MULTI-OBJECTIVE INVESTMENT OPTIMIZATION OF ENERGY SYSTEMS CONSIDERING LIFE-CYCLE ENVIRONMENTAL IMPACTS

Heidi Hottenroth, Pforzheim University, Institute for Industrial Ecology,
Tiefenbronner Str. 65, 75175 Pforzheim, Germany, Phone +49 7231 28 6403,
heidi.hottenroth@hs-pforzheim.de

Ingela Tietze, Pforzheim University, Institute for Industrial Ecology,
Tiefenbronner Str. 65, 75175 Pforzheim, Phone +49 7231 28 6002,
ingela.tietze@hs-pforzheim.de

Tobias Viere, Pforzheim University, Institute for Industrial Ecology,
Tiefenbronner Str. 65, 75175 Pforzheim, Phone +49 7231 28 6423,
tobias.viere@hs-pforzheim.de

Overview

When transforming to renewable energy systems, the decision on which energy technologies to prefer is mostly based on cost and climate indicators. However, this falls short when it comes to preventing burden shifting to other environmental concerns: e.g. the installation of renewable electricity generators in many cases leads to a high demand for mineral and metals.

To overcome these shortcomings, we propose a multi-objective optimization approach that combines energy system modelling (ESM) and life cycle assessment (LCA) to account for both environmental and cost impacts. Our decision support tool LAEND (Life cycle Assessment based ENergy Decision support) couples an ESM tool with LCA software and follows a multi-period myopic optimization approach applicable at the level of residential quarters. The resulting investment and dispatch planning of (renewable) energy systems covers electricity, heat, and mobility (in terms of electric mobility) and takes into account sector-coupling.

In a case study, we apply LAEND to a newly built residential neighborhood aiming to support decision-making towards a sustainable energy system.

Methods

LAEND links ‘oemof’, an open source ESM tool, with ‘openLCA’, an open source LCA tool, to incorporate environmental impacts into optimization computations and assessments. The model minimizes total impacts, which are the sum of weighted and normalized economics and environmental impacts. The European Union’s environmental footprint method 2.0 is applied as the impact method, providing data for 16 environmental indicators and corresponding normalization and weighting factors to aggregate all environmental impacts to a single score. This environmental single score is then aggregated with costs, which are also normalized. The weighting of environmental score and costs can be user-defined, and in a further multi-objective target function, all environmental indicators and costs are aggregated using equal weighting (objective named “equilibrium”). Alternatively, to the weighted sum, LAEND optimizes for a single objective like costs or single environmental indicators like climate impacts or depletion of minerals and metals.

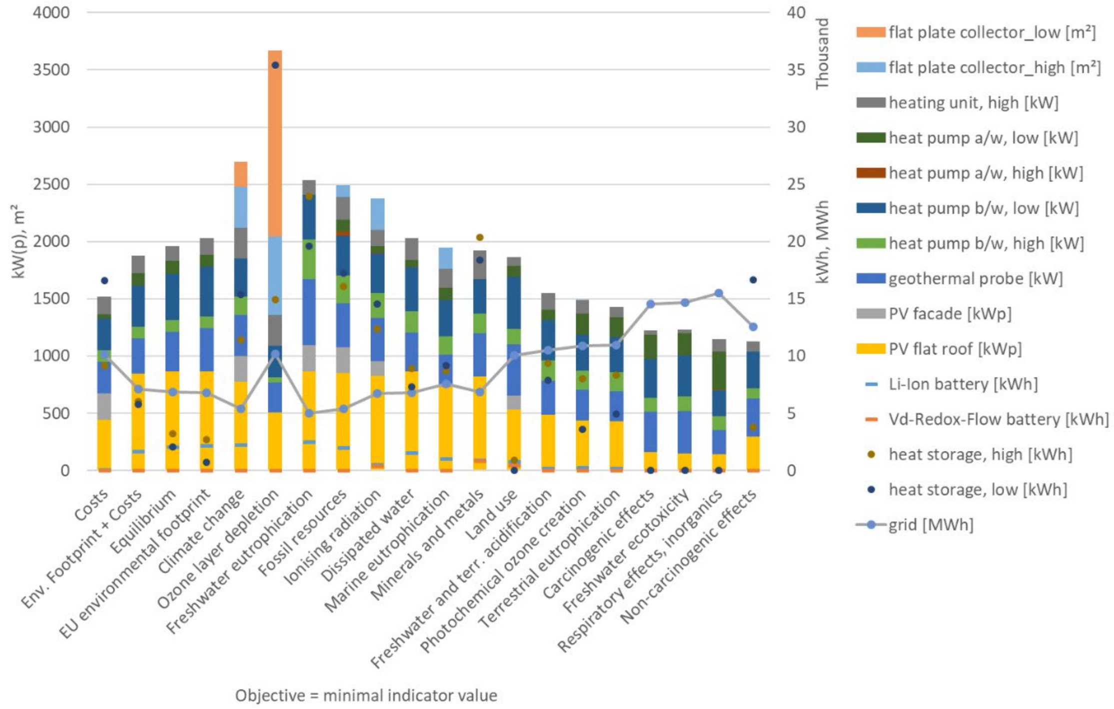
Sector-coupling is modeled through combined heat and power, electric mobility, heat pumps, and electric heating units. Further technologies considered are wind power, photovoltaics, solar collectors, wood furnaces, batteries, and thermal storages. Grid electricity is implemented in the model with different electricity mixes and thus environmental impacts over time.

A myopic approach is chosen to optimize a longer time horizon for reasons of calculation duration and proximity to the decision making process. The linear program is optimized for the first year representative of a period of five years (taking into account existing capacities). The results of the first year are input to the second five-year period and so on. The solution is a set of selected technologies with corresponding installed capacities and their utilization for each period.

For the optimized energy system, the full LCA with all impact indicators is calculated.

Results

In a case study, LAEND is applied to a newly built residential neighborhood with five multiple dwellings in an urban area in southern Germany. The model considers a constraint for roof area since the area of PV and solar thermal heat is limited. A rising electricity demand due to increasing electric mobility is taken into account. The results show different system configurations depending on the optimization goal (see figure): the solutions tend to higher installed capacity with higher weights of climate impact and therefore, relatively high costs. The configuration of the cost optimal solution differs strongly from the climate optimum. Most configurations for the different optimization goals prefer PV over solar thermal and brine-water heat pump over air-water heat pump. The multi-criteria optimization, which combines environmental and cost criteria (weighting by 0.7 environmental and 0.3 cost criteria), reveals a system configuration that compensates for the different objectives.



Conclusions

Optimizing single environmental impacts shows wide range of system configurations. Except for the optimization of climate impacts, the results of single indicator optimization are merely of hypothetical character since burden shifting cannot be reliably avoided. Analyzing the environmental impacts of the individual system configurations reveals high impacts for single environmental indicators (e.g. acidification and respiratory effects for the minerals and metals optimization). In conclusion, LAEND provides a decision support tool for optimizing energy systems, which considers the environmental footprint and costs simultaneously. Thus, relevant sustainability criteria can be systematically considered to support substantiated, but not necessarily uncomplicated, decisions regarding sustainable energy systems.