INTEGRATING ENERGY SYSTEM MODELLING AND LIFE CYCLE ASSESSMENT FOR BOTH COST AND ENVIRONMENTAL OPTIMISATION OF A DECENTRALISED RESIDENTIAL ENERGY SYSTEM

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Overview

Energy related activities are the worldwide biggest contributor to climate change, particulate matter and NO_x emissions (IPCC, 2014; Umweltbundesamt, 2018a, 2018b). Due to rising environmental pressures energy systems demand for sustainable solutions to meet energy security and the Sustainable Development Goals (United Nations, 2018) at the same time. This demands the design of a sustainable policy for future decades and the adaption to technological advancement, based on scientific tools to support integrated economic, environmental and social decision-making procedures. Energy System Modelling (ESM) allows to balance supply and demand at each point in time and simultaneously minimize costs by linear optimisation. However, climate policy and technological advancements demand the integration of new dimensions to cost optimisation. Life Cycle Assessment (LCA) provides a comprehensive tool to analyse environmental and social burdens of energy systems and services. In the current state LCA is limited to a post evaluation of specific systems. Out of this requirements we coupled a linear energy optimisation model with a parametrised Life Cycle Assessments to achieve an integrated optimisation. This integrated tool was used to analyse an expansion planning of a decentralised residential energy system including households, photovoltaics (PV), wind, Combined Heat and Power (CHP), battery storage and electricity from the grid. The optimisation model minimises both costs and 18 Life Cycle Impact Assessment indicators respectively from the year 2018 to 2040. Moreover both a single score environmental and an economic-environmental optimisation were applied and compared to the individual minima.

Methods

For the development of a linear optimisation model which supports both the technical resolution of a decentralised residential energy system and economic variables such as operational, fixed and investment costs, we use the open source energy system modelling framework "oemof" (Hilpert et al., 2017). To allow an expansion planning up to the year 2040, we extended the functionality of the economic tools integrated in oemof to include cost degression and future investments. Moreover, to include environmental impacts, we coupled oemof with the open source LCA modelling software openLCA (Ciroth, 2007) connected to the ecoinvent 3.5 database (Wernet et al., 2016) and ILCD 2.0 midpoint 2018 Impact Assessment also called EF 2.0 (Fazio et al., 2018). For this implementation into the energy system model, the Life Cycle Inventory data is paramterised into investment and operational environmental intervention following the economical scheme. The LCAs have been conducted according to ISO 14040, 14044 (Deutsches Institut für Normung, 2006, 2009) and recent ILCD recommendations (European Commission, 2010). The energy technologies are based on the data implemented in ecoinvent 3.5 to achieve a maximum overlap of technical and environmental modelling. Futhermore, electricity demand is modelled with 74 representative electric load profiles of residential buildings (Tjaden et al., 2015). The optimisation considers costs and each environmental impact separately to compose minima scenarios for each indicator. Moreover the model allows an integrated economic and environmental optimisation and simultaneously showing the risk of the combined assessment by comparing to the minimum of each indicator. For the integrated environmental optimisation (JRCII), recent normalisation and weighting factors provided by the European Commission's Joint Research Centre are used, based on the publications of Sala et al. (2017) and Huppes and van Oers (2011). Costs are included additionally to the environmental single score in the '5050' scenario, weighted with 50 % and normalised by the gross world product. Uncertainty and sensitivity analysis shows the robustness of the results and uncovers critical assumptions and influenctial parameters.

Results

First preliminary results show that within the cost scenario PV and grid power are preferred, whereas within the climate change scenario grid power is reduced and replaced by PV and battery storage. The optimisation regarding terrestrial eutrophication, non-carcinogenic human toxicity, ozone depletion, respiratory effects show a similar picture to climate change, however the scenarios regarding acidification, freshwater eutrophication, ecotoxicity, freshwater/marine eutrophication, ionising radiation, photochemical ozone creation, water use, fossil resources and land use almost fully avoid grid power and prefer CHP.

Conclusions

Under the limitations given and the assumptions made we conclude from the preliminary results that LCA and ESM are complementary adding the environmental sustainability dimension to an optimisation model. Eventhough combined environmental assessments including normalisation and weighting procedures are object of controversial discussions in environmental sciences, a combined optimisation has the advantage to deliver a communicable and decision-supporting result. Here the coupling of ESM and LCA allows to draw recommendations, uncover target conflicts and as well indicate the risk that occurs by the applied normalisation and weighting procedures. Thus the combined optimisation can adapt to changing conditions and contribute to the design of a sustainable policy for the future.

By the preliminary results we conclude that the energy system changes essentially by optimising with differing impact indicators. The climate change scenario reveals that wind power and PV installation can be beneficial from a climate perspective in locations which are considered economically non-viable. Because climate change is one of the biggest challenges of our time and the exceedance of the 2° C goal can lead to dramatic consequences with tremendous costs, we question if costs alone are still a reasonable indicator for an energy system optimisation. Nevertheless climate change optimisation has to be seen in the context of target conflicts: From the preliminary results we can already draw the conclusion that renewables show peaks in other impact categories such as land use, resource use (minerals and metals) and ecotoxicity which have to be fully taken into account to avoid the risk of any side effects.

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