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Current status and future prospects of hydropower in Saxony (Germany) compared to trends in Germany, the European Union and the World

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ABSTRACT

Hydropower plays an important role as the main renewable source of energy generation with an installed capacity of 990 GW in 2012 worldwide contributing to climate protection. However, the main sources of electricity generation are large dams contributing to more than 90% of electricity generated from hydropower. In Saxony (ca. 300 hydropower plants with an installed capacity of 88 MW), comparable to most of the other German federal states (Bundesländer, with ca. 7.600 hydropower plants and an installed capacity of ca. 4 GW in total) and industrial nations worldwide the developmental potential for increasing electricity generation by hydropower is almost exploited. Future prospects for development of large hydropower and pump-storage hydropower plants are generally more positive in some countries as the need for storage of surplus electricity generation will increase. Small hydropower might be of increasing interest in developing countries if locations for hydropower that are economical to develop and that can be exploited with respect to environmental protection will be available. Developmental potential for increasing hydropower in Saxony will be mainly the improvement of technical efficiency (refurbishment) of existing hydropower plants and to a much lesser extent the use of existing non-hydropower low head dams that must be not necessarily removed to achieve the environmental objectives for the particular streams according to the Water Framework Directive (WFD). Nevertheless, statutory requirements for environmental protection especially for migratory fish and for improvement of stream ecosystem functions will restrict the future development of hydropower in Germany as well as in most countries of the European Union.

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1. Introduction

Climate change induced by emissions of greenhouse gases (GHG) from anthropogenic activities is the greatest challenge for mankind during the next decades. Main effect of increased anthropogenic greenhouse gas concentrations in the atmosphere is the increase in global mean temperature that could be observed during the last decades [1]. Human use of fossil fuels (especially oil, coal and gas) for total primary energy supply accounts for the majority of global anthropogenic GHG emissions leading to emission of ca. 29 billion tons carbon dioxide (CO_2) in 2009 [2]. Shares to CO_2-emmissions of coal/peat (43%) were the highest followed

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by oil (36.7%), and natural gas (19.9%). Significant lowering of GHG emissions will be urgently necessary to achieve the objective of limiting the increase in global temperature to 2 °C above pre-industrial levels, to which all major emitting countries agreed in the Copenhagen Accord. Several possible options exist to reduce GHG emissions including energy conservation and efficiency, fossil fuel switching, renewable energy, nuclear and carbon capture and storage.

Even assuming a new policy scenario in which fossil-fuel subsidies are completely phased out in all net-importing regions by 2020 (at the latest) and in net-exporting regions where specific policies have already been announced, the world electricity demand continues to grow from 16,819 TWh in 2008 to about 30,300 TWh in 2035 [3]. Renewable energy sources can replace fossil fuels for electricity generation to a certain extent, contributing to the reduction of worldwide CO_2-emmissions. Hydropower is today the most important renewable source for generation of electricity worldwide. Hydropower contributed 16.5% to world electricity generation in 2012, while other renewables including geothermal, solar, wind, biofuels and waste, and heat contributed only 5.2% [4]. Furthermore, many countries actually use the potential to increase the use of renewables for electricity generation, especially non-OECD countries, first of all in Asia [3,5], but also in South America, the Russian Federation and, remarkably for Europe, in Turkey [6]. Nevertheless it is expected that shares of renewable energy sources to worldwide electricity generation will significantly increase from 19% in 2008 to 32% in 2035, but shares of hydropower are expected to remain around 16% while shares of other renewables will significantly increase (e.g. wind power from 1% in 2008 to expected 8% in 2035) [3].

Electricity generation in Germany will be determined during the next years by the phase-out of nuclear power, an energy market reform and climate change policy. Nuclear power phase-out as the consequence of the Fukushima catastrophe will result in a progressively shut down of nuclear power stations as they age – with complete shut-down of all plants estimated to occur by 2022 [7].

Increasing electricity generation by renewables, energy conservation and efficiency in heating, especially thermal insulation of buildings are the main measures to reduce the emissions of 70–80 Mio. t CO_2/a until 2020. Considering the long term period until 2050, the electricity generation by renewables become more important as reducing potentials of other possible measure to reduce GHG emissions decrease by time [8].

Twenty years ago, hydropower was the only renewable energy source contributing significantly to electricity generation in Germany (91% of renewables), while electricity generation by all other renewables together was rather negligible with 1836 GWh in 1992. Nevertheless, the use of hydropower, even small or mini hydropower schemes, cause environmental problems [9] that have to be addressed and considered as the Water Framework Directive [10] demands the protection, enhancement and restoration of streams and rivers with the aim of achieving a good surface water status. Thus, the European Small Hydropower Association recently raised some concern about the implementation of the WFD and the threats to the future development of small hydropower in some EU-member states [11]. The present study reviews available information on the possible development of hydropower electricity generation, comparing worldwide trends to the European Union (EU), Germany and Saxony as a part of Germany, with a long history in hydropower use for different purposes. Focus will be laid on medium, small and mini-hydropower, as no hydropower scheme with an installed capacity >10 MW exist in Saxony (except two pump storage plants), but large hydropower will be mentioned due to its predominant role in electricity generation by renewables. In the following hydropower will be classified into large (installed capacity >10 MW), medium (>1 MW and <10 MW), small (>0.1 MW and <1 MW) and mini (≤ 0.1 MW).

2. Electricity production by hydropower worldwide

Hydropower is rated to be the farthest developed technology of all renewables to generate electricity. Additionally, it is commercially proven and small run-of-river hydropower yield the highest energy payback ratio for all renewables [12]. Water is present and usable all over the year in contrast to wind and solar that are intermittent technologies and only usable when these resources are available.

Hydropower can be used to balance short-term variability in electricity demand, especially for systems with electricity inputs from various energy sources which can result in load imbalances within the grid. Electricity generation capacity and availability by large dams with high water storage capacity is very different from small run-of-river hydropower schemes [13]. Small hydropower depend on natural flow regime of the particular stream and river, with sometimes high seasonal variability, while large dams can be flexibly used to generate electricity, especially during short periods of high demands, due to the storage of a large water volumes. Small hydropower plants are characterized by high load factors (ratio of annual electricity generation to installed capacity), due to the utilization of the whole water potential available to them. The ability of large hydropower (especially pumped storage hydropower) to de-couple the timing of hydropower generation from variable river flows and to store water for later electricity generation enables large hydropower to fulfill the requirements of a peak-load power plant when much electricity is consumed. As a consequence the load factor is often significantly lower compared to run-of-river schemes [13].

Typical energy costs for large hydropower range between 3 and 5 US cents/kWh and are among the lowest costs of all renewables, while typical energy costs for medium and small hydropower ranged between 5 and 12 US cents/kWh, but can increase up to 40 US cents/kWh in rural areas or when the plant is very small (<1 kW installed capacity) or not connected to the grid [14]. Levelised costs considering the main cost components (capital costs, fuel costs and operations and maintenance costs) in relation to the life-span of the hydropower plant can be very competitive against other energy sources, when plants were localized in the best available sites, e.g. mountainous regions accessible for heavy construction equipment with high effective heads for small hydropower [15]. Other renewable sources of electricity generation exhibit levelised costs of 9–40 US cents/kWh for ground-mounted solar PV, 4–16 US cents/kWh for onshore wind power or 5.5–20 US cents/kWh for bioenergy combustion [4]. However, the most favorable sites for hydropower use were almost exploited in most of the industry countries, increasing the levelised costs of new hydropower in less favorable sites, making it uneconomical. Main economic advantage of hydropower are the generally low costs for operation and maintenance, while costs for civil works, especially the costs for construction of the plants and all other necessary constructional works (building of dams, penstocks, etc.) could be very high depending on the design and the location of the plant [16]. Additionally, investment costs (US dollars/kW installed capacity) for small hydropower significantly increase with decreasing effective head and decreasing installed capacity and electricity generation [17]. Nevertheless, the costs of hydropower can be highly variable depending on many site-specific factors, but the lowest investment costs were assumed for projects increasing the capacity of an existing hydropower plant or the installation of new hydropower facilities to an existing dam that was not used for electricity generation before.