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Sharing Water: Multi-Purpose of Reservoirs and Innovations

Hydropower as a catalyst for the energy transition within the European Green Deal Part I: urgency of the Green Deal and the role of Hydropower

L'hydro-électricité catalyseur de la transition énergétique du Pacte Vert européen Partie I : l'urgence du Pacte Vert et le rôle de l'hydro-électricité italiques)

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Abstract. The European Union has the ambition to be the first carbon-neutral continent by 2050. To fulfil this objective and integrate into the grid the large amount of power from solar and wind, Europe can rely upon the high storage and flexible capacity of hydropower. Thus, new reservoirs and innovative use of current reservoirs will be needed to provide an effective contribution to this unprecedented European Green Deal. The project Hydropower Europe, funded by the H2020 research programme, is tasked with identifying innovative uses of reservoirs and prioritizing the associated innovation actions targeting an energy system with high flexibility and renewable share. The project deliverables are a Research and Innovation Agenda (RIA) listing the top strategic research and innovation directions and a Strategic Industry Roadmap (SIR) addressing non-technical actions and requests for the hydropower sector. This paper describes the vision of the project: "Hydropower as a catalyst for the energy transition". In this paper (Part I), the Green Deal and the role of hydropower are outlined and discussed. In Part II of the paper, after highlighting the complex environment that hydropower is situated within in Europe, and the challenges of biodiversity, the main innovation and research directions (extracted from the RIA) and the main steps for combining multipurpose hydropower, in a sustainable, efficient and cost-effective manner (extracted from the SIR), are presented.

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Résumé. L'Union européenne a l'ambition d'être le premier continent neutre en carbone d'ici 2050. Pour atteindre cet objectif et intégrer dans le réseau d'électricité la quantité d'énergie croissante provenant du solaire et de l'éolien, l'Europe peut compter sur l'importante capacité de stockage et de flexibilité de l'hydroélectricité. Ainsi, de nouveaux réservoirs et une utilisation innovante des réservoirs actuels seront nécessaires pour apporter une contribution efficace à ce "Pacte Vert" européen sans précédent. Le projet Hydropower Europe lancé par le programme de recherche H2020 est chargé de définir les utilisations innovantes requises des réservoirs et de fixer la priorité des innovations associées visant un système énergétique à haute flexibilité basé sur les énergies renouvelables. Les livrables du projet sont un programme de recherche et d'innovation (RIA) énumérant les principales orientations stratégiques en matière de recherche et d'innovation et une feuille de route stratégique pour l'industrie (SIR) traitant des actions et des demandes non techniques pour le secteur de l'hydroélectricité. Ce document décrit notre vision : "L'hydroélectricité comme catalyseur de la transition énergétique". Dans cette première partie de rapport, le Pacte Vert et le rôle de l'hydro-électricité sont décrits et discutés. Dans la seconde partie du rapport, après avoir souligné l'environnement complexe dans lequel se situe l'hydroélectricité en Europe et les défis de la biodiversité, les principales innovations et directions de recherche extraites du RIA et les principales étapes (issues de la SIR) pour combiner les usages multiples de l'hydroélectricité d'une manière durable, efficace et rentable, sont présentées.

1 Introduction: the urgency of the Green Deal

1.1 Climate change: the unprecedented global emergency

Climate change due to global warming is the biggest threat in the 21st century. We must stop the harm we are causing to the natural world that is pushing other species to the point of extinction. If we do not address the causes of climate change in time, communities across the world stand to simultaneously face multiple intensifying climate hazards that pose a broad threat to humanity. To make a better world, protected from climate hazards, our energy system has to decarbonise.

1.2 The European Green Deal addressing climate challenge

European Union (EU) policy has led the way in the fight against global warming and climate change, courageously showing actions that other countries can take to save the planet. It aims to enshrine the commitment to making Europe the first carbon-neutral continent by 2050! The European Commission's vision outlines seven strategic building blocks showing how Europe can lead the way towards climate neutrality - an economy with net-zero GHG emissions. The purpose of the second strategic building block is to maximise the deployment of renewable and the use of electricity to fully decarbonise Europe's energy supply [1].

1.3 The future decarbonised energy system for the EU

Consistency with the 2-degree Celsius global warming target set by the Paris Agreement (2015) can only be done through massive deployment of renewable energies. Decreasing levelized costs for solar and wind energy sources are boosting their deployment, but at the same time they are requiring huge energy storage capacity and flexibility for integrating their variable supply of electricity generation into the grid. It should also be noted that deployment of some technologies (e.g. for electric vehicles or batteries) raises concerns in terms of the future supply of raw materials. These issues make progress towards a circular economy even more important. To fulfil these objectives and build a secure and reliable electric system, with a large share of variable RES, Europe needs to integrate the storage potential and flexibility capacities of hydropower into the current and future energy system.

1.4 What role for hydropower?

Europe has the ambition to be a world leader in renewable energy, and fortunately, is already a world leader in hydropower technology. However, hydropower has not often been mentioned or even properly considered [2, 3] within EU energy development perspectives.

This current situation requires an updated analysis to elaborate a decarbonisation strategy that is fully integrated within the Commission's political priorities, which notably focuses on jobs and growth, further integration of the internal market, and a fairer and more sustainable economy.

1.5 The purpose of Hydropower Europe forum

Hydropower Europe is a forum launched through the H2020 call LC-SC3-CC-4-2018: "Support to sectorial fora (to Hydropower)", bringing together the relevant stakeholders of the hydropower sector from 2018 to 2021. The final objective is to give a seat to hydropower in the 2050 neutral carbon energy system by making it more flexible for integrating variable renewable energy sources in the electric system and even more productive over the coming decades. In that perspective, the forum firstly identifies research and innovation needs and priorities for hydropower deployment, including its contribution to flexibility in the energy system as a key driver; these actions are identified in the Hydropower Europe Research and Innovation Agenda (RIA). In a second step, the forum delivers a Strategic Industry Roadmap (SIR), which outlines the deployment strategies of hydropower, based upon its services to the energy system, evidence of its direct contribution to economic and social wellbeing and also sustainability improvements to overcome non-technical barriers to projects.

2 How hydropower can be the backbone the Green Deal

2.1 A fully renewable energy system requires hydropower

Hydropower, supplying clean, affordable and secure energy, supports the main climate and energy targets of the European Green Deal. Hydropower is the best technology to integrate variable renewable energy sources into the electricity system. There can be no fully renewable energy system without hydropower, as no other single renewable electricity technology can offer all of the benefits and services that hydropower provides to the energy system (Table 1).

Moreover, hydropower is one of the most efficient renewable technologies to limit global warming.

Table 1. Ancillary services provided by Hydropower to the electricity system.

Balancing	**Reactive power**	**Black start**
- Frequency control - Storage capacity with long-term and seasonal reserves if reservoirs are present - Near zero-carbon back-up for variable output RES	- Voltage stabiliser - Loop flow control - Bottleneck control - Short circuit capacity	- Power system reconstruction

2.2 Hydropower contributes to global warming attenuation

Several environmental indicators of the global survey carried out by [4] demonstrate that hydropower is the energy to use as much as possible to help attenuate global warming, triggered by energy consumption. Estimating the value of these indicators over the technology lifecycle is the best way to compare the contribution of each type of generation technology to attenuation of global warming.

Hydropower plants have the lowest value (3-7 gCO_2-eq./kWh) of the Climate Change indicator of generation technologies in Nordic or mountainous area countries (Figure 1). The Climate Change indicator is related to lifecycle greenhouse gas (GHG) emissions into the atmosphere per kWh. This CO_2 emission is impressively lower than the average value of electricity supplied in the European Union in 2018 (240 gCO_2-eq./kWh), and than the 2040 Sustainable development scenario (28-80 gCO_2-eq./kWh [5].

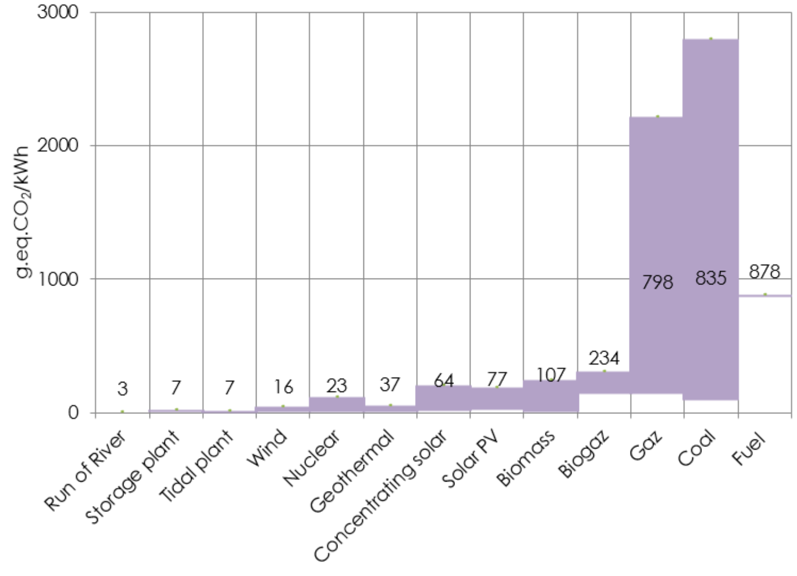


Fig. 1. Mean, min and max of the indicator "Climate Change" by technology [4].

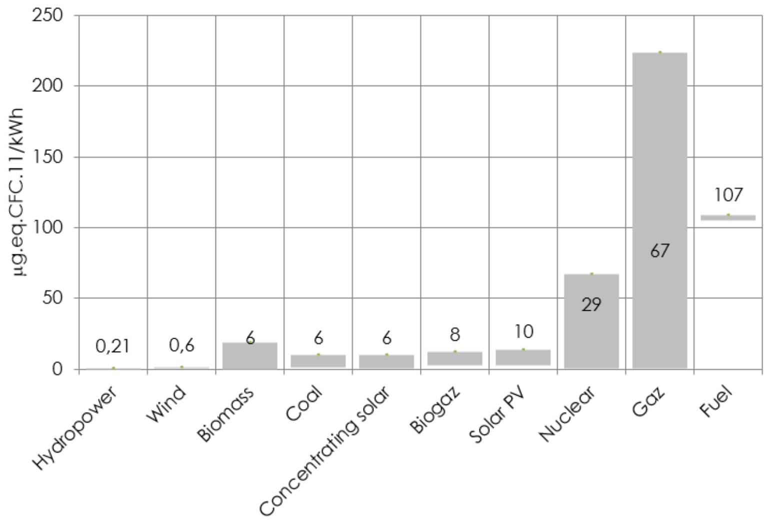


Fig. 2. Mean, min and max of the indicator "Destruction of the ozone layer" by technology [4].

Hydropower plants have the lowest Ozone Layer Depletion indicator (Figure 2). The Ozone Layer Depletion indicator is related to the depletion of the stratospheric ozone layer, which results in an increase in ultraviolet (UV) radiation reaching the earth. The Ozone Depletion Potential (ODP) is measured in kilograms of trichlorofluoromethane equivalent (kg/kg CFC-11).

Hydropower generation systems have the highest Energy Returned On Energy Invested ratio (Figure 3). The mean EROI value is 82:1 (n of 17 from 12 publications), of electric power generation systems [6].

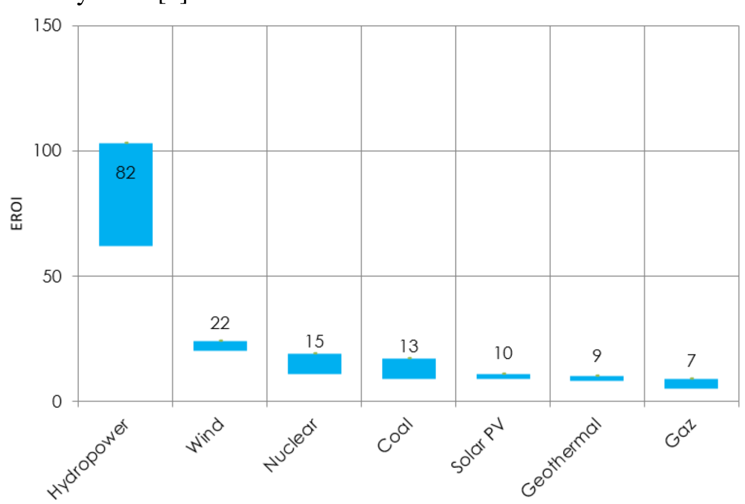


Fig. 3. Hydropower has the best EROI [6].

ERoEI, or EROI, also sometimes called recovery factor of energy or gain factor of energy, is the ratio of the amount of usable energy (the energy) delivered from a particular energy resource to the amount of energy used to obtain that energy resource. A lot of studies have been carried out with various assumptions (for example in Switzerland by [7] and most of them found that hydropower generation systems have the best gain factor of energy compared to other electricity generation technologies.

2.3 Circular economy

One of the main blocks of the European Green Deal is the circular economy [8]. Decoupling economic growth from resource use, the circular economy will make a decisive contribution to achieving climate neutrality by 2050. Hydropower has demonstrated its implementation of most of the sustainability principles and has the ambition to fully contribute to the 7 key elements of circularity (Figure 4).

Fig. 4. The seven circularity principles (Circle economy 2008).

1. Prioritise regenerative resources: Hydropower is also the best renewable energy for reducing pressure on mineral resources (Figure 5). The Extraction of Mineral Resources indicator is measured in kilograms of antimony equivalent (kgeq.Sb) per kilogram extracted to take into account existing reserves, the rate of extraction and the "depletion" of each mineral substance [4]. Hydropower has amongst the best values and solar PV the worst.

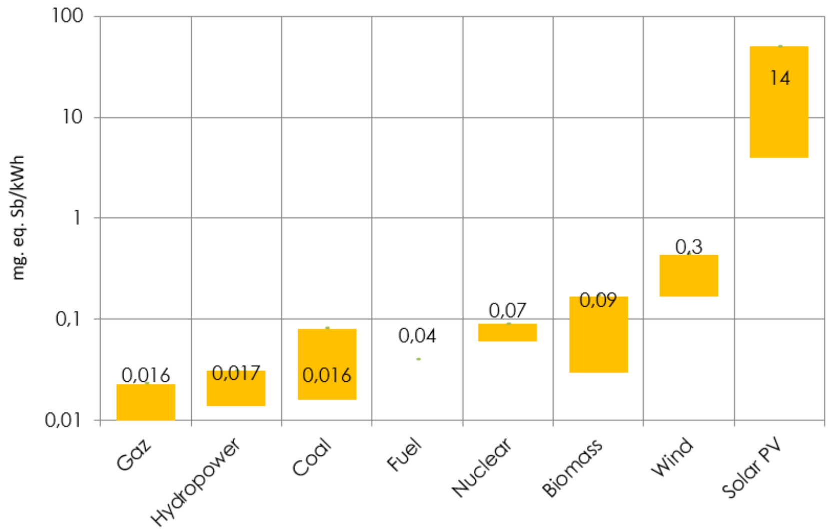


Fig. 5. Comparison of mean, min and max values of the Mineral Resource Extraction indicator between generation technologies [4].

Moreover, hydropower is the best renewable source minimising energy losses and global warming. Thanks to a high electricity conversion efficiency, which typically reaches from 85% to 95%, hydropower minimises losses of energy and heat release in the transformation process.

2. Design for the future: Hydro plants and dams have a very long technical lifetime often exceeding 100 years. At the end of their lifespan, plants and dams may be theoretically decommissioned and removed, allowing the site to regain its natural appearance. Whilst hydropower has impacts that are clearly visible during its operational life, these are in general reversible and sites could be restored. Nevertheless, after more than 100 years of operation, hydropower schemes very often become historical monuments and also new rich biotopes are created in the reservoir area.

3. Preserve and extend what is already made: Due to this very long lifespan, maintenance, surveillance and safety are key actions that have to be permanently implemented for improving durability, upgradability and reparability [9].

4. Use waste as a resource: Hydro plants contribute to clean rivers. These plants are equipped with trash racks and automatic cleaning machines, which remove floating debris including waste and garbage. This waste is then sorted and sent to waste disposal plants for recycling.

However, greater efforts are needed to ensure the continuity sediment which can be trapped within the reservoir and starved from downstream channels.

5. Incorporate digital technology: Digitalisation is increasingly used for tracking and optimising water and energy uses.

6. Collaborate to create joint value: Owners of multipurpose reservoirs are used to create joint value of water and energy. Today, hydropower creates values with surplus of solar PV and wind energies.

7. Rethink the business model: Hydropower is considering opportunities to create greater value to power flexibility and water services through business models that build on the interaction between services.

2.4 Sustainable Development Goals (SDG)

The 17 Sustainable Development Goals were adopted by all member governments of the United Nations and provide a blueprint of priorities for national governments, multilateral organisations, business and civil society. It is outstanding to note that hydropower can contribute to all of these 17 societal and environmental goals! Hydropower projects, when developed and operated responsibly, directly support the achievement of Sustainable Development Goals (SDG) 6, 7, 9 and 13 (Figure 6).

Fig. 6. Hydropower directly supports SDG 6, 7, 9 and 13 [5].

Hydropower projects can also contribute towards economic development, social investment and environmental outcomes which support goals 1,2, 3, 4, 5, 8, 10, 11, 12, 14, 15, 16 and 17.

2.5 High value creation

Hydropower creates significant value to the European economy and contributes to massive exports. On average, each employee in the European hydropower generation sector creates an annual value of more than €500,000. This value is ten times more than in the construction sector.

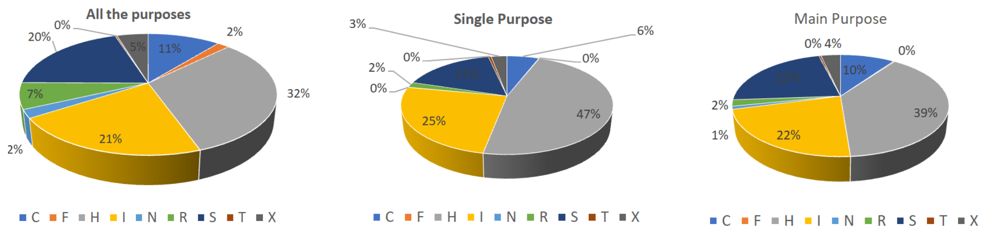
The contribution of hydropower (including electricity generation, manufacturing and VAT revenues) to the European gross domestic product (GDP) is estimated to be about €38 billion (EU-28, Norway, Switzerland, Turkey), of which €25 billion is in the EU-28 [8].

Hydropower contributes to employment in Europe with more than 100 000 full time equivalent jobs (FTE). Of these, more than 50 000 are directly related to hydropower generation (42 000 in EU-28), 7 000 in manufacturing (5 000 in EU-28) and the remaining part in other sectors providing external services to the hydropower sector, including operations and maintenance, planning, engineering and consulting.

Hydropower is also a considerable source of investment in the European economy. Hydropower is a capital-intensive generation technology and requires high long-term investments both for the construction of dams and hydropower plant infrastructure as well as for maintenance and refurbishment. It invests € 8-12 billion a year, of which € 5-6,3 billion in EU-28 between 2010 and 2013 [8].

2.6 Hydropower boosts regional sustainable development

Hydropower is not only a renewable, low carbon, cost effective, mature and long asset life technology, but it also provides sustainable development of European regions. Large hydroelectric plants associated with reservoirs have a remarkably beneficial impact on territories where they are located. They are banks, which store a valuable natural resource, the water, and support its use for many economic services: irrigation and drinking water storage, sustainable transport, prevention of flood and drought, tourism, recreation and sport, fisheries, improvement of infrastructures (Figure 7).



Legend: C =Flood F = Fisheries H = Hydropower I = Irrigation S = Water Supply N = Navigation R = Recreation and tourism T = Tailings X = Unknown or unclassified

Fig. 7. Share of reservoirs uses by purpose in Europe [10].

But first and foremost, hydropower is a money-maker for communities near the dam and the plant, not only producing electricity revenues but also creating jobs and providing taxes and licence fees.

2.6.1 A financing resource for local communities

Hydropower projects are playing a significant role in accelerated GDP growth. A substantial share of generation revenues is transferred to the economy in the form of value added tax (VAT), local shareholders' income, taxes and job employment. Total revenues for governmental budgets amounted to more than € 8 billion for EU-28 or € 14 billion when also including Norway, Switzerland and Turkey. In other words, more than 32% and 37% of the gross value created by hydropower in the EU-28 and Europe respectively, are directly transferred to national or regional budgets [8]. There is no other renewable source giving back so much money to society.

2.6.2 Irrigation, drinking water supply and hygiene

Hydropower reservoirs have always been used for water security and sustainable development goals, since they were first constructed. As hydropower stations are often located in rural areas, the water used by these power stations is usually shared and/or reused for irrigation and for aquatic ecosystems [11].

2.6.3 Sustainable transport

Rivers act as a key source of economic activity: from trade to agriculture and energy, as well as many other activities that can be developed along a water course. For example, at first a wild river, historically the Rhine meandered between marshlands bringing malaria and catastrophic floods that cut off villages. Man then protected himself by building levees. These helped provide better protection and also increased the agricultural surface area, while on the other hand the water flow rate and erosion issues increased making navigation impossible in some places. To solve this, the Rhine was first channelled by rows of groins and then by a wide canal, which was financed by hydropower. The canal reduced the transport of solids and sediments but also increased the risks of floods. Polders were built to slow down the flooding, and water releases were made more frequent to revitalise sediments and reserved flows with fish ladders (side rivers) to improve ecological transfer.

The history of the Rhine River is a good illustration of the relationship between mankind and rivers. From this history we learn that the symbiosis between people and the river goes through three phases, first is the protection against its dangers, second is the exploitation of its potential (for navigation, irrigation, energy, water supply, industrial water, recreation) and the last phase is the preservation of its ecosystems.

Transportation on canals and inland rivers is the most effective sustainable transport. 1 litre of fuel is required to transport 1 ton over 100 km. Whereas road transport by trucks, fuel use is 5 litres, and on railroad tracks it is 1.5 litres (non renewable electricity production for trains).

2.6.4 Prevention of floods and droughts

Flood control is covered by the ability of dams and reservoirs to retain water during floods. They can release water in advance and store additional volumes during extreme floods. Drought can severely affect the ecosystem and agriculture. Many dams and their associated reservoirs supply additional water to mitigate this detrimental impact.

2.6.5 Tourism and leisure attractiveness

Water bodies provided by many reservoirs often allow some recreational uses such as swimming, windsurfing, fishing, sailing, water-skiing, canoe, and kayaking. These activities are becoming increasingly important for people living close to the reservoir and also attract tourism along a lake.

2.6.6 Fisheries

In addition to recreational fishing some reservoirs support commercial fisheries. As a result of intensive fishing in oceans, the development of commercial fish farming has also recently increased.

2.6.7 Improvement of infrastructures

The realisation of a hydroelectric development requires good transport infrastructure. It often presents the opportunity to rebuild the road network at the beginning of the project, if sufficient in size, or at the end of the project, if roads have deteriorated. Bridges and roads are therefore built or consolidated alongside hydropower infrastructure activities. It is also an opportunity to build residential housing when serving workers assigned to hydropower projects, as well as local schools and other social infrastructures that can be left to the local communities after the project construction finishes.

2.7 Hydropower as a pillar of the future neutral carbon power system

Hydropower is a highly flexible power generation technology, which can be used to balance and store electricity generated by variable renewable sources like wind and solar. Hydropower provides an essential link for integrating them within the future carbon-neutral power system. Hydropower operates at all timescales (Table 2) supporting power quality (monitoring and regulation of voltage fluctuations, frequency disruptions and harmonic distortions), power management (short-term power supply for critical demands) and energy management (energy storage for extended periods of time: storing energy during periods when the retail electricity price is low and discharging when prices are high – "retail energy time shift").

Table 2. Different timescales of power flexibility [12].

Flexibility type	Short-term			Medium term	Long-term	
Time scale	**Sub-seconds to seconds**	**Seconds to minutes**	**Minutes to hours**	**Hours to days**	**Days to months**	**Months to years**
Issue	Ensure system stability	Short term frequency control	More fluctuations in the supply / demand balance	Determining operation schedule in hour- and day-ahead	Longer periods of VRE surplus or deficit	Seasonal and inter-annual availability of VRE
Relevance for system operation and planning	Dynamic stability: inertia response, voltage and frequency	Primary and secondary frequency response	Balancing real time market (power)	Day ahead and intraday balancing of supply and demand (energy)	Scheduling adequacy (energy over longer durations)	Hydro-thermal coordination, adequacy, power system planning (energy over very long durations)

To fully contribute to the European Green Deal, hydropower must incorporate sustainability criteria, with measures protecting the environment and biodiversity.

3 Conclusions

It may be concluded that hydropower in Europe and worldwide has many advantages including:

- Renewable energy with insignificant direct emission of CO_2 and unbeatable energy gain or pay-back during a long technical lifetime.
- Excellent efficiency; production can be easily adapted to the demand (very flexible and timely delivery of peak energy).
- In-country energy creating jobs and financial resources in remote areas (taxes and concession fees).
- Improvement of infrastructure and attractive for tourism.
- Contribution to flood and drought protection.
- Facilitating navigation on the large rivers in Europe.

Looking in more detail into life cycle analysis, hydropower is by far the best option in view of sustainability. Hydropower has a long tradition in Europe and contributed significantly in the first half of the last century to the industrial development and welfare of most countries in Europe. The ambitious plan for energy transition in Europe seeks to achieve a low-carbon climate-resilient future in a safe and cost-effective way serving as an example worldwide. With its broad services going beyond just electricity generation, hydropower has all the characteristics to provide strong supportto the European Green Deal, not only in Europe but also worldwide.

In Part II of this paper, after highlighting the complex environment for hydropower within Europe, and the challenges of biodiversity, the main innovation and research directions extracted from the RIA and the main steps of the SIR for combining multipurpose hydropower in a sustainable, efficient and cost-effective manner, are presented.

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