmental spending”).

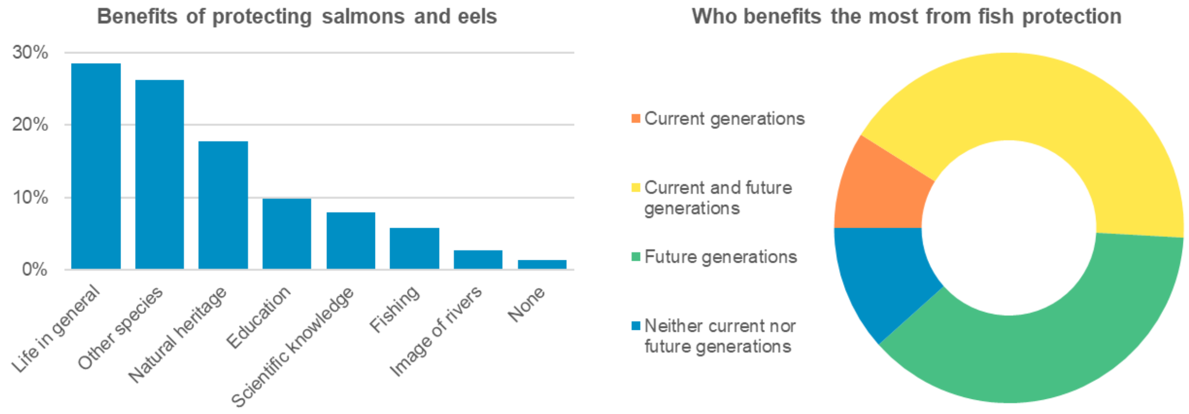

Figure 10 Perceived benefits of protecting salmon and eels and their generational distribution

This result is also independent from a specific protection action and its actual effect on population statuses (it does not for instance differentiate between projects having an impact above or below reasonable biological limits). It however suggests the relatively high benefits of biodiversity conservation and water quality improvement measures generally and their contribution to well-being in the region. Given this importance, and considering the magnitude of investments required to deliver these benefits, a fully-fledged research project on the value of protected species and of water ecosystems across the Meuse river basin would be needed to guide decision-making more precisely.

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[37] 519,045 inhabitants in 11 communes: Namur, Andenne, Huy, Amay, Engis, Saint-Georges sur Meuse, Flémalle, Seraing, Liège, Oupeye and Visé

Conclusion and perspectives

The Low Meuse has been undergoing over a century of alterations in support of economic development in the region, and is today a heavily modified water body with a considerable infrastructure enabling inland navigation, water supply and energy production. Policy developments in the last decades have progressively started to take into account broader river regulation objectives such as ecological continuity preservation, acknowledging that the ecosystem services of rivers are an integral part of the effective functioning of society. This requires to reconcile the services provided by the water infrastructure with the prevention of further biodiversity losses.

The LIFE4FISH project has aimed to demonstrate the effectiveness of technical innovations reducing the impact of hydropower installations on the mortality of silver eels and salmon smolts. Its operational challenges related to water flow management reflect the need for an increased coordination in water infrastructure management, and more largely for an integrated management of river regulation along the Meuse as it affects multiple water uses while delivering public goods on an international scale. The project has proposed an innovative approach for limiting hydropower production losses and maintaining hydropower plants in operation, in line with the extended economic lifecycle of power production assets. Hydropower plants contribute to renewable energy production, in a context where the predictability and substitutability of power generation capacities remain essential for the functioning of the energy system. The hydropower plants of the project also contribute, to a certain extent, to regional employment and investment, as well as to the cultural heritage of Wallonia.

As protected species, the Atlantic salmon and the European eel play a highly symbolic role for water quality improvement and, through their existence, effectively contribute to well-being in the region. The protection of their downstream migration is coherent with the important regional efforts to restore endemic populations, which entail restocking and infrastructure adaptation works. Measurement of the negative impacts of the water infrastructure on these populations contributes to a broader improvement of the understanding of anthropogenic pressures and evolution of population statuses.

The measures to restore ecological continuity on the Meuse may be better apprehended within a wider analysis of ecosystem services provided by the river: it would call for a broader approach of the socioeconomic benefits of its river services, taking into account the variety of pressures and water ecosystem contributions to society. This would additionally require to consider the uncertainty inherent to biodiversity scenarios: actual population statuses, causality and magnitude of negative pressures, efficiency of preservation measures, risk of “bottleneck events” etc. The development of a shared understanding of biodiversity impacts based on population monitoring appears to be a prerequisite for the development of a strengthened governance of river regulation.

Lastly, downstream fish migration and hydropower production are both intrinsically linked to water flow. Climate change observations on the Meuse suggest a modification of its hydrological regime with increasing extreme events in rainfall and water run-off, and important variations in river discharge. This underlines the need to ensure the operational adaptability of the infrastructure, but also to integrate longer-term considerations in both environmental objectives and infrastructure planning.

Annexes

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