Forecasting Models and Value-Based Decisions: Weak Evidence, Strong Perceptions?

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Contents

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I. Introduction

Major building or development projects such as hydroelectric power plants surpassing a certain size must undergo an Environmental Impact Assessment prior to their approval.[1] Within this process, the assessing authority analyses the expected impacts of the project and whether they affect certain public interests.

In the case of hydroelectric power plants, negative effects could be the irreversible destruction of a natural habitat, microclimatic disruptions, or biodiversity loss due to dam construction.[2] Positive effects might be the reduction of CO_2-emissions, ensuring energy security or creating certain desired economic effects.[3] The assessing authority must then decide whether the positive or negative effects prevail, which is done by balancing the affected public interests against each other.[4]

To assess future impacts, experts usually apply models and scenarios.[5] These models and scenarios are used to simulate future developments such as energy consumption or production and how these will affect the future impacts of the power plant. While such forecasts are a viable source of information, they come with specific downfalls.

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[1] § 3 Bundesgesetz über die Prüfung der Umweltverträglichkeit (Umweltverträglichkeitsprüfungsgesetz 2000 – UVP-G 2000), BGBl 697/1993 idF BGBl I 26/2023 (UVP-G).

[2] U.S. Energy Information Administration, 'Hydropower explained' (*EIA*, 7 November 2022) <https://www.eia.gov/energyexplained/hydropower/hydropower-and-the-environment.php> accessed 13 February 2024.

[3] Office of Energy Efficiency & Renewable Energy, 'Benefits of Hydropower' (*Office of Energy Efficiency & Renewable Energy*, 2022) <https://www.energy.gov/eere/water/benefits-hydropower> accessed 13 February 2024.

[4] § 17 Para 5 UVP-G; Nicolas Raschauer '§ 17 UVP-G' in Daniel Ennöckl, Nicolas Raschauer, Wilhelm Bergthaler (eds.), *UVP-G: Kommentar* 3rd edn., (Wien: Jan Sramek Verlag KG, 2013) para. 87 f.

[5] As can, e.g., be seen in the example of the PSP Koralm (chapter V.).

These include uncertainties due to unavailable data or unknown developments[6] but also biases in assumptions about possible future developments.[7]

To better understand the impact models and scenarios have on future-prone legal decisions, this article investigates the role of forecasting in Environmental Impact Assessments of hydroelectric power plants in Austria. It first sets the theoretical framework by outlining Environmental Impact Assessments and key aspects of hydroelectricity. It then explains the main factors relevant when assessing a hydroelectric power plant and the models and scenarios used to do so before taking one specific project as an example to illustrate the main challenges of using models and scenarios in future-prone legal decision-making.

II. Environmental Impact Assessments

A. General

The aim of the Environmental Impact Directive[8] is the proper integration of environmental concerns into the decision-making process and the establishment of environmental protection and transparency by optimising the project's environmental indicators.[9] Therefore, major building or development projects must first be assessed for their impact on the environment. One key feature of Environmental Impact Assessments is the broad public participation, aiming to ensure that those affected can participate in the decision-making process,[10] thereby potentially strengthening the acceptance of planned projects.[11]

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[6] *See,* e.g., Bert Enserink, Jan H. Kwakkel, Sietske Veenman, 'Coping with uncertainty in climate policy making: (Mis)understanding scenario studies' (2013) Futures 53 (2 f).

[7] *See,* e.g. Joseph Voros, 'A Primer on Futures Studies, Foresight and the Use of Scenarios', (2001) prospect, the Foresight Bulletin 6 (1 f).

[8] Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment.

[9] European Commission, '35 years of EU environmental impact assessment' (*Publications Office of the European Union,* 2021) < https://environnement.public.lu/content/dam/environnement/documents/emweltprozeduren/eie/eie-infobox/EIA-Directive-35-years.pdf> (3 f) accessed February 13 2024.

[10] European Commission, 'Environmental Impact Assessments' (*European Commission,* 2024) <https://environment.ec.europa.eu/law-and-governance/environmental-assessments/environmental-impact-assessment_en#objectives> accessed 13 February 2024.

[11] Rec 16, Directive 2011/92/EU; Raschauer, '§ 9 UVP-G', para. 1.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

In Austria, this is implemented by the Federal Act on Environmental Impact Assessment (UVP-G).[12] Projects subjected to an Environmental Impact Assessment are, e.g., waste management facilities, power stations, infrastructure projects, agricultural projects, urban or industrial development projects, waste disposal installations, and other projects that are expected to have a substantially negative impact on the environment.[13] Apart from the project type, its size, emissions, and location are relevant in determining whether a project must undergo an Environmental Impact Assessment.[14] The assessing authority is the respective provincial government, although this might deviate under specific circumstances, e.g., if federal roads or high-speed railroads are assessed.[15]

B. Permit Procedure

A specific aspect of Environmental Impact Assessments is the 'consolidated development consent procedure.'[16] This means that all required provisions under federal or provincial administrative law are consolidated simultaneously[17] and all sectoral and community legislation – such as forestry, water, or landscape protection – is assessed within one single procedure by one single authority.[18]

The procedure starts with the project applicant submitting the application for development consent to the assessing authority.[19] This includes the Environmental Impact Statement, which must provide key information on the project as well as on the expected impact on the environment, tested alternatives or planned offsetting measures.[20] The project applicant must commission competent experts to draft the

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[12] See FN 1.

[13] The projects subject to an EIA can be found in Annex I UVP-G.

[14] § 3 UVP-G; Annex I UVP-G; Daniel Ennöckl '§ 3 UVP-G', Daniel Ennöckl, Nicolas Raschauer, Wilhelm Bergthaler (eds.), *UVP-G: Kommentar* 3rd edn., (Wien: Jan Sramek Verlag KG, 2013) para. 1.

[15] § 39 UVP-G; Raschauer '§ 39 UVP-G', para. 1.

[16] § 3 Para 3 UVP-G; translation provided by the Federal Ministry for Agriculture, Forestry, Environment and Water Management, available at https://www.ris.bka.gv.at/Dokumente/Erv/ERV_1993_697/ERV_1993_697.html> accessed 13 February 2024.

[17] § 3 Para 1 UVP-G; Wolfgang Berger '§ 3 UVP-G' in Dieter Altenburger (ed.), *Kommentar zum Umweltrecht* (2019), para. 28.

[18] Ennöckl '§ 1 UVP-G' para. 17.

[19] § 5 Para 1 UVP-G; Raschauer, '§ 9 UVP-G', para. 3.

[20] § 6 UVP-G para 1.

statement.[21] These experts could be civil engineers, biologists, energy experts, or experts on (regional) economic development.[22] Once the application process has started and all relevant documentation is available, the assessing authority must disclose the project documentation to the public for inspection.[23] During this inspection phase, everyone may submit a written statement regarding the planned project.[24]

Following the inspection phase, the assessing authority commissions experts of the subjects in question to prepare the Environmental Impact Report.[25] The report must not only evaluate the Environmental Impact Statement and any other information submitted by the project applicant,[26] but also the statements made during the public inspection phase.[27] Once the public inspection period is completed and the Environmental Impact Report drafted, the authority holds a hearing with the involved parties.[28]

C. Decision

After the hearing and the consideration of all available evidence, the assessing authority decides whether to issue a permit. If the overall assessment shows that serious environmental damages are to be expected that cannot be prevented or reduced to a tolerable level by stipulations, amendments, or offsetting, the application must be rejected.[29] If both negative and positive effects are expected, the authority will assess whether specific public interests may speak in favour of the project and whether they outweigh the negative impacts.[30] To reach a decision, the authority must balance different public interests against each other and define whether other public

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[21] § 6 UVP-G para 2.

[22] Dieter Altenburger, '§ 6 UVP-G' in Dieter Altenburger (eds.), *Kommentar zum Umweltrecht,* 2nd edn., (Wien: LexisNexis, 2019), para. 49.

[23] § 5 Para 5 UVP-G; Daniel Ennöckl, Nicolas Raschauer and Wilhelm Bergthaler '§ 5 UVP-G' in Daniel Ennöckl, Nicolas Raschauer, Wilhelm Bergthaler (eds.), *UVP-G: Kommentar* 3rd edn., (Wien: Jan Sramek Verlag KG, 2013), para. 5.

[24] § 9 UVP-G para. 1; Raschauer '§ 9 UVP-G', para. 14.

[25] § 12 UVP-G.

[26] § 12 para. 5 UVP-G; Raschauer '§ 12 UVP-G', para. 3.

[27] § 12 UVP-G; Raschauer '§ 9 UVP-G', para. 15.

[28] § 16 UVP-G; Raschauer '§ 16 UVP-G', para. 2.

[29] § 17 para 5 UVP-G.

[30] § 17 para 4 UVP-G.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

interests, e.g., producing renewable energy, outweigh the interest of environmental protection.[31]

It is important to note that the assessing authority is taking its decision *ex ante,* as the project is yet to be built. The authority must assess possible future impacts of the project and is thereby forced to take a 'prognostic decision'[32] regarding the expected impacts and how they will affect specific public interests.[33]

III. Hydroelectricity

A. Common plant types

Using the kinetic energy of flowing water to move millstones, lift heavy objects, and transport goods has been a common practice for thousands of years. With the development of electricity and the availability of turbines, producing and storing electricity through hydropower became increasingly important.[34] Today, the three main types of hydropower plants are run-of-river plants, impoundment facilities and pumped-storage plants.[35]

Run-of-river plants harness the kinetic energy of flowing water to generate electricity. To enhance the energy potential, a portion of the river's water is usually accumulated upstream, creating an increased altitude difference between the upper and lower sections. Higher heads and greater flow rates translate to enhanced electricity generation potential.[36]

Impoundment facilities use large dams to contain water in a reservoir. The ability to store water allows the generation of power at the times that are most advantageous to

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[31] § 17 para 5 UVP-G; Raschauer '§ 17 UVP-G', para. 87f.

[32] Raschauer '§ 17 UVP-G', para. 4.

[33] Dieter Altenburger and Wolfgang Berger '§ 17 UVP-G' in Dieter Altenburger and Wolfgang Berger (eds.), *UVP-G Umweltverträglichkeitsprüfungsgesetz* (Wien: LexisNexis, 2010), para. 7; Raschauer '§ 17 UVP-G', para. 4.

[34] Paul Breeze, 'Power Generation Technologies' (Oxford: Elsevier, 2005) 104.

[35] *See*, e.g., International Hydropower Association, 'Types of Powerplants' (Office of Energy Efficiency & Renewable Energy, 2024) <https://www.hydropower.org/iha/discover-types-of-hydropower> accessed 13 February 2024.

[36] *See*, e.g., Paul Breeze, 'Power Generation Technologies' (Oxford: Elsevier, 2005) 107f; Dominique Egré and Joseph C. Milewski, 'The diversity of hydropower projects' (2002) Energy Policy 30 (1227); International Hydropower Association, 'Types of Powerplants'.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

the system operator. The generation of power is fairly flexible, meeting baseload as well as peak-load demand.[37]

The reservoirs of impoundment facilities are often large enough to store water for several months or years. Due to their long-term storage, impoundment facilities often have additional functions such as flood control, water storage or recreation.[38]

Pumped-storage hydropower is a dynamic method of energy storage. It utilizes the gravitational potential energy of water to generate and store electricity. The process involves two reservoirs at different elevations. In the electricity generation phase, water is released from the upper reservoir, flows downhill, and activates a turbine. The storage aspect is achieved by reversing this process. During periods of low energy demand, surplus electricity is used to pump water from the lower reservoir back up to the higher one.[39]

Although pumped-storage plants are net consumers because energy is lost during the pumping process, the system leverages the fluctuations in electricity prices, capitalizing on periods of peak demand when prices are highest. By selling the stored energy at these times, pumped storage plants can offset the energy losses incurred during pumping, contributing to the overall economic viability of the system.[40]

B. Current Developments

Hydropower is currently the third largest source of electricity worldwide after coal and natural gas, generating more electricity than all other renewable technologies combined.[41] Hydropower provided most of the power to the economies of Norway, Canada, Switzerland, and Austria in 2023, while the largest hydropower fleets are

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[37] *See*, e.g., Breeze, 'Power Generation Technologies' 108f; Egré and Milewski (2002) Energy Policy 30 (1227); International Hydropower Association, 'Types of Powerplants'.

[38] Emmanuel Branche, 'The multipurpose water uses of hydropower reservoir: The SHARE concept' (2017) Comptes Rendus Physique 18 (470 f).

[39] *See*, e.g., Egré and Milewski (2002) Energy Policy 30 (1227); Anund Killingtveit 'Hydropower', Trevor M. Letcher (ed.) *Future energy: improved, sustainable and clean options for our planet,* 2nd edn. (Amsterdam: Elsevier, 2014) 453 (468 f).

[40] *See*, e.g., Felix A. Diawuo and Roland Teye Amanor 'Need for pumped hydro energy storage systems', Amos T. Kabo-Bah, Felix A. Diawuo and Eric O. Antwi (eds.) *Pumped Hydro Energy Storage for Hybrid Systems* (London: Academic Press Elsevier, 2023) 23 (27f); Egré and Milewski (2002) Energy Policy 30 (1227); National Hydropower Association 'Pumped Storage' (NHA, 2024); National Hydropower Association 'Pumped Storage' (NHA, 2024) <https://www.hydro.org/policy/technology/pumped-storage/> accessed 13 February 2024.

[41] Energy Institute, 'Statistical Review of World Energy 2023' (2023), 52, available at <https://www.energyinst.org/statistical-review>, accessed 13 February 2024.

currently operated by China, followed by Brazil, the United States, Canada, Russia, Japan, and India.[42]

According to the International Energy Agency, hydropower is expected to remain the world's largest source of renewable electricity into the 2030s, whereafter it will still play a crucial role for decarbonisation and flexibilization.[43] This is mainly a result of slowdowns in development in China, Latin America, and Europe due to growing concerns over environmental impacts and the decreasing availability of economically attractive sites.[44]

China will remain the leader in net capacity growth into the 2030s, followed by India and sub-Saharan Africa. In Europe, expansion will mostly occur in Turkey. The main driver for continued expansion of hydropower sites in the remaining European countries are renewable energy targets and required system flexibilization, but they are met with key constraints such as environmental regulations and permitting complications. As a result, development is shifting towards plant expansions or upgrades as well as fleet modernisation.[45]

According to the current draft of the Austrian national energy and climate plan, 5 TWh of hydropower-generated electricity should be added until 2030.[46]

C. Impacts of Hydropower

1. Positive

Hydropower plants can have a significantly positive environmental impact because they reduce the need for fossil fuels. Yet they can also cause severe and irreversible environmental damage, provoking an inner-environmental conflict that must be resolved in the Environmental Impact Assessment.[47]

The main benefit of hydroelectric power plants is electricity production. As hydroelectric power plants do not consume a non-renewable good, they cause

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[42] International Energy Agency, 'Hydropower Special Market Report' (IEA, 2021) 18 f, available at <https://www.iea.org/reports/hydropower-special-market-report>, accessed 13 February 2024.

[43] International Energy Agency, 'Hydropower Special Market Report' 43.

[44] International Energy Agency, 'Hydropower Special Market Report' 43f.

[45] International Energy Agency, 'Hydropower Special Market Report' 44.

[46] Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, 'Integrierter nationaler Energie- und Klimaplan für Österreich', 3 July 2023 (Draft) 74.

[47] On the role of inner-environmental conflicts in environmental law *see*, e.g., Klaus Ferdinand Gärditz, 'Ökologische Binnenkonflikte im Klimaschutzrecht' (2010) DVBl (214 f);.

substantially less emissions than non-renewable plants. On average, a hydroelectric power plant emits 23 gCO_2-eq/kWh, compared to 490 gCO_2-eq/kWh emitted by a gas-fired plant.[48]

Hydroelectric power plants also play a major role in stabilising the electricity grid.[49] To ensure a reliable supply, voltage and frequency within the energy grid need to be at the same level. Otherwise, large scale power outages might occur, seriously impacting societal and economic life. Since the liberalisation of the European electricity market, grid stabilisation has become even more important, as electricity can be traded and distributed throughout the European power grid. To ensure that the grid has the right amount of energy at any given time, control energy is used to add or subtract electricity when necessary.[50]

The storing of excess electricity in pumped-storage plants has become more important through the rise of wind and solar. Unlike e.g. gas-fired power plants, wind and solar plants can only produce electricity if a certain amount of wind or radiation is present.

Unfortunately, this often correlates with times when this electricity is not required, as more electricity is used on a cold, dark winter day than on a blazing summer day with a steady breeze.[51] To keep the grid stable anyways, operators must curtail renewable energy sources, losing renewable energy and reducing the share of renewables within the system.[52] This curtailment can be partly avoided by redirecting the surplus energy towards storage facilities such as pumped-storage hydropower plants.[53]

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[48] María Ubierna, Cristina Díez Santos, Sara Mercier-Blais, 'Water Security and Climate Change: Hydropower Reservoir Greenhouse Gas Emissions', Asit K. Biswas, Cecilia Tortajada (eds.) *Water Security Under Climate Change* (Singapore: Springer Nature Singapore, 2022) 69 (69).

[49] National Renewable Energy Laboratory, 'Grid Integration: Hydropower's Role in the Next-Generation Grid' (National Renewable Energy Laboratory, 2024) <https://www.nrel.gov/water/grid-integration.html> accessed 13 February 2024.

[50] For a very basic explanation of the Austrian Energy System *see*, e.g., Oesterreichs Energie, 'Keeping the lights on: how Austria's power grid remains stable', (Österreichs E-Wirtschaft, 2024) <https://oesterreichsenergie.at/en/our-electricity-system/how-austrias-power-grid-remains-stable> accessed 13 February 2024.

[51] *See*, e.g., Manfred Seeh, 'Weniger Strom im Sommer', (Die Presse, 21. August 2022) < https://www.diepresse.com/6179924/weniger-strom-im-sommer> accessed 13 February 2024.

[52] Paul Denholm, 'Energy storage to reduce renewable energy curtailment', IEEE Power and Energy Society (2012) (1f).

[53] *See*, e.g., Umweltbundesamt, 'Verwirklichung des Potenzials der erneuerbaren Energien durch Höherauslastung des Bestandsnetzes und zügigen Stromnetzausbau auf Verteilnetzebene' (2020) (4).

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

Hydropower plants can also have significant economic effects. While regional benefits mainly occur during the building phase, overall economic benefits are gained mostly by energy trading throughout a power plant's lifetime.[54] The ownership structure, national regulations, and operating schemes determines the beneficiaries of these economic developments.[55] Apart from economic benefits, hydropower plants can offer additional structural benefits, such as flood protection, water supply, irrigation and drainage, leisure, or recreation.[56]

2. Negative

The immediately recognisable disadvantages of hydropower plants are the irreversible landscape changes caused by dams, flooding, artificial lakes, or in-river-barriers.[57] These changes can severely affect surrounding terrestrial and aquatic habitats while irreversibly destroying natural landscapes, causing not only environmental, but also economic[58] and emotional[59] losses. Depending on the specific type of power plant, the areas most affected are the direct aquatic habitat and potentially submerged areas as well as riparian and shoreline vegetation.[60] The main cause for the significant impact in this area are altered flow regimes which leads to significant vegetation changes in both the impoundment region and downstream

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[54] *See*, e.g., Jürg Meier, 'Die Wasserkraft in der Schweiz lohnt sich', (NZZ am Sonntag, 13 April 2019), https://magazin.nzz.ch/wirtschaft/schweizer-kraftwerke-machen-oft-gewinn-wasserkraft-lohnt-sich-ld.1475025?reduced=true accessed 13 February 2024.

[55] On the ownership structures of hydropower in Austria *see*, e.g., Andreas Bachmann, 'Energiekonzerne schütteten 756 Millionen Euro Dividenden aus', (Moment.at, 9 May 2022) <https://www.moment.at/story/rekordgewinne-energiekonzerne-jammern> accessed 13 February 2024.

[56] *See*, e.g., Office of Energy Efficiency & Renewable Energy, 'Benefits of Hydropower' (*Office of Energy Efficiency & Renewable Energy*, 2022).

[57] *See*, e.g., Astrid Björnsen Gurung, Axel Borsdorf, Leopold Füreder, Felix Kienast, Peter Matt, Christoph Scheidegger, Lukas Schmocker, Massimiliano Zappa, Kathrin Volkart, 'Rethinking pumped storage hydropower in the European Alps' (2016) Mountain Research and Development 36 (225f); Breeze 'Power Generation Technologies' (119 f).

[58] *See*, e.g., Armando González-Cabán, John Loomis, 'Economic benefits of maintaining ecological integrity of Río Mameyes, in Puerto Rico (1997) Ecological Economics 21 (63f); Roberto D. Ponce, Felipe Vásquez, Alejandra Stehr, Patrick Debels, Carlos Orihuela, 'Estimating the Economic Value of Landscape Losses Due to Flooding by Hydropower Plants in the Chilean Patagonia' (2011) Water Resource Management 25 (2463 f).

[59] *See,* e.g., U.A.D. Prasanthi Gunawardena, 'Inequalities and externalities of power sector: a case of Broadlands hydropower project in Sri Lanka' (2010) Energy Policy 38 (727f).

[60] *See*, e.g., Stuart Bunn and Angela Arthington, 'Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity' (2002) Environmental Management 30 (492f).

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

reaches through spontaneous changes in water quality regarding temperature, turbidity or dissolved compounds.[61]

Fish and other aquatic organisms are negatively affected in all aspects, including with regards to migration, age and growth, spawning and reproduction, or food availability. Additionally, they are stranding more often, showing altered habitat behaviour; there are also changes in species composition and diversity as well as in biomass and density.[62] As migratory movement is restricted, other populations and dependent organisms that have no initial proximity to the power plant can be affected.[63]

Besides directly impacting the environment, hydropower plants can also have adverse effects on the global climate. Large open water reservoirs contribute to positive radiative forcing due to the Albedo-effect and emit biogenic greenhouse gases such as methane.[64]

IV. Forecasting

A. Future Efficiency

Apart from the technical specifics of the power plant such as installed turbine capacity, the technically feasible efficiency depends on the available water flow. While water availability is generally influenced by local conditions, seasons, and

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[61] *See*, e.g., Bunn and Arthington (2002) Environmental Management (492f, 499); Karen Smokorowski, Robert A. Metcalfe, S. D. Finucan, Nathan F. Jones, Jérôme Marty, Michael Power, Richard S. Pyrce, Russell J. Steele, 'Ecosystem level assessment of environmentally based flow restrictions for maintaining ecosystem integrity: a comparison of a modified peaking versus unaltered river' (2011) Ecohydrology 4 (792).

[62] *See*, e.g., Tim J. Haxton and C. Scott Findlay, 'Meta-analysis of the impacts of water management on aquatic communities' (2008) Canadian Journal of Fisheries and Aquatic Sciences 65 (442f); Andreas H. Melcher, Tor H. Bakken, Thomas Friedrich, Franz Greimel, Nona Humer, Stefan Schmutz, Bernhard Zeiringer, Angus Webb, 'Drawing together multiple lines of evidence from assessment studies of hydropeaking pressures in impacted rivers' (2017) Freshwater Science 36 (223f); J. Angus Webb, Kimberly A. Miller, Elise L. King, Siobhan C. de Little, Michael J. Stewardson, Julie K. H. Zimmerman, N. LeRoy Poff, 'Squeezing the most out of existing literature: a systematic re-analysis of published evidence on ecological responses to altered flows' (2013) Freshwater Biology 58 (2445f).

[63] Bunn and Arthington (2002) Environmental Management (499).

[64] *See,* e.g., Edgar Hertwich, 'Addressing Biogenic Greenhouse Gas Emissions from Hydropower in LCA' (2013) Environmental Science & Technology 47 (9605 f); Universität Innsbruck, 'Wasserkraft ist nicht per se klimaneutral' (Newsroom 02 March 2021) <https://www.uibk.ac.at/de/newsroom/2021/wasserkraft-ist-nicht-per-se-klimaneutral/> accessed 13 February 2024; Laura Scherer and Stephan Pfister, 'Hydropower's Biogenic Carbon Footprint' (2016) PLOS One (1 f); Georg Wohlfahrt, Enrico Tomelleri, Albin Hammerle, 'The albedo–climate penalty of hydropower reservoirs' (2021) Nature Energy 6 (372f).

precipitation patterns, global climate change plays an increasingly vital role for single power plants.[65]

Climate change causes fluctuations in precipitation patterns and seasonal flows and thereby directly affects the future efficiency of power plants.[66] Especially in alpine regions, retreating glaciers and permafrost as well as shifting snow melt influence seasonal water availability.[67] This also increases sediment yield and reservoir sedimentation, leading to a shortened lifespan of turbines, increasing the cost of electricity production, and reducing the lifetime efficiency of power plants.[68] Additionally, competition for water resources could further decrease power plant efficiency.[69]

Economically, the price of electricity respective to the overall market situation has the highest impact on the benefits realized. Since Europe's electricity markets were liberalised, the price of electricity is – in simplified terms – mainly determined by supply and demand.[70] It is important to note that supply and demand not only depend on consumer behaviour, but are influenced by complex trading relationships, both long and short term.[71] Apart from trading on international markets, the already available energy mix within the system has an important impact on electricity prices, as a large share of high-cost suppliers such as oil and gas plants increase overall prices

[65] *See*, e.g., AFRY Austria GmbH, 'Auswirkungen des Klimawandels auf die Wasserkraft in Österreich' (2023) 31 f; International Institute for Applied Systems Analysis, 'Climate change induced waterstress: challenges and opportunities in Austrian regions (IASA Research Projects, 28 June 2023) <https://iiasa.ac.at/projects/WaterStressAT> accessed 13 February 2024; Umweltbundesamt, 'Wasserkraft und Klimawandel' (Fachgebiet II 2.4 Binnengewässer, 18 September 2019) <https://www.umweltbundesamt.de/themen/wasser/fluesse/nutzung-belastungen/nutzung-von-fluessen-wasserkraft#wasserkraft-und-klimawandel> accessed 13 February 2024.

[66] *See*, e.g., Gurung et al (2016) Mountain Research and Development (226f).

[67] *See*, e.g., Ludovic Gaudard, Manfred Gilli, Franco Romerio, 'Climate Change Impacts on Hydropower Management' (2013) Water Resource Management 27 (5155); R Weingartner, B Schädler, P Hänggi, 'Auswirkungen der Klimaänderung auf die schweizerische Wasserkraftnutzung' (2013) Geographica Helvetica 68 (293f).

[68] Mélanie Raymond Pralong, Jens Martin Turowski , Dieter Rickenmann, Alexander Beer, Valentin Métraux, Thierry Glassey, 'Auswirkungen der Klimaänderung auf die Geschiebefracht in Einzugsgebieten von Kraftwerksanlagen im Kanton Wallis' (2011) Wasser, Energie, Luft 4 (282f).

[69] *See*, e.g., Gurung et al (2016) Mountain Research and Development (227).

[70] *See*, e.g., Oesterreichs Energie, ‚The electricity market: how electricity prices are set', (Österreichs E-Wirtschaft, 2024) <https://oesterreichsenergie.at/en/our-electricity-system/the-electricity-market> accessed 13 February 2024.

[71] *See*, e.g., ESO, How is electricity priced?, (National Grid ESO, 2024) <https://www.nationalgrideso.com/electricity-explained/how-electricity-priced> accessed 13 February 2024.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

due to the merit order system.[72] National and international regulations, such as caps or subsidies, also influence electricity prices.[73]

As shown, the aspects influencing a power plant's future efficiency are difficult to predict, as they depend on complex ecological and socio-technical interactions. Nevertheless, the assessing authority must outweigh future benefits against adverse impacts.

To do this, it uses expertise that has been derived through forecasting techniques such as models and scenarios.[74]

B. Models and Scenarios

Very generally speaking, a mathematical model describes a 'set of ideas and numbers that describe the past, present, or future state of something.'[75] An energy model could, e.g., aim to capture and forecast complex interactions between technologies, energy options, economic development, and social acceptance of energy policies.[76]

Based on such an energy model, an energy scenario is then used to describe possible development paths of energy supply or demand, for example.[77] Often, the aim of

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[72] *See*¸ e.g., Energy Information Administration, 'How is Electricity Priced?', (Electricity Explained, 2024) <https://www.Environmental Impact Assessment.gov/energyexplained/electricity/prices-and-factors-affecting-prices.php> accessed 13 February 2024.

[73] National regulations have been instituted, e.g., in Austria through the Erneuerbaren-Ausbau-Gesetzespaket – EAG-Paket, BGBl I 150/2021; regarding the impact the bill had on the electricity market *see*, e.g.,Tobias Rieder, 'Das EAG auf einen Blick', (Wien Energie, 24 January 2022) <https://positionen.wienenergie.at/blog/das-eag-auf-einen-blick/> accessed 13 February 2024. *See also* European Commission, 'Actions and Measures on Energy Prices', (Markets and Consumers, 2024) <https://energy.ec.europa.eu/topics/markets-and-consumers/actions-and-measures-energy-prices_en> accessed 13 February 2024; Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, 'Stromkostenbremse', (BMK, 2024) <https://www.bmk.gv.at/themen/energie/energieversorgung/stromkostenbremse.html> Accessed 13 February 2024.

[74] See FN 5.

[75] The Britannica Dictionary, 'Model' (Britannica, 2024) <https://www.britannica.com/dictionary/model> accessed 13 February 2024.

[76] *See*, e.g., O Bahn, A Haurie, D. S. Zachary, 'Mathematical Modeling and Simulation Methods in Energy Systems' (2004) Encycl. Life Support Syst. (EOLSS), Dev. Under Auspices UNESCO (3f).

[77] As is e.g. regularly done by the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSO-G) in their scenario reports available at < https://2022.entsos-tyndp-scenarios.eu/>, accessed 13 February 2024.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

such a scenario is to provide guidance for political, social, and economic decisions.[78] It is important to note that the main purpose of a model or scenario must not necessarily be the prediction of certain events, but that models or scenarios are often employed to actively shape the future according to social, technological, or economic goals.[79]

Depending on the goals set and the methods applied, different aspects influence the outcome.[80] First and foremost, a model's outcome is determined by the underlying question it aims to answer, the model approach, and the data used.[81] The question asked could depend on political goals, e.g., reaching a specific share of renewable energy by a given year.

Modelers then choose approaches and data that they see fit to answer the questions. The same is done when choosing the modelled processes or the spatial and temporal resolutions. All these choices, which are made prior to the model's deployment, will influence possible outcomes.[82]

In the case of energy models, one specific challenge is that energy demand is a derived demand and a fundamental resource not only for the economy, but also for private households. It is highly related to not only technological, but also social and governmental choices and developments. Additionally, it is specifically sensitive towards macro-economic adjustments such as taxes, caps, or subsidies.[83] Nevertheless, modelers must integrate today's assumptions about these long-term

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[78] *See*, e.g., World Energy Council, 'World Energy Scenarios', (Transition Toolkit, 2024) <https://www.worldenergy.org/transition-toolkit/world-energy-scenarios> accessed 13 February 2024.

[79] *See*, e.g., Niki Popper, Data, Models, and Decisions: How We Can Shape Our World by Not Predicting the Future, Hannes Werthner, Erich Prem, Edward A. Lee, Carlo Ghezzi (eds.) *Perspectives on Digital Humanism* (Cham: Springer Nature Switzerland, 2022) 297 (297).

[80] *See*, e.g., Iris Eisenberger, Stefan Steininger, 'Modelle als Umweltinformation' (2017) ÖWAW 201 (308); Iris Eisenberger, 'Prognosemodelle und generelles Verwaltungshandeln' (2022) ÖJZ 51, 418 (422f).

[81] Volker Grimm, Alice Johnston,H.-H- Thulke, V. E. Forbes, P. Thorbek 'Three questions to ask before using model outputs for decision support' (2020) Nature Communications 11 (2f).

[82] *See*, e.g., Karl-Kiên Cao, Felix Cebulla, Jonatan J. Gómez Vilchez, Babak Mousavi, Sigrid Prehofer, 'Raising awareness in model-based energy scenario studies—a transparency checklist' (2016) Energy, Sustainability and Society 6 (2f); European Commission, Models for policy decision-making: The questions you need to ask when confronted with model-based evidence (2021), available at <https://knowledge4policy.ec.europa.eu/sites/default/files/JRC126926_jrc126926_2021-11-22_ccmod-workshop-guidelines.pdf>.

[83] On the specific challenges of energy models *see*, e.g., Cao et al (2016) Energy, Sustainability and Society (2ff).

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

socio-technical interactions in an energy model or scenario, thereby already determining its possible outcome.[84]

While models and the scenarios built on them are highly influenced by volatile factors such as political and economic development, decision makers tend to perceive the obtained results as hard evidence.[85] Research across disciplines has been concerned with this effect.[86] Although future prone legal decisions, such as Environmental Impact Assessments, rely heavily on forecasting methods,[87] discussion on their known susceptibility to underlying assumptions is missing in legal literature.[88] The following example shows that this discussion is way overdue.

V. Example: PSP Koralm

A. Project Description

The 'Pumpspeicherkraftwerk Koralm' (PSP Koralm) project is set in the border region of Styria and Carinthia. Initially permitted in 2021 by the Styrian Provincial Government,[89] the permit was revoked by the Federal Administrative Court in June

[84] On the general problem of forecasting future developments from today's perspective *see*, e.g., Voros (2001) prospect Swinburne University of Technology (1); Joseph Voros 'A generic foresight process framework' (2003) Foresight 5 (16).

[85] *See*, e.g., Enserink, Kwakkel, Veenman, (2013) Futures 53 (2f); Ricarda Schmidt-Scheele, ''Plausible' Energy Scenarios?! How users of scenarios assess uncertain futures' (2020) Energy Strategy Reviews 31 (2 ff); more generally Joshua Schwartzstein and Adi Sunderam, 'Using Models to Persuade' (2021) The American Economic Review 111 (276 f).

[86] *See*, e.g., Myanna Lahsen, 'Seductive Simulations? Uncertainty Distribution Around Climate Models' (2005) Social Studies of Science 35 (896f); Theodore M. Porter, 'Trust in numbers: the pursuit of objectivity in science and public life', new edition (Princeton University Press, 2020) e.g. (33 ff); Erica Thompson, 'Escape from model land: how mathematical models can lead us astray and what we can do about it' (Basic Books London, 2022) e.g. (53f); more generally on the interplay of scientific evidence and legal decisions *see*, e.g., Sheila Jasanoff, 'What judges should know about the sociology of science' (1992) Jurimetric 32 (345 f) and Sheila Jasanoff, States of knowledge: the co-production of science and social order (Routledge, 2010).

[87] *See*, e.g., Simone Pulver, Stacy D. VanDeever, 'Thinking About Tomorrows: Scenarios, Global Environmental Politics, and Social Science Scholarship' (2009) Global Environmental Politics 9 (2).

[88] *Exemptions* are, e.g., Eisenberger, (2017) ÖWAW; Eisenberger, (2022) ÖJZ; David Lehr, Paul Ohm, 'Playing with the Data: What Legal Scholars Should Learn About Machine Learning' (2017) U.C. Davis Law Review 51 (65 f).

[89] GZ ABT13-205895/2020 – 53, following 'Permit 2020'.

2023.[90] Nevertheless, the documentation gives valuable insights into scenarios as decision support tools.

The analysis of the initial permit concludes that unjustifiable negative effects must be expected in two key areas.[91] The first key area covers surface waterbodies, where the ecological status would significantly deteriorate.[92] The second covers structural changes, which would lead to an irreversible transformation of the unique regional landscape characteristics.[93]

The effects quoted in favour of the project are the contribution to achieving national climate and energy goals; the PSP Koralm project, should it be realized, would reduce chances of penalties and contribute to the CO_2 emission reduction of the Austrian electricity production.[94] Also quoted are reduced fossil imports and the reduction of the necessity of nuclear imports, which would reduce the health risk posed by a potential reactor accident.[95] Further, the project would increase energy security within the region and, as a result, strengthen the regional and local economy by creating and securing jobs.[96] Additionally, reduced flood risks would be expected.[97]

In its overall assessment, the assessing authority concluded that the positive effects, which are 'demonstrably proven based on concrete model calculations,'[98] outweigh the negative impacts. The project was therefore permitted by the Styrian Provincial Government.

B. Applied Scenarios

The prevailing public interests with regards to the PSP Koralm project are laid out in an expert opinion on 'Public Interest'.[99] This expert opinion was commissioned by

[90] GZ W109 2247200-2/201E.

[91] Permit 2020 (259).

[92] Permit 2020 (263).

[93] Permit 2020 (273).

[94] Permit 2020 (358).

[95] Permit 2020 (282).

[96] Permit 2020 (282).

[97] Permit 2020 (283).

[98] Permit 2020 (356).

[99] Institute of Energy Systems and Electrical Drives (ESEA), 'Gutachten zum Nutzen des Vorhabens und zum öffentlichen Interesse an dem Vorhaben PSW Koralm' (2018) 11, following 'ESEA PSW Koralm (2018)'.

the Styrian Provincial Government as part of the procedure and was carried out by the Institute of Energy Systems and Electrical Drives (ESEA), Technical University of Vienna, in 2018.

The expert opinion calculates three different scenarios, based on the 'Sustainable Transition 2030' and 'Sustainable Transition 2040' scenarios created by the European Network of Transmission System Operators for Electricity (ENTSO-E) together with the European Network of Transmission System Operators for Gas (ENTSO-G).[100]

The scenarios are part of a series of scenarios developed by the ENTSOs together with stakeholders from industry, NGOs, Member States and regulators in 2018 with European 2050 emissions targets as an objective. The scenarios initial purpose is not to forecast the most likely development of the electricity market, but rather to represent roadmaps towards specific emission targets.[101]

The key assumptions of both the 2030 and the 2040 scenarios are that coal and lignite will be replaced by gas in the power sector. This is eased by low gas prices, steady economic growth, and a stagnating electricity demand until 2030 due to increased efficiency. Shale gas is not developed, bio-methane sees a strong growth, and the regulatory framework decreases the use of coal-fired power stations. Carbon capture and storage is a viable option in high load industries, while heavy goods and shipping sectors increasingly rely on LNG. Rapid development will be necessary during the 2040s to reach the 2050 targets. The 2040 scenario therefore sees a sharp increase in electric vehicles and electric heat pumps as well as an 11% increase of renewables compared to the 2030 scenario.[102] Differences in the underlying assumptions of the 2030 and 2040 scenarios should reflect that the level of uncertainty grows over time.[103]

In the expert opinion, three distinct modifications of the Sustainable Transition scenarios are used to calculate expected benefits of the PSP Koralm. The first scenario is based on the Sustainable Transition 2030 scenario, with no further assumptions.[104] The second scenario is also based on the Sustainable Transition 2030 scenario, but adds the assumption that planned DC lines will be operating in 2030,

[100] ENTSO-E, ENTSO-G, 'Scenario Report TYNDP 2018' (Brussels, 2018), available at <https://eepublicdownloads.entsoe.eu/clean-documents/tyndp-documents/TYNDP2018/_Scenario_Report_2018_Final.pdf>, accessed 13 February 2023.

[101] ENTSO-E, ENTSO-G, 'Scenario Report TYNDP 2018' 9.

[102] ENTSO-E, ENTSO-G, 'Scenario Report TYNDP 2018' 19.

[103] ENTSO-E, ENTSO-G, 'Scenario Report TYNDP 2018' 41.

[104] ESEA PSW Koralm (2018) 12.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

and includes trading of secondary balancing power.[105] The third scenario is based on the Sustainable Transition 2040 scenario, assumes that all planned DC lines will be operating in 2030, and includes trading of secondary balancing power.[106]

C. Calculated Benefits

Each scenario used in the expert opinion compares nine Key Performance Indicators for Austria; each scenario covers the overall system annually and over a 50-year period. The Key Performance Indicators cover energy costs, overall costs, CO_2 emissions, gas, curtailment of renewables, and the overall share of renewables.[107] They are partly calculated using the EDisOn+Balancing model, a model designed to optimize power plant deployment.[108] Although some model assumptions are listed in the annex, they do not always match the cited source.[109] It therefore remains unclear, which exact assumptions were applied within the model and whether they are similar to those made in the scenarios developed by the ENTSOs.

The results of the individual scenarios are presented in different manners. The Key Performance Indicators for each scenario are presented in a separate table, making it difficult for the reader to compare the outcomes per scenario directly. Each table shows the expected changes as total numbers and percentual changes. The percentual changes are underlined with red bars. In some instances, the bars vary in size, although they stand for the same value.[110]

Depending on the underlying scenario, the outcome of the Key Performance Indicators varies, with the highest difference between scenarios being seen for the expected curtailment of renewable energy (-0,8% vs. -4,7%). Another remarkable difference between the scenarios is that one scenario predicts an increase in derived CO_2 emissions.[111] This, however, is not further explained in the text, and it remains unclear if this development is likely or which other conclusions should be drawn from this result. Detailed results are only presented for the 'Sustainable Transition 2030

[105] ESEA PSW Koralm (2018) 12.

[106] ESEA PSW Koralm (2018) 13.

[107] ESEA PSW Koralm (2018) 31.

[108] The model is explained in Bettina Burgholzer, Evaluation of different balancing market designs with the EDisOn+Balancing model (2016) 13th International Conference on the European Energy Market (EEM) 1-6; ESEA PSW Koralm (2018) 29.

[109] *See*, e.g., ESEA PSW Koralm (2018) 32, Table 5.

[110] *See*, e.g., ESEA PSW Koralm (2018) 11.

[111] ESEA PSW Koralm (2018) 13.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

with no further assumptions' scenario. There is no clear indication why this scenario is preferred over the others.

Apart from the Key Performance Indicators, several possible benefits are stated within the expert opinion, including general information on the benefits of pumped hydropower.[112] There is no mentioning of uncertainties related to the 50-year forecasting period.

In its summary, the expert opinion states six main reasons for the prevailing public interest in the PSP Koralm. It is not clearly indicated which of these aspects are backed by which scenario or calculation and whether some of these aspects are connected to more uncertainties than others.[113]

D. Decision Support

The main purpose of the example analysis was to trace which evidence from the expert opinion is used by the assessing authority to support its decision, and whether this evidence has been retrieved from scenarios. If so, the question was if this was in any way mentioned in the permit, indicating awareness of the scenario.

There is no evidence stated in the permit that has not been stated in the expert opinion. Of the evidence stated in the permit, the reduction of curtailment of renewable energy, a declined primary energy demand for gas as well as an increased share of renewables are directly backed by scenario-based calculations in the expert opinion.

While the permit includes evidence that has been retrieved through a scenario, it does not indicate this. It is important to note that the expert opinion only explains one scenario in detail. It remains unclear to the reader why this specific scenario has been chosen over the others.

The example shows that evidence sustained from scenarios played a substantial role in supporting the authority's decision. However, the expert opinion did not explain why one scenario was preferred over another, and the permit did not mention the different scenarios at all. This suggests that information on the differences between the scenario outcomes went missing along the way.

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[112] ESEA PSW Koralm (2018) 4.

[113] ESEA PSW Koralm (2018) 26.

University of Vienna Law Review, Vol. 7 No 1 (2023), pp. 68-93, https://doi.org/10.25365/vlr-2023-7-1-68.

VI. Conclusions

Environmental Impact Assessments require the assessing authorities to evaluate effects that will become relevant in the future. This requires them to rely on evidence retrieved through models and scenarios, which at least partly depends on underlying assumptions about complex socio-technical interactions and developments. A first analysis has shown that neither the expert opinion nor the issued permit explicitly addresses the possible impact of scenario choices in their assessment. This underlines the necessity of further research on how models and scenarios can be used to truly support legal decision-making.

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