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Human health impacts in the life cycle of future European electricity generation

Karin Treyer*, Christian Bauer, Andrew Simons

Laboratory for Energy Systems Analysis, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

HIGHLIGHTS

- Life cycle human health impacts (HHI) due to electricity production are analysed.
- Results are shown for the three ReCiPe perspectives and IMPACT2002+LCIA method.
- Total HHI of nuclear and renewables are much below those of fossil technologies.
- Climate change and human toxicity contribute most to total HHI.
- Fossil fuel combustion and coal mining are the most polluting life cycle stages.

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ABSTRACT

This paper presents Life Cycle Assessment (LCA) based quantification of the potential human health impacts (HHI) of base-load power generation technologies for the year 2030. Cumulative Greenhouse Gas (GHG) emissions per kWh electricity produced are shown in order to provide the basis for comparison with existing literature. Minimising negative impacts on human health is one of the key elements of policy making towards sustainable development: besides their direct impacts on quality of life, HHI also trigger other impacts, e.g. external costs in the health care system. These HHI are measured using the Life Cycle Impact Assessment (LCIA) methods "ReCiPe" with its three different perspectives and "IMPACT2002+". Total HHI as well as the shares of the contributing damage categories vary largely between these perspectives and methods. Impacts due to climate change, human toxicity, and particulate matter formation are the main contributors to total HHI. Independently of the perspective chosen, the overall impacts on human health from nuclear power and renewables are substantially lower than those caused by coal power, while natural gas can have lower HHI than nuclear and some renewables. Fossil fuel combustion as well as coal, uranium and metal mining are the life cycle stages generating the highest HHI.

1. Introduction

Sustainable future power generation should meet basic requirements in all of the three pillars of sustainable development, i.e. ecology, economy and society, mainly:

- reduce damages to human and ecosystem health.
- emit less greenhouse gases than today in order to mitigate climate change.
- result in lower indirect costs and support a stable economy.
- be safe, secure, affordable and locally acceptable.

The debates and complexities surrounding current and future energy supply demonstrate that no technology in use today can comply with all these requirements, meaning that it is important to identify trade-offs. Stakeholders (enterprises, private people and organisations as well as politicians) should be aware of them and act accordingly. Energy policies should in the same way take into account strengths and weaknesses of specific energy technologies and take decisions transparently weighting all the identified trade-offs against each other. Negative impacts on human health due to power generation technologies are one important aspect to be considered in the context of sustainable development: these human health impacts (HHI) do not only corrupt quality of life of each affected individual both in the short and in the long term, but also lead to burdens and costs for the whole society, e.g. in the health care system. Reduced life expectancy also has negative effects on the economic performance of a society. An essential

* Corresponding author. Tel.: +41 56 310 57 45; fax: +41 56 310 44 11.
E-mail address: karin.treyer@psi.ch (K. Treyer).

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aspect in the development towards sustainable electricity production is therefore to reduce its polluting emissions which impact on our own health, but also on ecosystems.

With the increased use of dispersed and/or stochastic sources such as solar, wind, biomass, hydro, etc., the way power is generated is undergoing a radical transition. This transition underpins the need to conduct analyses of the complete life cycle of the future power plants and associated fuel cycles. Only the methodology of life cycle assessment (LCA) according to official standards (ISO, 2006) and used for assessing the environmental impacts of a product or service allows for a comprehensive and balanced comparative evaluation of fossil, renewable and nuclear power generation technologies. It is commonly applied in criteria based sustainability assessments of energy technologies for measuring environmental, social and economic sustainability indicators such as GHG emissions, impacts on human health, external costs, etc (Schenler et al., 2009; Streimikiene et al., 2012; Roth et al., 2009; Stein, 2013; Hunt et al., 2013; Stamford and Azapagic, 2012; Pappas et al., 2012). These are essential elements in the "strengths and weaknesses profile" of the technologies and need to be used as support for decisions on sustainable development and policies.

This particular contribution to the special issue focuses on the potential impacts on human health due to emissions from the complete life cycle of future power generation. Previous LCA based comparisons of electricity production have largely focused on greenhouse gas (GHG) emissions. The Journal of Industrial Ecology ran a special issue which compiled systematic reviews and harmonization studies on life cycle GHG emissions of all important power generating technologies (JIE, 2012). The most recent literature reviews of life cycle GHG emissions of nuclear power (Lenzen, 2008; Sovacool, 2008; van der Zwaan, 2013; Warner and Heath, 2012) report cumulative GHG emissions per kWh electricity produced being within a range of 1–288 g/kWh, depending on comprehensiveness and completeness of the studies. Sovacool (2008) discusses possible reasons for the diversity of the Life Cycle Impact Assessment (LCIA) results such as the reactor type investigated. Simons and Bauer (2012) made an LCA based intra-nuclear comparison of the European pressurised reactor (EPR–Gen III) and potential fuel cycles in 2030 and compared these to the current operation of a Gen II pressurised water reactor (PWR). Various studies, such as Simons and Bauer (2012) or Sathaye et al. (2011), compare GHG emissions of nuclear power with those of other electricity generating technologies. The scientific literature shows a general consensus that the life cycle GHG emissions of nuclear power are much below those of fossil power generation and in a similar range as the GHG emissions from most renewable electricity sources. With regard to climate change, energy policies should therefore consider nuclear power to be a part of future energy scenarios, as other low-carbon technologies. Volkart et al. (2013) demonstrate that with the use of carbon capture and storage (CCS) the life cycle GHG emissions from fossil fuel power plants can be substantially reduced, but in general remain higher than nuclear and several renewable options.

The life cycle impacts on human health from (nuclear) power generation are less frequently quantified or discussed on a consistent basis than GHG emissions. One example however was in contribution to the measurement of the external costs of power generation in the ExternE and NEEDS projects (ExternE, 2006; NEEDS, 2009). These studies show that coal and oil fuelled power generation cause the highest impacts on human health while natural gas, with its cleaner combustion, generates least human health impacts among the fossil fuels. Nuclear and most renewable technologies (except of direct biomass combustion) generate lower human health impacts than fossil power generation chains according to the external cost calculation methodology. NEEDS (2009) also shows that the damages as a consequence of climate change are associated with high uncertainties and that the spread of estimated damage costs differs by a factor of more than ten.

2. Goal and scope

The goal of the research presented in this paper is to quantify and compare impacts on human health including effects of climate change due to power generation with centralised future generating technologies relevant to the year 2030 using LCA methodology. The contributions to human health impacts from different stages of the life cycles of the individual power generation chains are quantified for eachhuman health damage category. The influence of using different LCIA methods as well as using different perspectives in a particular LCIA method is shown.

2.1. Technology specification

The selection of technologies for 2030 was made by estimating an average European situation for expected efficiencies and technological development status on the one hand and a minimum capacity factor of around 50% on the other hand as overarching criteria. For all chosen technologies, comparability with nuclear power had to be ensured. For this comparability, only power plants with electricity as their main product were considered, i.e. combined heat and power (CHP) plants were not included. The latter normally are operated for heat production, so that the electricity is rather a by-product than a self-standing base-load product. Including CHP plants in the comparative LCA would also introduce the subjective element of allocation or system expansion in order to account for the environmental impacts of combined heat and power generation. With the minimum availability factor the technologies can all be considered to be of a centralised nature and are largely of base-load capacity. There are other energy carriers and technologies which could potentially play a significant role in 2030 such as ocean tide and wave power or photovoltaics coupled with advanced storage mediums, all of these not being at development stages ready to be implemented at once. Synthetic natural gas from various biomass sources might be another option, however, electricity from biomass combustion is considered to be limited by the availability of sustainably harvested biomass and to be in concurrence with other uses of this biomass. The overall potential is therefore considered to be too low for being a large-scale base-load technology. The technologies included in this study were limited to those which are estimated to be commercially available in 2030 and for which LCA data were available and of consistent quality (Table 1). Carbon Capture and Storage (CCS) is assumed to be implemented in fossil fuel power plants in Europe by 2030. Co-generation of coal with biomass was not taken into account; apart from reduction of GHG emissions, datasets for such co-generation would not provide new insights, since the LCA results would be very similar to those of electricity from coal power plants.

3. Methodology

Life Cycle Assessment (LCA) is a standardised method used to quantify environmental burdens and the potential impacts on human health and the environment due to the production and consumption of goods and services (ISO, 2006). It allows for a consistent, unbiased and comparative evaluation of the environmental performance of fossil, nuclear and renewable power generation technologies due to its comprehensive approach and analysis of complete energy chains. In the case of power generation, the life cycle of each technology