Decarbonization Wedges Exercise

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HYDRO ENERGY

1. State of the art and current development in different world regions

Hydro energy is the third source of electricity at the global level and the first source of renewable electricity (80% of global renewable energy production). Hydro energy technologies can be classified according to several criteria —among which the type of plant (taking into account drop height notably), operation type, turbine type, and amount of generated electric power. This template will assess hydro plants according to their environmental impact, which, according to this criterion, fall into three main categories:

- Plants with a high environmental impact: all high power output power plants with water impoundment fall under this category. They include:

  i) Conventional water impoundment (with a drop height over 200m) for a seasonal storage in the reservoir;

  ii) PHES[1] (also with high drop heights);

  iii) Pondage plants (with moderate drop heights —i.e. between, 50 and 200m) with a significant debit for daily or weekly storage according to the needs of the electricity network;

  iv) Run-of-the-river systems with high power (small drop heights —i.e. less than 50m).

Each of these technologies corresponds to specific drop heights. One can also distinguish different types of turbines —e.g. Pelton, Francis and Kaplan— which use is conditioned rather by the drop heights than by the power of the plant.

- Plants with a moderate environmental impact: most of them are run-of-the-river systems with no storage that harness natural waterfalls thanks to a turbine —usually Kaplan and Francis as they can be used with low drop heights— continuously operating on the watercourse. These plants are classified as small hydro —between 2 and 10 MW— and mini hydro —between 500 kW and 2 MW— plants and their output is conditioned by the flow rate.
- Plants with a small environmental impact: very low power hydro power plants —between 20 kW and 500 kW for micro hydro and less than 20 kW for pico hydro energy— are also run-of-the water systems and need less specific installations than plants with a moderate environmental impact. This third category mainly includes floating dams —also called hydrokinetic turbines— which do not require foundations as they are attached to the riverbed or to riverbanks. Hydrokinetic turbines do not require a waterfall either as they use the kinetic energy produced by the water flow.

2. Maturity level and technological perspectives: costs, performances, markets

Maturity of elementary technologies associated with hydro energy

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Water impoundment	5	5	5	5	5
Run-of-the-river	5	5	5	5	5
Floating dams	3-4	4	4-5	5	5

[1] PHES: Pumped HydroElectricity Storage

Water impoundment is a mature and largely deployed technology. Run-of-the-river technologies are also mature but research still has to be carried out for this type of hydro energy in order to bring down costs and use new materials and concepts from other fields —e.g. using variable speed to operate turbines.

Potential development of technologies related to hydro energy

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2015	2020	2030	2040	2050
All technologies	4	4	4	4	4

Floating dams, especially hydrokinetic turbines, have not reached the same maturity level as water impoundment and run-of-the-river technologies. After the demonstration phase come the first industrial implementations of the technology, but floating dams are not stabilized yet either. A regulation and institutional environment must be created for this technology, and efforts have to be carried out concerning connection between the plant and the electricity network. No large diffusion of the technology is expected before 2030-2040.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

Technology		**Research & technological bottlenecks**	**Economy and Financial bottlenecks** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Water impoundment	Rank	1	6	2	4	5	4
	Key-words		Financing — mobilizing capital	Significant constraints in Europe			Various acceptability degrees according to countries
Run-of-the-river	Rank	5	4	6	2	1	3
	Key-words			New possibilities			Average maintenance requirements
Floating dams	Rank	6	4	5	2	1	3
	Key-words	Instability of concept					Low maintenance requirements

For water impoundment with large power the main bottlenecks pertains to financing and resources: indeed mobilizing capital is what hinders dam development most. Using resource only for electricity generation can also be a bottleneck. This is why it is crucial to consider possible multiple use of dam water as this can help remove the bottleneck linked to financing for some plants —possible irrigation— and some water supply systems —recreational use.

The other major bottleneck linked with water impoundment technologies is plant safety in some countries —i.e. qualities of geological studies, quality of the concrete used, etc.

Eventually water impoundment technologies have a double environmental impact —both on reserve and on submerged land, and also on downstream agricultural land: i.e. erosion linked to lack of sediments.

Run-of-the-river technologies are mostly hindered by technological research, which must be considered: indeed downstream plants can be improved with turbines —hydro-electricity converters, generators and alternators, etc. — to adapt the systems to fluctuating flow rates. Environmental impact and socio-technical feasibility can hinder the development of small hydro power energy, but these bottlenecks are clearly easier to remove than for large water impoundment systems. Finally financing issues must be considered, even if they are less significant than for the first technology.

Floating dams also come with a bottleneck. The technology has started its deployment at the industrial scale but floating dams are not a stable system, especially in the case of pico hydro energy. Regulations must also evolve to make room for issues related to other uses of water involved with dams —e.g. recreational use, use of water for fishing, etc.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Economy and Financial innovations** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Water impoundment	I or R	I	I	R	I	I	I
	Keywords		Economies of scale	Energy storage	Optimization of resource use (see storage)		Network Intermittence of energy
Run-of-the-river	I or R	I	I	I	I	I	I
	Keywords	Adaptable turbines	High costs in developing countries				
Floating dams	I or R	R	I	I	I	I	I
	Keywords	Adaptable turbines					

In industrial countries acceptability is the main issue with small and pico hydro energy —it is not an issue with large dams as there are no projects. There is not such an issue in developing countries. This issue should not be excluded for PHES power stations.

Regarding public policies, developing countries could offset environmental and safety issues for large plants by sharing commissioning.