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The future of hydropower in Europe: Interconnecting climate, markets and policies

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ARTICLE INFO

Article history:

Received 16 April 2013

Accepted 17 September 2013

Available online xxx

Keywords:

Hydropower

Climate change

Electricity markets

Energy policy

ABSTRACT

Hydropower is very important for electricity supply security in the European inter-connection as well as for the economy of regions (primarily peripheral) that possess water resources. Its future may however be jeopardized by several factors: climate change, the development of new renewable energy, the creation of super and micro-grids, and progress in power storage technology. Energy and climate policy, as well as electricity market design and dynamics play a pivotal role.

This article carries out a comprehensive analysis of all these factors and discusses the future of hydropower. This discussion follows an overview of the present situation and of future drivers. The technical, environmental, economic and political aspects of the problem are analyzed with an interdisciplinary approach. The stakes as well as the uncertainties are highlighted.

The conclusion is that hydropower has a promising future, particularly in light of emerging sustainable energy policy, but that the risks should not be overlooked. Academics will find a comprehensive interdisciplinary analysis of hydropower in this article, whereas public bodies, communities and hydropower companies can identify the strategic variables that should be taken into consideration in the decision making process. The end of water concessions or authorizations is also evoked.

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1. Introduction

The fact that hydropower faces a constantly evolving environment blurs its future. From climate change to emerging energy policy and electricity reforms, uncertainties impact any predictions relating to this technology. It is therefore important to carry out a holistic assessment of the present situation and of future changes. This article provides an overview of the most important aspects that influence hydropower's future. It provides stakeholders and decision-makers with information on and analysis of the most relevant environmental, technical, economic and institutional

issues. All these aspects are considered in order to answer the following questions: What is the future of hydropower? How will it be impacted by climate change and changes in the energy sector? Which problems must be addressed today in order to ensure the sustainable development of hydropower?

Two approaches can be used in order to explore hydropower's future. On the one hand, we can analyze very specific aspects, for instance the impact of climate change on a specific power plant. This is what we did in other studies (Gaudard et al., 2013a,b). On the other hand, we can adopt a complementary approach, by developing a comprehensive analysis of hydropower. This is the approach adopted in this paper. Due to the fact that problems are complex and data is

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<http://dx.doi.org/10.1016/j.envsci.2013.09.008>

relatively poor, it is almost impossible to build a quantitative model without introducing too many simplifications. We instead opted for a qualitative approach, encompassing climate, electricity markets and policy. A variety of knowledge areas should be combined in order to assess the whole problem using an interdisciplinary approach.

We demonstrate that hydropower can have a promising future. Uncertainties however should not be overlooked, as problems are complex and many factors play an important role. These uncertainties not only affect this technology, they also affect electricity markets, energy and climate policies, as well as impacting the adoption of new technologies. Our study focuses on European countries, but also raises more general questions relating to hydropower. It takes into consideration a medium and long-term perspective.

The article includes three main parts. In Section 2, we present hydropower in the present situation by focusing on its technical and economic characteristics; its potential; its contribution to electricity system reliability; the role that it plays on the market. Section 3 is devoted to future drivers, namely the impact of climate change on electricity markets and in particular hydropower; the development of new renewable energy; the creation of smart super-grids and micro-grids; and the development of new storage technologies. In Section 4, we carry out a synthesis with the aim of mapping out the future of hydropower. Uncertainties are emphasized. Section 5 provides a conclusion.

2. Hydropower in the present situation

2.1. Hydropower's characteristics

2.1.1. Technical aspects

Hydropower produces electricity using kinetic energy from water (Eq. (1)). Using this energy, a turbine rotates powering a rotor that generates electricity. Assuming a flow of a certain speed, the theoretical power is:

$$P_t = \frac{1}{2} \rho Q_t u_t^2 \quad (1)$$

where P_t is the power at time t [W], ρ is the water density [kg/m³], Q_t is the water flow [m³/s], u_t is the water velocity [m/s] (Twidell and Weir, 2006).

Hydropower does not store electricity directly, but stores it in the form of potential energy (Eq. (2)). A pump uses electricity to bring water into an upper reservoir. When energy needs to be generated, this water is turbined. The theoretical power generated from this is:

$$P_t = g \rho Q_t H_t \quad (2)$$

where g is the gravitational acceleration [m/s²] and H_t the head of water [m]. The latter is the difference in altitude between the surface of water in the reservoir and the turbine levels.

The ratio between the theoretical power and effective power represents the efficiency. Because there is no thermal limit, it may reach 100% in theory (Twidell and Weir, 2006). In practice, it is up to 95% (Eurelectric and VGB PowerTech, 2003; IHA et al., 2000). Concerning storage, the total cycle of a pump-storage-turbine has an efficiency between 65% and 85% (Evans

et al., 2012; Ibrahim et al., 2008). Hydropower is therefore one of the most efficient technologies at producing and storing electricity.

The efficiency is also dependant on the turbine type. There are reaction and impulse turbines (Twidell and Weir, 2006). The first type includes all turbines that are submerged into the water, e.g. Francis. The main advantage is that reverse pumping is possible. The same turbine is used to both produce electricity and pump water. In contrast, impulse turbines, e.g. Pelton, use propelled water on the pales. Both cost and efficiency are higher than in reaction turbines. The choice between types of turbines depends mainly on the hydropower plant's type, head of water, services desired and costs.

2.1.2. Classifications of installation

Hydropower is a general term that covers a broad range of installations. Depending on the type, the services provided vary. Moreover, institutional and environmental constraints are not always the same.

In this article, we make a classification by facility type covering three main categories: run-of-river, storage and pumped-storage hydropower. In some papers, hydropower installations are classified by water head, storage capacity, purpose or size (IHA et al., 2000). We do not consider these categories, as there is no consensus between countries (Egre and Milewski, 2002; IEA, 2012a). We should however point out that a hydropower plant of up to 10 MW is small according to the EU (ESHA, 2012). They may therefore take advantage of certain measures aimed at promoting decentralized renewable energy (Kumar et al., 2011).

2.1.2.1. Run-of-river. The energy production of run-of-river hydropower plants depends on the timing of the inflow. Some have a reservoir with a capacity no greater than a few days production (IEA, 2012a). They generate base-load power with seasonal fluctuations.

These installations are found in many parts of Europe. They are mainly built in flatter areas (Egre and Milewski, 2002; IEA-HA, 2000). The energy comes mainly from the water volume and not from the head of water. In mountainous regions, on the other hand, where it is also possible to build such plants, the flow rate may be low and head of water high. Thus, important differences exist amongst run-of-river power plants.

Run-of-river hydropower plants have a low environmental impact as long as the entire ecosystem is adequately protected (EAWAG, 2001). Fish ladders represent an important achievement in this respect. Plants without reservoirs provoke fewer problems. Because the civil engineering works require less concrete than storage hydropower plants, greenhouse emissions are lower (IEA-HA, 2002).

2.1.2.2. Storage. The storage time is the main difference between run-of-river and storage hydropower, which can be used to manage output seasonally or even annually. They are mostly situated in mountainous regions or in areas with large natural reservoirs (Balat, 2006). The high head of water provides the possibility of storing significant energy potential with minimal storage volume.

Although the resource is renewable, this power production may provoke an important environmental impact. The

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