Mapping the divergent perspectives surrounding Finnish hydropower and its removal

Epari Ritesh Patro[a], Outi Autti [b], Sahand Ghadimi[c], Jenni Hakovirta[d], Päivi Magga[e], Anu Soikkeli[f] and Ali Torabi Haghighi[g]

[a] *ritesh.patro@oulu.fi, Water, Energy and Environmental Engineering Research Unit, Faculty of Technology, University of Oulu, Oulu, Finland*
[b] *outi.autti@oulu.fi, Oulu School of Architecture, Faculty of Technology, University of Oulu, Oulu, Finland*
[c] *sahand.ghadimi@oulu.fi, Water, Energy and Environmental Engineering Research Unit, Faculty of Technology, University of Oulu, Oulu, Finland*
[d] *jenni.hakovirta@oulu.fi, Oulu School of Architecture, Faculty of Technology, University of Oulu, Oulu, Finland*
[e] *paivi.magga@oulu.fi, Oulu School of Architecture, Faculty of Technology, University of Oulu, Oulu, Finland*
[f] *anu.soikkeli@oulu.fi, Oulu School of Architecture, Faculty of Technology, University of Oulu, Oulu, Finland*
[g] *ali.torabihaghighi@oulu.fi, Water, Energy and Environmental Engineering Research Unit, Faculty of Technology, University of Oulu, Oulu, Finland*

Abstract

As the values and power relations in the world change, so do the desires regarding water use and recreation. The general appreciation and debate emphasize the importance of rivers and their role in ecosystem functions. Dismantling of dams is seen as one way to restore the diversity of watercourses and, in particular, the natural life cycle of migratory fish. However, in practice, it is evident that other factors besides their ecological benefits influence dam removal decisions. In the past, the large dams suffered from a monodisciplinary view on storing water only for electricity generation. The local population and the environment did not play a major role in the past. Dam removal is inherently transdisciplinary effort, multiple objectives are at stake and have to be addressed concurrently. A transdisciplinary approach is needed to address sustainable water management issues at a local to regional scale, this can be achieved in collaboration with various stakeholders. The main aim of this article is to show how to develop a framework that can support the decision-making process by accommodating the input of different stakeholders while increasing the transparency of the decision analysis process about the future of aging Finnish hydropower dams.

Keywords

Hydropower; Ageing infrastructures; Stakeholders; Multi-Criteria Decision making; Dam removal; Finland

1. Introduction

Current energy and climate policies worldwide induce an increased pressure for a higher share of renewable sources in the global electricity production portfolio. Hydroelectricity has been an attractive energy choice globally as a renewable, flexible, and affordable source (Bonato et al., 2019; Patro et al., 2018; Ranzani et al., 2018). Currently, hydropower is the primary source of electricity in many countries such as Brazil, Canada, Norway, Switzerland, and Austria, while damming the river for power production is still on the rise worldwide (Frey & Linke, 2002; IEA, 2020; Zarfl et al., 2015).

Simultaneously, hydropower development is facing multiple challenges. The massive infrastructures are associated with complex, considerable, intertwined social, economic, and ecological impacts (McNally et al., 2009). The scientific, political, and public concerns about these impacts, which have long been overlooked, are growing (Friedl & Wüest, 2002), leading researchers to investigate the alternative benefits of undammed rivers (Auerbach et al., 2014; Brismar, 2002). Additionally, facilities'

Mini-Conference on Transdisciplinary Research and Design, 14th February 2022, Oulu, Finland.

aging increases operation and maintenance costs to remain secure and efficient (Doyle, Harbor, et al., 2003; Patro et al., 2018). In some drastic instances, these issues have even encouraged the complete dismantlement of hydropower facilities (Gowan et al., 2006; O'Connor et al., 2015; Vahedifard et al., 2020), despite the potential adverse environmental impacts induced by full removals (Pacca, 2007; Stanley & Doyle, 2003).

While hydropower is still the dominant renewable source of energy worldwide, maintenance and operation of aging hydropower infrastructures are becoming increasingly challenging. Reduced reservoir capacity due to sedimentation, increasing security concerns due to the risk of old infrastructure failure, rising maintenance and operation costs, in addition to the realized socio-economic and ecological impacts of reservoirs are among the reasons for questioning the necessity of the continued operation of aged hydropower or complete removal. Transdisciplinary approach is key technique in evaluating multi-faceted decisions regarding the future of hydropower infrastructure as they enable the integration and evaluation of miscellaneous social, economic and ecological aspects (Brennan et al., 2021; Kumar et al., 2022). A common and consensual feature of transdisciplinary assessment approaches is the integration of local specifications and knowledge through local stakeholders' involvement (Lawrence et al., 2022; McGreavy et al., 2021).

The purpose of this work in progress is twofold. First, it attempts to carry out a multi-perspective (social-cultural-ecological-hydrological) analysis to support the decision-makers regarding removal and retrofit. Second, it demonstrates the implications of both the configuration of the process and the consideration of various stakeholders' preferences on hydropower debate and society. Using case studies in Finland, in this article we attempt to understand how the environmental history can support the decision-making process by accommodating the social-cultural-ecological-hydrological-driven multi-criteria perspectives to increase the transparency of the decision analysis process involving multiple criteria and multiple decision-makers.

2. Indicators considered for comprehensive evaluation

2.1. Changes in hydrology and ecosystem

Damming a river changes the water and sediments, nutrients, and others that move with it through the river system from its smallest headwaters to the mainstream and beyond to a lake or sea. This has several short- and long-term hydrological, physical, and morphological effects. In particular, the natural flow of water, the natural flood cycle, and as sediment drift changes, the structure of the river basin is simplified, and the water temperature can increase or decrease. After the dam, the dammed part of the river is more like a lake, stagnant water ecosystem than the actual river ecosystem. In addition, also inherent strong attachment to the catchment area often weakens. Dam structures smooth out the extreme effects of river flows, reducing their strength and in addition to which the times of flood peaks can be delayed by up to half a year (Ashraf et al., 2016; Graf, 2006; Torabi Haghighi et al., 2014). Dams and reservoirs can modify the chemical composition and temperature of the water, sediment movement, modify the structure of the river basin and floodplains, and generally disturb the continuity of the river ecosystem (Graf, 2006; Santucci et al., 2005). As the climate warms, water bodies are also projected to warm, especially small dams (Firoozi et al., 2020; Sinokrot et al., 1995). Warming contributes to the evaporation of water from the dam basin. Elevated humidity can affect the area's natural rain cycles, intensifying heavy rains (Hossain et al., 2009).

The damming of rivers has a significant impact on the functioning of their ecosystems and the diversity of their species. As a whole, the dam interrupts the river's natural upstream to downstream, interrupting the free movement of organisms in the river network between different parts of the river and in many ways also affects the natural connection with the catchment area. Aquatic species that require their habitat tend to decline or even disappear completely from the dam basin (Hitt et al., 2012; Nieland et al., 2015). Such species that also occur in Finland are, for example, salmon and trout. Dams slow down or prevent the movement of migratory fish between their different habitats (Gido et al., 2015). Large dams often prevent crossing completely, unless fish-bypass structures have been built to assist the

passage (Ashraf et al., 2018), and even then dam basins slow down migration and expose fish to predation and the spread of disease (Huusko et al., 2020).

The dam basin may have accumulated a lot of sediment over the decades. The sudden release of such sediments is the most common concern when planning the removal of dams and cannot be completely certain in advance (Cui et al., 2016; Major et al., 2017). Sediment can easily pass through the river into a larger standing water basin, affecting the water ecosystem only for a very short time, or it may stop in the vicinity of the dam covering and destroying microhabitats (Cannatelli & Curran, 2012). The quality and composition of the sediment accumulated in the dam basin are affected by the climate, upstream geographical and hydrological characteristics, the height and age of the dam, and the characteristics of the snow area (Cui et al., 2016). If a large amount of sediment is released quickly, then in the downstream sediment may accumulate on riverbanks or in estuaries, altering flow conditions, the shape, and water quality of the river (Major et al., 2017). Sediment pulse intensity and the changes it causes in the river are affected by the distance from the dam, the quantity, quality, and periodicity of the discharge, as well as the shape, slope and flow conditions of the river (Doyle et al., 2008; Doyle, Stanley, et al., 2003)

2.2. Socio-cultural impacts

The huge postwar reconstruction and modernization project that started in the late 1940's in Northern Finland was a direct consequence of the war years. It changed the physical and cultural environment of the area profoundly. Traditional buildings were replaced by type planned houses, the rivers were dammed to produce hydropower, and new roads were built to serve more efficient forest industry. There is a body of research that has analyzed the social and cultural impacts of damming rivers in Northern Finland (e.g., Autti, 2013; Järvikoski, 1979; Luostarinen, 1982; Rusanen, 1989; Suopajärvi, 2001). The damming of northern rivers focused on engineering and economic growth, while environmental and cultural values at the time were overlooked. The damming of rivers Kemi and Ii was a death blow for rich salmon fishing culture that was centuries old. Damming changed the river landscapes: river areas beneath the dams became dry riverbeds, while elsewhere homes and places for different activities were flooded. The soundscape, scents and the essence of the rivers changed. The new built environment included power plants, dams, and electricity distribution constructions. These rapid changes caused a disconnection between local people and their environment: the active role of people living along the rivers turned to passive observing, and many lost their sense of belonging. The change in the environment shook the bases of human-environment relationship of many in the area, and the impacts easily spread to all walks of life: on well-being, economy, social life, and local culture.

Environmental and cultural changes speeded up the structural and economic change in local communities. Significant salmon fishing cultures vanished quickly, and the importance of other livelihoods such as crofting, logging and log floating also declined. Unemployment caused migration to Sweden and cities in Southern Finland. The change in the traditional livelihoods broke the shared reality of older and younger generations and created a social gap between them. Older generation felt useless in the new situation. Their work was no longer appreciated, and younger generation left the area to study and work elsewhere. This had a negative impact on the sense of belonging, place attachment and participation in local communities, moreover the unwanted change weakened the residents' experienced health and wellbeing. Environmental change and its further consequences resulted as experiences of collective and personal environment related traumas (Autti, 2022).

Over the last two decades, the attitudes towards dammed rivers in Northern Finland have started to change course. Social acceptance of hydropower has weakened, and alternative ways of river use have become subject of public debate. For example, many projects that aim to reintroduce salmon have tried to find ways to combine different water use interests and hydropower and migratory fish to coexist. Dam removals elsewhere or in smaller rivers have opened new sights for river restoration also in the northern context. However, from the cultural transformation point of view, dam removal process is yet again alteration of the existing situation and existing landscape. Damming has shaped the history of Northern Finland as it has brought about new activities and new people in the area, as well as new

connections, new experiences, and memories. Dam demolition will not take us to the situation before them, but rather leads to a new situation.

Hydropower related architecture and built environment are also part of the environmental history in the area. Many power plant entities have been classified as a nationally significant built cultural environment (RKY). Power plants and related residential areas were one of Finland's most important construction projects during the reconstruction period, and they are of tangible and intangible significance (Kinnunen, 2018). Many of the power plants were designed by Finland's leading architects. The planning provided an opportunity to test and apply architectural ideas at all levels, from spatial planning to the smallest building details. The structure of the power plant communities follows the open ideology of urban planning that blends in with nature and the landscape, but also the hierarchical, early industrial community structure.

Issues related to cultural heritage can be fundamentally contradictory (Soikkeli, 2005). The cultural heritage of hydropower can be a source of shared memories, understanding, identity, community, and creativity, in much the same way as the pre-dam cultural environment. The question of social justice and the traumatic histories of environmental change call for a methodological principle and aim to better involve local communities in planning processes. New ways of participation should be developed in which various interpretations of the past, as well as various views concerning the use of the rivers and river landscapes, are acknowledged. River restoration needs to be studied and discussed more widely than just through water management or ecological factors: we need research on social and cultural connections and impacts, we need to include the aspects of social justice and cultural heritage, and most importantly, involve stakeholders to participate and share their experiences and interests.

3. The way forward

The comprehensive evaluation of hydropower rehabilitation and removal is a complex and uncertain process that includes physical, hydrological, ecological, and social aspects. A quantitative and qualitative analysis method that can deal with multiple indicators and fuzziness is required. We also lack information about the effects of dam removal on the environment. Restoring or removal of hydropower projects will require careful planning, close monitoring of the state of the river, ecosystem, and local population. The work is in progress to understand the Finnish dam rehabilitation and removal issues from a transdisciplinary approach to address socio-economic, technological, and regulatory barriers. Such a transdisciplinary approach to hydropower rehabilitation is lacking. Such an evaluation approach considering local circumstances, will present more feasible guidance for local river eco-environmental and hydropower management. The main finding so far is a transdisciplinary approach is one way of better understanding some of the conflicting viewpoints evident in discipline-based approaches of narratives over the implications of the hydropower dams.

References

Ashraf, F. Bin, Haghighi, A. T., Riml, J., Alfredsen, K., Koskela, J. J., Kløve, B., & Marttila, H. (2018). Changes in short term river flow regulation and hydropeaking in Nordic rivers. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-35406-3

Ashraf, F. Bin, Torabi Haghighi, A., Marttila, H., & Kløve, B. (2016). Assessing impacts of climate change and river regulation on flow regimes in cold climate: A study of a pristine and a regulated river in the sub-arctic setting of Northern Europe. *Journal of Hydrology*, *542*, 410–422. https://doi.org/10.1016/J.JHYDROL.2016.09.016

Auerbach, D. A., Deisenroth, D. B., McShane, R. R., McCluney, K. E., & LeRoy Poff, N. (2014). Beyond the concrete: Accounting for ecosystem services from free-flowing rivers. *Ecosystem Services*, *10*, 1–5. https://doi.org/10.1016/J.ECOSER.2014.07.005

Autti, O. (2013). *Valtavirta muutoksessa – vesivoima ja paikalliset asukkaat Kemijoella* [University of Oulu,]. http://jultika.oulu.fi/files/isbn9789526202396.pdf

Autti, O. (2022). Environmental Trauma in the Narratives of Postwar Reconstruction: The Loss of Place and Identity in Northern Finland After World War II. In V. Kivimäki & P. Leese (Eds.), *Trauma, Experience and Narrative in Europe after World War II* (pp. 267–297). Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-84663-3_10

Bonato, M., Ranzani, A., Patro, E. R., Gaudard, L., & De Michele, C. (2019). Water-energy nexus for an Italian storage hydropower plant under multiple drivers. *Water (Switzerland)*, *11*(9). https://doi.org/10.3390/w11091838

Brennan, M., Rondón-Sulbarán, J., Sabogal-Paz, L. P., Fernandez-Ibañez, P., & Galdos-Balzategui, A. (2021). Conceptualising global water challenges: A transdisciplinary approach for understanding different discourses in sustainable development. *Journal of Environmental Management*, *298*, 113361. https://doi.org/10.1016/J.JENVMAN.2021.113361

Brismar, A. (2002). River Systems as Providers of Goods and Services: A Basis for Comparing Desired and Undesired Effects of Large Dam Projects. *Environmental Management 2002 29:5*, *29*(5), 598–609. https://doi.org/10.1007/S00267-001-0058-3

Cannatelli, K. M., & Curran, J. C. (2012). Importance of Hydrology on Channel Evolution Following Dam Removal: Case Study and Conceptual Model. *Journal of Hydraulic Engineering*, *138*(5), 377–390. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000526

Cui, Y., Booth, D. B., Monschke, J., Gentzler, S., Roadifer, J., Greimann, B., & Cluer, B. (2016). Analyses of the erosion of fine sediment deposit for a large dam-removal project: an empirical approach. *Http://Dx.Doi.Org/10.1080/15715124.2016.1247362*, *15*(1), 103–114. https://doi.org/10.1080/15715124.2016.1247362

Doyle, M. W., Harbor, J. M., & Stanley, E. H. (2003). Toward Policies and Decision-Making for Dam Removal. *Environmental Management 2003 31:4*, *31*(4), 0453–0465. https://doi.org/10.1007/S00267-002-2819-Z

Doyle, M. W., Stanley, E. H., Harbor, J. M., & Grant, G. S. (2003). Dam removal in the united states: Emerging needs for science and policy. *Eos*. https://doi.org/10.1029/2003EO040001

Doyle, M. W., Stanley, E. H., Havlick, D. G., Kaiser, M. J., Steinbach, G., Graf, W. L., Galloway, G. E., & Riggsbee, J. A. (2008). Aging infrastructure and ecosystem restoration. *Science (New York, N.Y.)*. https://doi.org/10.1126/science.1149852

Firoozi, F., Roozbahani, A., & Massah Bavani, A. R. (2020). Developing a framework for assessment of climate change impact on thermal stratification of dam reservoirs. *International Journal of Environmental Science and Technology*, *17*(4), 2295–2310. https://doi.org/10.1007/S13762-019-02544-8/TABLES/8

Frey, G. W., & Linke, D. M. (2002). Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy Policy*, *30*(14), 1261–1265. https://doi.org/10.1016/S0301-4215(02)00086-1

Friedl, G., & Wüest, A. (2002). Disrupting biogeochemical cycles - Consequences of damming. *Aquatic Sciences 2002 64:1*, *64*(1), 55–65. https://doi.org/10.1007/S00027-002-8054-0

Gido, K. B., Whitney, J. E., Perkin, J. S., & Turner, T. F. (2015). Fragmentation, connectivity and fish species persistence in freshwater ecosystems. *Conservation of Freshwater Fishes*, 292–323. https://doi.org/10.1017/CBO9781139627085.011

Gowan, C., Stephenson, K., & Shabman, L. (2006). The role of ecosystem valuation in environmental decision making: Hydropower relicensing and dam removal on the Elwha River. *Ecological Economics*, *56*(4), 508–523. https://doi.org/10.1016/J.ECOLECON.2005.03.018

Graf, W. L. (2006). Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology*. https://doi.org/10.1016/j.geomorph.2006.06.022

Hitt, N. P., Eyler, S., & Wofford, J. E. B. (2012). Dam Removal Increases American Eel Abundance in Distant Headwater Streams. *Transactions of the American Fisheries Society*, *141*(5), 1171–1179. https://doi.org/10.1080/00028487.2012.675918

Hossain, F., Jeyachandran, I., & Pielke, R. (2009). Have Large Dams Altered Extreme Precipitation Patterns? *Eos, Transactions American Geophysical Union*, *90*(48), 453–454. https://doi.org/10.1029/2009EO480001

Huusko, R., Jaukkuri, M., Hellström, G., Söderberg, L., Palm, S., & Söderberg, A. R. (2020). *Spawning migration behavior of salmon and sea trout in the Tornionjoki river system : Interim report 2018–2019.* Natural Resources Institute Finland. https://jukuri.luke.fi/handle/10024/546418

IEA. (2020). *Renewables 2020 – Analysis and forecast to 2025* . https://www.iea.org/reports/renewables-2020

Järvikoski, T. (1979). *Vesien säännöstely ja paikallisyhteisö : sosiologinen tutkimus valtakunnallisen päätöksenteon seurauksista esimerkkitapauksina Lokan ja Porttipahdan tekojärvet*. Turun yliopisto.

Kinnunen, V. (2018). Tulevaisuuksien muotoilua Lapin varhaisessa seutusuunnittelussa. . *Alue Ja Ympäristö*, *47*(1), 31–49. https://doi.org/10.30663/AY.65038

Kumar, M., Gikas, P., Kuroda, K., & Vithanage, M. (2022). Tackling water security: A global need of cross-cutting approaches. *Journal of Environmental Management*, *306*, 114447. https://doi.org/10.1016/J.JENVMAN.2022.114447

Lawrence, M. G., Williams, S., Nanz, P., & Renn, O. (2022). Characteristics, potentials, and challenges of transdisciplinary research. *One Earth*, *5*(1), 44–61. https://doi.org/10.1016/J.ONEEAR.2021.12.010

Luostarinen, M. (1982). *A social geography of hydro-electric power projects in northern Finland : personal spatial identity in the face of environmental changes*. University of Oulu : Oulu University Library, [distr.].

Major, J. J., East, A. E., O'Connor, J. E., Grant, G. E., Wilcox, A. C., Magirl, C. S., Collins, M. J., & Tullos, D. D. (2017). Geomorphic Responses to Dam Removal in the United States – a Two-Decade Perspective. In *Gravel-Bed Rivers: Process and Disasters* (pp. 355–383). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118971437.CH13

McGreavy, B., Ranco, D., Daigle, J., Greenlaw, S., Altvater, N., Quiring, T., Michelle, N., Paul, J., Binette, M., Benson, B., Sutton, A., & Hart, D. (2021). Science in Indigenous homelands: addressing power and justice in sustainability science from/with/in the Penobscot River. *Sustainability Science 2021 16:3*, *16*(3), 937–947. https://doi.org/10.1007/S11625-021-00904-3

McNally, A., Magee, D., & Wolf, A. T. (2009). Hydropower and sustainability: Resilience and vulnerability in China's powersheds. *Journal of Environmental Management*, *90*(SUPPL. 3), S286–S293. https://doi.org/10.1016/J.JENVMAN.2008.07.029

Nieland, J. L., Sheehan, T. F., & Saunders, R. (2015). Assessing demographic effects of dams on diadromous fish: a case study for Atlantic salmon in the Penobscot River, Maine. *ICES Journal of Marine Science*, *72*(8), 2423–2437. https://doi.org/10.1093/ICESJMS/FSV083

O'Connor, J. E., Duda, J. J., & Grant, G. E. (2015). 1000 dams down and counting: Dam removals are reconnecting rivers in the United States. In *Science*. https://doi.org/10.1126/science.aaa9204

Pacca, S. (2007). Impacts from decommissioning of hydroelectric dams: A life cycle perspective. *Climatic Change*. https://doi.org/10.1007/s10584-007-9261-4

Patro, E. R., De Michele, C., & Avanzi, F. (2018). Future perspectives of run-of-the-river hydropower and the impact of glaciers' shrinkage: The case of Italian Alps. *Applied Energy*, *231*, 699–713. https://doi.org/10.1016/j.apenergy.2018.09.063

Patro, E. R., Voltz, T. J., Kumar, A., & Grischek, T. (2018). Micro-hydropower in drinking water gravity pipelines: a case study in Uttarakhand, India. *ISH Journal of Hydraulic Engineering*. https://doi.org/10.1080/09715010.2018.1492977

Ranzani, A., Bonato, M., Patro, E., Gaudard, L., & De Michele, C. (2018). Hydropower Future: Between Climate Change, Renewable Deployment, Carbon and Fuel Prices. *Water*, *10*(9), 1197. https://doi.org/10.3390/w10091197

Rusanen, J. (1989). *Role of the local people in the utilization of water resources : a case study of the river Iijoki in Northern Finland*. [Pohjois-Suomen maantieteellinen seura].

Santucci, V. J., Gephard, S. R., & Pescitelli, S. M. (2005). Effects of Multiple Low-Head Dams on Fish, Macroinvertebrates, Habitat, and Water Quality in the Fox River, Illinois. *North American Journal of Fisheries Management*. https://doi.org/10.1577/m03-216.1

Sinokrot, B. A., Stefan, H. G., McCormick, J. H., & Eaton, J. G. (1995). Modeling of climate change effects on stream temperatures and fish habitats below dams and near groundwater inputs. *Climatic Change 1995 30:2*, *30*(2), 181–200. https://doi.org/10.1007/BF01091841

Soikkeli, A. (2005). Finland's Reconstruction Period Assets and the Venice Charter. . *N The Venice Charter – La Charte de Venise 1964-2004-2044? Serie Monuments and Sites XI, Hungarian National Committee of ICOMOS, Budapest, 168–176.*, 168–176.

Stanley, E. H., & Doyle, M. W. (2003). Trading off: The Ecological Effects of Dam Removal. *Frontiers in Ecology and the Environment*, *1*(1), 15. https://doi.org/10.2307/3867960

Suopajärvi, L. (2001). *Vuotos- ja Ounasjoki-kamppailujen kentät ja merkitykset Lapissa* [fi=Lapin yliopisto|en=University of Lapland|]. https://lauda.ulapland.fi/handle/10024/61734

Torabi Haghighi, A., Marttila, H., & Kløve, B. (2014). Development of a new index to assess river regime impacts after dam construction. *Global and Planetary Change*, *122*, 186–196. https://doi.org/10.1016/J.GLOPLACHA.2014.08.019

Vahedifard, F., Madani, K., Kouchak, A. A., & Thota, S. K. (2020). Preparing for proactive dam removal decisions. *Science*, *369*(6500), 150. https://doi.org/10.1126/SCIENCE.ABC9953/ASSET/6F6B6883-33E6-4155-9588-CDABCF9F1394/ASSETS/GRAPHIC/369_150A_F1.GIF

Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2015). A global boom in hydropower dam construction. *Aquatic Sciences*, *77*(1), 161–170. https://doi.org/10.1007/s00027-014-0377-0