AN ENVIRONMENTAL ASSESSMENT FRAMEWORK WITH SYSTEMATIC REGIONAL AND TIME SCENARIOS

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ABSTRACT

A multiregional and scenario-based framework for environmental assessment is presented. Applied to energy production systems, this model clearly shows wide variations in various impact categories. An illustration of these variations is provided by the modeling of a concentrated solar power plant. Results show most of the environmental impacts are embodied in infrastructure; hence impacts are also strongly related to the temporal development of the background electricity mix. We conclude that, whereas greenhouse gas emissions are significantly lowered in comparison with fossil-fuel counterparts, material requirements are higher for this kind of technology, and even increasing with time.

INTRODUCTION

Low-carbon energy production technologies are part of the proposed solutions to mitigate anthropogenic greenhouse gas emissions due to current energy systems (Intergovernmental Panel on Climate Change 2011; International Energy Agency 2012). These technologies are expected to rollout significantly on a global scale within the next decades, the most optimistic scenarios foreseeing a 57% share of renewable electricity in the global production mix of 2050 ("2DS scenario" in (International Energy Agency 2012)). While the effect of this deployment on the evolution of anthropogenic greenhouse gas emissions is well analyzed and documented, little is known about the environmental consequences of low-carbon electricity production. Combining life cycle assessment and input-output for that purpose is possible through hybridization, for which a few methods have been described (Suh et al. 2003). The objective of this paper is to illustrate the use of a multiregional and scenario-based framework for environmental assessment.

METHODS

The THEMIS model was used to assess both the potential environmental impacts and resource requirements of the concentrating solar power. The model was developed as part of a UNEP IRP report, "Environmental Sustainability Benchmarking of Low-carbon Energy Technologies", currently under review. The model features a systematic assessment across nine regions and three years. Based upon Ecoinvent 2.2, with modifications brought from the NEEDS project (ESU and IFEU 2008) as well as the latest energy scenarios from the

International Energy Agency's Energy Technology Perspectives (International Energy Agency 2012) and other sources (Burnham et al. 2011), this model extends the scope of any life-cycle assessment study to a set of local conditions and parameters. A hybridized version of this framework has subsequently been developed (Gibon et al. forthcoming) to tackle truncation bias of system definition in life-cycle assessment (Majeau-Bettez et al. 2011). The EXIOPOL multi-regional input-output database is used in this context to complete physical inventories (Tukker et al. 2013). Inventory data for the concentrating solar power tower plant was gathered from (Viebahn et al. 2008). Material requirements were derived from the life cycle inventory of stressors (elementary flows) for the primary inputs of metals, and from the technology matrix (inter-industry flows) for the secondary inputs of metals and inputs of cement. Furthermore, a contribution analysis for these flows is provided in this study. A comparison with fossil-fuelled power plants is also shown.

RESULTS

Results are shown for the following impact categories: global warming potential, freshwater ecotoxicity, eutrophication, particulate matter formation, as well as cumulated energy demand, land use area, from ReCiPe 1.08 (Goedkoop et al. 2009), and material use. Material use is characterized for primary and secondary aluminium, copper and iron, as well as cement. The selected region is Africa and Middle-East, where CSP power generation is expected to be the highest of the nine regions in 2050.

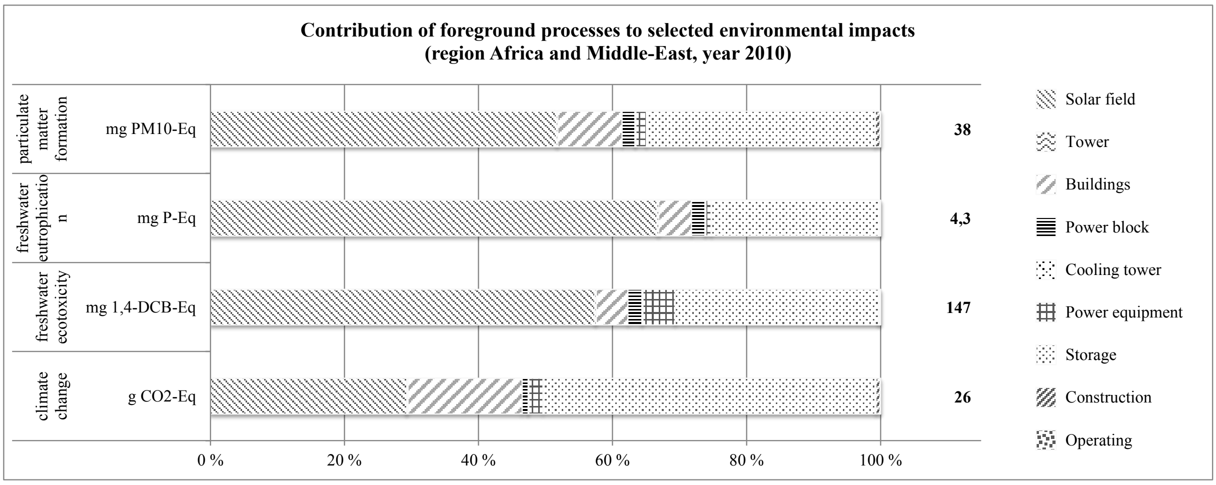

Figure 1. Contribution of foreground processes (plant parts) to selected environmental impacts, broken down and normalized to 100%. Totals are indicated in bold on the right hand side of the figure.

Figure 1 shows the environmental impacts per kWh of electricity generated by a concentrating solar tower power plant. The greenhouse gas emissions are dominated by solar field and storage. Buildings contribute too to the global warming potential, to a lower degree. The remaining selected impact categories follow a similar pattern, with solar field and storage as main contributors. Figure 2 shows a selection of material requirements for the same functional unit. While copper and iron & steel requirements breakdowns follow a similar pattern as for non-GHG environmental impact categories, cement requirements are dominated by the buildings part of the plant.

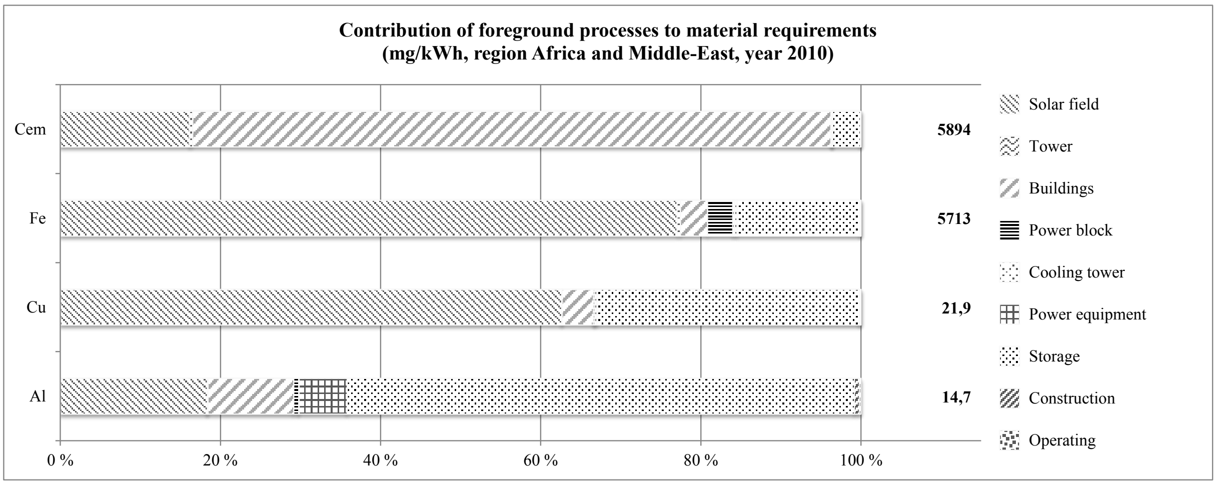

Figure 2. Contribution of foreground processes (plant parts) to selected environmental impacts, broken down and normalized to 100%. Totals are indicated in bold on the right hand side of the figure. Al = aluminium, Cu = copper, Fe = iron & steel, Cem = cement.

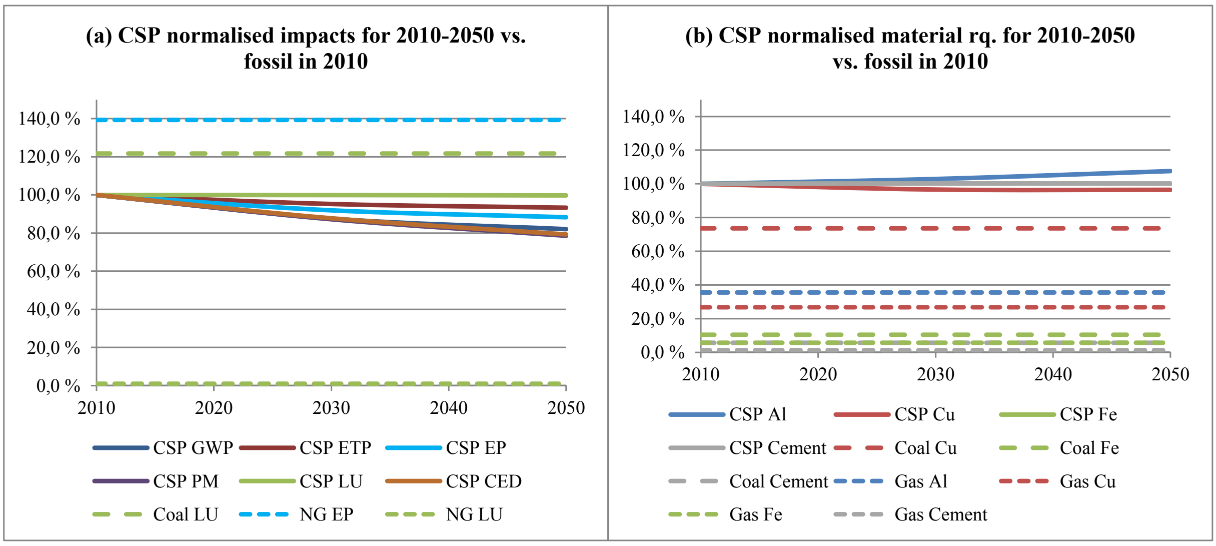

Figure 3. (a) Normalized impacts for the CSP plant ("CSP" on the graph), all set to 100% in 2010, compared with the impacts of a coal power plant (subcritical, "Coal") and a natural gas power plant (NGCC, "NG")[1]. (b) Normalized material requirements for the CSP plant and the fossil-fuelled power plants, all set to 100% in 2010. Abbreviations are the same as in Figure 2. The region is Africa and Middle-East, for the fossil-fuelled power plants, only the results in the 0%-150% range of CSP values are shown.

Figure 3 (a) shows that all selected CSP impacts are lower than for the fossil-fuelled power plants, aside from the land use of the natural gas-fired power plant. All impacts decrease with time. Figure 3 (b) shows an increase of material requirements with time for CSP. This is

[1] GWP = global warming potential, ETP = ecotoxicity potential, EP = eutrophication potential, PM = particulate matter, LU = land use, CED = cumulative energy demand

explained by the fact that the background electricity mix is increasingly composed of low-carbon technologies, themselves being more material intensive than their fossil counterparts.

DISCUSSION

The inventory data was gathered from different sources, and differences in scope are hardly evitable. When material requirements are calculated, it becomes clear that a few specific parts of an electricity plant become primary contributors. The example of concentrating solar plant illustrates the importance of overhead buildings and infrastructure in general in cement requirements.

CONCLUSIONS

Pursuing climate change mitigation goals may entail unforeseen tradeoffs such as high non-climate-related environmental impacts and high material requirements. These tradeoffs can however be quantified by using thorough inventories, and possibly hybrid assessment. Furthermore, regional (not shown here) and time variations can bring interesting insights.

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