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A typology for world electricity mix: Application for inventories in Consequential LCA (CLCA)

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ABSTRACT

Over the past two decades, the integration of environmental concerns into decision making has been gaining prominence both at national and global levels. Sustainable development now factors into policy design as well as industrial technological choices. For this purpose, Life Cycle Assessment (LCA) – which evaluates environmental impacts of products, processes and services through their complete life cycle – is considered a crucial tool to support the integration of environmental sustainability into decision making. In particular, Consequential LCA (CLCA) has emerged as an approach to assess consequences of change, considering both direct and indirect impacts of changes. Currently, no long-term datasets of Consequential Life Cycle Inventories (CLCI) are available, particularly in the case of electricity production mixes. A first and fundamental step to begin filling this gap is to make available data on national level greenhouse gas emissions from electricity and create a typology of electricity production mixes to support policy making. The proposed typology is based on the analysis of the composition of electricity production mixes of 91 countries producing more than 10 TWh in 2012, on the one hand, and of their calculated greenhouse gas (GHG) emissions (in gCO_2eq/kWh) from LCA using IPCC 2013 data, on the other hand. All types of primary energy resources are considered, and some are grouped according to similarities in their emissions intensities. Using graphical observations of these two characteristics and a boundary definition, we create a 4-group typology for GHG emissions per kWh, i.e., very low (0–37 gCO_2eq/kWh), low (37–300 gCO_2eq/kWh), mean (300–600 gCO_2eq/kWh) and high (>600 gCO_2eq/kWh). The typology is based on the general characteristics of the electric power generation fleet, corresponding respectively to power systems heavy on hydraulic and/or nuclear power with the remainder of the fleet dominated by renewables; hydraulic and/or nuclear power combined with a diversified mix; gas with a diversified mix; coal, oil and predominantly fossils. This typology describes the general tendencies of the electricity mix and, over time, it can help point to ways in which countries can transition between groups. Further steps should be devoted to the development of indicators taking into account grid interconnection, energy sector resilience in the quest for a mix optimum.

Keywords: Electricity production mix; Life Cycle Assessment; Consequential Life Cycle Inventory; Greenhouse gas emissions; Energy transition

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Abbreviations: ALCA, Attributional Life Cycle Assessment; CLCA, Consequential Life Cycle Assessment; CLCI, Consequential Life Cycle Inventory; FU, Functional Unit; GHG, Greenhouse gas; GR, Group; GWP, Global Warming Potential; LCA, Life Cycle Assessment; LCIA, Life Cycle Impact Assessment.

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1. Introduction

The growing concern regarding climate change from greenhouse gas (GHG) emissions, 60% of which are generated by the energy sector (OECD/IEA, 2014), is receiving a lot of attention. More than ever, the strong relation between the development of the energy sector and our planet's environment and climate requires a fuller understanding of the relations between energy and environmental and climate policies. Recent world events, such as the Conference Of Parties 21 in Paris, brought lots of expectations of institutional and governmental agreements (Hopwood, 2015). Decisions have then been made by all world countries concerning actions about climate change, especially those related to energy production (United Nations, 2016), and countries have pledged commitment to achieve their energy transition. An energy transition is viewed here as a fundamental structural change in the energy sector of a certain country. Several items can be highlighted such as the increasing contribution of renewable energies and the promotion of energy efficiency. Those transitions could thus take different pathways (Geels and Schot, 2007) and should help to change paradigm from emitting energy production mixes to more virtuous ones. Careful attention needs to be paid to the specific area of electricity production in energy transition. In fact, electricity production worldwide is diverse and complex, and specific literature has been reported about this concern in different countries, such as Germany or France (Strunz, 2014; Verbong and Geels, 2007, 2010; Percebois, 2012; Alazard-Toux et al., 2013). This concept of diversity in the energy portfolio as applied to electricity generation is attractive for diverse reasons: having a range of energy options increases grid stability, reduces consumers exposure to price spikes in any energy source, and creates the choosing policy options for energy and environmental and climate policies. In that context, electricity production has to be seen not as juxtaposed production means, but as a single mix for each country (or area) which revolves around static drivers (Herbert et al., 2015). This transition towards decarbonized energy systems involves mix disruptions that can occur through major changes (for example energy and environmental policies, new types of power plants).

Several methods and tools are available to assess environmental impacts and can help for decision support. Finnveden and Moberg (2005) listed an overview of those numerous tools, such as Ecological Footprint (EF), Environmental Impact Assessment (EIA), Material Flow Analysis (MFA), Life Cycle Assessment (LCA). It must be yet emphasized that the choice of the tool largely depends on the decision level. For example, at policy level, methods such as EIA are particularly adequate for assessing environmental impacts of projects and use of natural resources. LCA is viewed as a mature, systems-oriented and analytical tool assessing potential impacts of products or services using a life cycle perspective. This study is focused on the impacts of electricity generation and, in that context, the LCA methodology is particularly relevant (Finnveden and Moberg, 2005). In LCA, the assessment of environment impacts is normalized by ISO 14040-44 (Comité Technique, 2006a; Comité technique, 2006b) following a four-step iterative process: goal and scope definition, Life Cycle Inventory (LCI), impact assessment (LCIA) and interpretation. By definition, LCA is a multicriteria-oriented analysis and gives the opportunity to assess a wide range of indicators, such as Global Warming Potential (GWP), acidification, eutrophication and land-use (Hauschild et al., 2013). A large amount of LCA works have been conducted concerning electricity production (Curran et al., 2001, 2005; Davidsson et al., 2012; Gagnon et al., 2002; Hawkes, 2010; Mallia and Lewis, 2013; May and Brennan, 2003; Treyer and Bauer, 2013, 2014; Turconi et al., 2013).

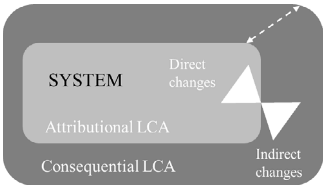

Fig. 1 – Boundaries of Attributional and Consequential LCA. Rectangles in light and dark grey represent the system boundaries respectively in Attributional and Consequential LCA. The boundaries of system expansion are represented by the white arrow. The Functional Unit (FU) is represented by white triangles. FU is defined according to ISO 14040 standards (Comité Technique, 2006a) as the quantified performance of a product system for use as a reference unit. In Attributional LCA, FU represents a portion of inventory and only direct changes, while either direct or indirect consequences due to FU are taken into account in Consequential LCA.

Furthermore, LCA is in constant methodological development. Over the past two decades, Consequential LCA (CLCA) (Weidema, 1993; Earles and Halog, 2011; Guiton and Benetto, 2013) has emerged as a modelling approach to assess consequences of changes (Ekvall, 2002). CLCA as a macro-systemic approach differs from classical Attributional LCA (ALCA) which is generally applied at a micro-system level (Guiton and Benetto, 2013). The main differences in both LCA approaches refer to goal and scope as well as inventory steps. Weidema et al. (1999) showed that Consequential modelling implies changes from Attributional in unitary processes interactions to expand the system, so that both direct and indirect impacts have to be considered, which is not the case in ALCA. CLCA has been discussed since the nineties (Weidema, 1993; Weidema et al., 1999) but its development is more recent. Indeed, Zamagni et al. (2012) emphasized the evolution of this method with an increasing number of publications devoted to "Consequential" and "LCA" as keywords, highlighting the growing interest of LCA practitioners for assessing the consequences of change in addition to product Attributional assessments.

Inventory in CLCA yet requires specific inventory data, especially to assess indirect changes (Ekvall, 2002; Weidema et al., 1999). The quality of inventory data is crucial for a reliable assessment: variability in Consequential Life Cycle Inventory (CLCI) may lead to uncertain LCIA results and may hamper the development of CLCA. Several methodologies using economic models to evaluate those data are available in the reported literature (Weidema et al., 1999). As CLCA includes all processes (direct and indirect) affected by change, some processes or energy fluxes remain in most studies (Guiton and Benetto, 2013; Weidema et al., 2009). Fig. 1 illustrates the main differences between Attributional and Consequential assessment mainly affecting system boundaries and direct/indirect changes.

Electricity, as a major energy provider for processes (Fernandez Astudillo et al., 2015), is intrinsically often taken into account in system expansion with indirectly affected processes. But, in some cases, the lack of data concerning electricity makes practitioners exclude electricity change

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