Challenges of electricity-based decarbonisation

Due to significant success in technology development and cost reductions, the electricity system is now widely perceived as the part of the energy system to be first in decarbonisation. This means a double challenge for the system: Firstly, it will undergo significant change due to rapidly increasing shares of fluctuating renewable generation; Secondly, there will be an expansion of electricity into other fields of the energy system such as heat generation and transport.

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Introduction

One of the major fields of success on the way towards sustainable energy systems in recent years has been renewable energies in electricity generation. They grew by 5.5% annually from 2006 to 2013, and are expected to grow even faster over the next few years. RES generation technologies have seen huge cost decreases, and in 2013 they amounted to a share of more than 20% of electricity generated ([1], p. 64ff).
This strong trend has added to the expectation that the electricity sector will be the leading energy market segment in decarbonisation. This proposition has already been included in several scenario studies, and refers not only to the current situation but also to developments within the next decades. Due to the potential of decarbonising electricity, its role in the overall energy system will step by step increase through the electrification of heat generation, transport, and possibly even industrial processes [2, 3, 4, 5, 6].
The most recent IEA's energy technology perspectives report expresses this in its programmatic title: "Harnessing electricity's potential" for decarbonising the energy system [1].
The fact that a large share of the new renewable technologies uses fluctuating energy sources, such as wind and solar radiation, results in the integration of high shares of variable generation into the electricity system. This integration is a technological as well as institutional challenge with the potential to significantly transform the electricity system itself.
In the following, some core challenges for this change as well as for the internal transformation of the electricity system will be sketched.

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Electricity generation as a forerunner for decarbonisation

While the recent ETP study sees RES shares in global electricity generation rising from 20% in 2011 to 65% by 2050 ([1], p. 11), other studies ([4], p. 118) expect such shares as early as 2040. Moreover, they anticipate a full RES electricity supply by 2050 in the context of an increase in electricity generation by 277%, thereby achieving a share of 50% of final energy by 2050.

For Germany a recent study by the Federal Environment Agency [7] even sketches an almost fully electricity-based energy system. Here, on top of a direct share of electricity of almost 40% of final energy demand, the remaining fuels for transport as well as industrial feedstock are supplied by electricity-based hydrogen and derived synthetic fuels (methane, methanol). These are expected to be indirectly produced from electricity via renewables-based hydrogen. This vision not only assumes an increasing share of electricity in the final energy demand but, on top of this, also further electricity demand for the production of hydrogen, methane and synthetic fuels. Eventually, this would mean a tripling of electricity demand by 2050.

Core challenges for the expansion of low-carbon electricity

As shown before, scenario studies generally agree that electricity will be on the centre stage of decarbonising energy systems over the next four decades. Such a development, however, would require a reversion of several recent trends. Furthermore, it would impose a number of significant and interlinked challenges to the electricity system. Six of the most relevant of these challenges will be briefly discussed in the following:

(1) The first challenge is to foster the recent trend of increasing renewable electricity generation and at the same time phase out fossil generation. Fossil generation is not only dominating current generation but also still has the lion's share in new generation investments. In order to break such a trend, high incentives and significant investment into renewable generation technology as well as a rapid stop in developing fossil, and here particularly coal-based assets in all parts of the world, are needed. These developments must be asserted against strong interests and often (at least seemingly) attractive economies of fossil-based electricity generation. So far this issue has been rarely tackled by governments. NGOs, however, are lobbying for fossil fuel divestment, e.g. to convince investors to withdraw from new and existing assets in fossil power generation (http://gofossilfree.org).

(2) A successful expansion of RES electricity generation will in most countries be based on wind (onshore and offshore) and solar energy. This can be inferred from their importance in recent developments as well as the current and projected costs of generation. Due to the fact that their generation characteristics are directly dependent on the availability of wind and sun, the electricity system will need to adapt to the bulk of fluctuating electricity generation, which cannot be directly controlled. To accommodate these characteristics as well as local differences in natural potential and demand, electricity can be exchanged over long distances and be stored centrally or decentrally. This means that an expanded electricity grid plus several options to store electricity, including a flexibilisation of demand, have to be implemented as enabling technologies for a RES-based electricity system. These needs, however, are quite in line with the needs and options of a significant expansion of electricity into other energy markets.

(3) Besides (fluctuating) renewables other low-carbon electricity generation options, such as fossil power plants equipped with carbon capture and storage technology, as well as nuclear generation are or will be available. These, however, are characterized by low flexibility due to their technical and particularly economical characteristics with very high shares of investment costs. It is thus another challenge to design electricity systems in a way that results in an effective and economic combination of these technologies with fluctuating renewable generation [8].

(4) The conversion of the electricity system will also impose strong challenges on liberalised electricity markets in many countries. Due to the characteristics of wind and solar generation, they are producing at zero marginal costs. This complicates the al-location of costs and refunding of power generation via market systems. As already visible in leading markets, renewable expansion thus requires significant reforms of electricity markets, including appropriate instruments for capacity remuneration of low carbon as well as back-up capacities [8].

(5) Another challenge will be to solve the potential contradiction of achieving high efficiency gains in traditional uses such as electrical appliances and lighting while, on the other hand, expanding the use of electricity into new fields such as heat supply with heat pumps, the transport sector, and possibly also industry.

Increasing the efficiency of electricity use is a major strategy. Lechtenböhmer and Samadi [3] show that most climate protection scenarios for the EU expect high electricity savings of at least a third vs. business as usual developments. Such a policy would, among other instruments, benefit mainly from high electricity prices, which increase the economic incentives for electricity saving. However, substituting fuels by electricity in heat generation and transport would require lower electricity prices as compared to fuels. In this context this could mean increasing the prices of the competing fuels, e.g. via tax exemptions in the transport sector, in order to make electric technologies competitive [3].

(6) Finally, electricity for low-temperature heat generation and mobility is not only a potentially attractive low-emission energy carrier, but it also offers higher efficiency of the end use technologies. However, it cannot be applied in all energy sectors. For example, large shares of the transport sector (long distance freight transport, air transport) cannot be directly supplied by electricity. This holds also true for several industrial processes, e.g. conventional primary steel making and particularly the feedstocks for the chemical industry, which are mainly supplied from natural gas. In principle, however, natural gas, which mainly consists of methane, can be produced from electricity, which is first used to produce hydrogen via electrolysis of water. Then, the hydrogen can be directly used, e.g., in steelmaking or ammonia production, or be further combined with CO_2 to produce renewable synthetic methane or fuels. These processes offer a technical route to substitute fossil fuels by electricity-based renewable fuels, with the advantage of very small changes in the characteristics of the energy carrier. The disadvantage of this route, however, are its high costs. They result from the two conversion steps needed to transform renewable electricity into fuels which come with high losses as well as high costs for the necessary technology. Such a strategy, which enables in principle a full decarbonisation of an industrial economy, as sketched by UBA [7], is therefore very expensive and also needs high amounts of green electricity [6].

Conclusions

The recent successes in expansion and particularly cost reduction of renewable electricity generation, mainly from wind and solar energy, are promising. They put the electricity system at the center stage of strategies for achieving a low-carbon economy. Electricity is not only expected to become the leading energy segment to be decarbonised but is also expected to expand into other (if not all) energy markets in order to supply low-carbon energy. While techno-economically justified, the studies promoting these visions make clear the huge technical but also regulatory challenges to be overcome for realising an electricity-based, low-carbon energy system.

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