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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).

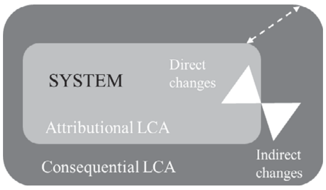

Fig. 1 – Boundaries of Attributional and Consequential LCA. Rectangles in light and dark grey represent the system boundaries respectively in Attributional and Consequential LCA. The boundaries of system expansion are represented by the white arrow. The Functional Unit (FU) is represented by white triangles. 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

Table 1 – Selected countries for typology design. Each country is selected from its total production in 2012 superior to 10 TWh (The Shift Project, 2015).

Africa	Asia		Middle East	Europe		America	Oceania
Algeria	Azerbaijan	Kyrgyzstan	Bahrain	Austria	Iceland	Argentina	Australia
Egypt	Bangladesh	Lao	Iran	Belarus	Ireland	Brazil	New Zealand
Ghana	India	Malaysia	Iraq	Belgium	Italy	Canada	
Morocco	Indonesia	Sri Lanka	Israel	Bulgaria	Netherlands	Chile	
Mozambique	Pakistan	Taiwan	Oman	Croatia	Norway	Colombia	
Nigeria	Philippines	Tajikistan	Qatar	Denmark	Poland	Cuba	
South Africa	Singapore	Thailand	Saudi Arabia	Estonia	Portugal	Ecuador	
Zambia	Japan	Uzbekistan	Jordan	Finland	Romania	Mexico	
Tunisia	Kazakhstan	Viet Nam	Kuwait	France	Russia	Paraguay	
	Hong Kong	China	Lebanon	Georgia	Serbia	Peru	
			Lybia	Germany	Slovakia	Uruguay	
			Syria	Greece	Slovenia	USA	
			United Arab Emirates	Hungary	Spain	Venezuela	
				Bosnia and Herzegovina	Sweden	Dominican Republic	
					Switzerland		
				Czech Republic	Turkey		
					UK		
					Ukraine		

(Ekvall and Andrae, 2006), or take too general data in databases (Fernandez Astudillo et al., 2015). Only short-term country-level data have recently become available in the literature (Amor et al., 2014).

A consistent approach concerning electricity production for CLCA has not been established till now to our knowledge and the development of more generalized electricity production CLCI data represents a major challenge for CLCA application (Zamagni et al., 2012; Ekvall and Andrae, 2006). If short-term country-level data start to be available in literature, reliable data are still lacking in a long-term perspective.

A first step to address this issue is to better understand electricity production mix worldwide. The aim of this work is to set a typology of electricity production mixes, based on potential greenhouse gas (GHG) emissions for electricity production and mix composition. Even if only GHG emissions are considered, the conceptual framework of LCA is used for several reasons: (i) LCA is particularly interesting as a system-oriented environmental assessment method; (ii) the typology that will be proposed could be further used for Consequential LCA which is the core of the work and (iii) could be finally extended to other criteria. Specific attention will thus be given to the relation between GHG for electricity production and mix composition factors in order to determine a mix typology.

2. Material and methods

2.1. *Scope definition*

The first step of the proposed methodology is to determine an appropriated time scale for the study. The year 2012 is used a starting reference date to observe the effects of energy transition, following the growing concerns about GHG emissions and global warming (OECD/IEA, 2014; den Elzen et al., 2014).

The typology has to be representative of most of mixes in the world. To avoid bias in the analysis, a well-established database and a set of representative countries must be taken into account. For this purpose, a same database for typology design is used. A freely accessible online world database that is TSP Database from The Shift Project (2015) has thus been selected. TSP data portal is an information platform that provides a free access to a wide range of global energy and climate statistics and combines data from IEA (OECD/IEA, 2015) and The World Bank (2015) in downloadable excel files.

The typology will have to be also representative of global mix dynamics. For this purpose, only countries with significant annual electricity production capacity will be considered. A preliminary screening of the potential of the electricity production of a more exhaustive list of countries shows that several production levels (5, 10, 20 TWh) can be highlighted. In that context, a 10 TWh level can be viewed as an average value for representing the minimal production level of the countries that will contribute to the typology. This finally leads to a set of 91 countries from every continent to be considered in the analysis.

2.2. *Data collection and calculation of GHG emissions*

The typology is based on two kinds of data, first, mix composition, expressed in percentage of the total production in 2012, and secondly GHG emissions of an energy amount of 1 kWh.

2.2.1. *Mix composition*

Using TSP Database (The Shift Project, 2015), the electricity generation data for the 91 countries satisfying a minimal production of 10 TWh used in this study are listed in Table 1.

The primary resources and their related power plants taken into account in the typology are biomass and waste, coal, gas, geothermal, hydroelectric, hydroelectric pumped storage, nuclear, oil, solar/tide/wave and wind.

2.2.2. *GHG emissions*

GHG emissions are defined here as the potential greenhouse gas (GHG) emissions per kWh calculated using LCA methods. Well-established and average values for GHG emissions are required for the typology design. As shown by Hauschild et al. (2013), the best way to evaluate climate change is to use the IPCC (The Intergovernmental Panel on Climate Change) baseline model of 100-year model and radiative forcing based

Table 2 – GHG emissions vs. type of primary resource, from SREEN report (Moonmaw et al., 2011). GHG emissions represent potential emissions in gCO_2eq/kWh, from LCA results.

Type of primary resource	GHG emissions in gCO_2eq/kWh
Biopower and waste	18
Coal	1001
Gas	469
Geothermal	45
Hydroelectric (pump storage included)	4
Nuclear	16
Oil	840
Solar/Tide/Wave	46
Wind	12

on global warming potential (GWP100), provided in the SREEN report, Appendix II, Table A.II.4 Strunz (2014) and Herbert et al. (2015). From the available data, the computation of the 50^{th} percentile has been considered as a good compromise between all the technological specificities. The technologies represented in Table A.II.4 of the SREEN report (Moonmaw et al., 2011) are arranged in the same manner as in the definition of the mix composition adopted in this study.

For example, biomass and waste are merged in the proposed terminology and considered separately in the SREEN report. So, in order to use single LCA data for that case, we calculate the mean between non-aggregated of SREEN global warming potentials, that is, the mean between global warming potential of biomass and of that of waste thus obtaining an aggregated value.

The LCA results that will be used in our calculations are presented in Table 2:

Considering each country from $i = 1$ to 91 and using data from mix composition, the GHG emission for each primary resource m (for a total of 9), of each country is computed as follows:

$$GHG_{i,m} = (Q_m/Q_{Tot}) \times GHG_m \quad \text{for } m = 1 \text{ to } 9 \qquad (1)$$

$GHG_{i,m}$: GHG emission of the primary resource for the country i in gCO_2eq/kWh
Q_m: quantity of electricity produced by primary resource in TWh
Q_{Tot}: total production in TWh
GHG_m: GHG emission of the primary resource in gCO_2eq/kWh.

The cumulative calculation for all primary resources then gives:

$$CF_i = \sum_m (Q_m/Q_{Tot} \times GHG_m) \qquad (2)$$

m: primary resource
CF_i: GHG emissions for country i in gCO_2eq/kWh.

This method is implemented for the 91 countries considered in the study.

2.3. Typology development

2.3.1. Ranking and boundary definition

Fig. 3 presents the GHG emissions ranked from the less to the most emitting country and Fig. 4 displays the mix composition histogram per country.

First, the GHG emissions are analysed to identify the occurrence of a change in the curve (for example plateau or increase) that may constitute the boundary of a potential group. Second, the mix composition histogram is analysed concurrently to establish if the observed change in GHG emissions is correlated with a mix change. In case of agreement, the boundaries of a group are identified as boundary candidates that will be further considered for typology development.

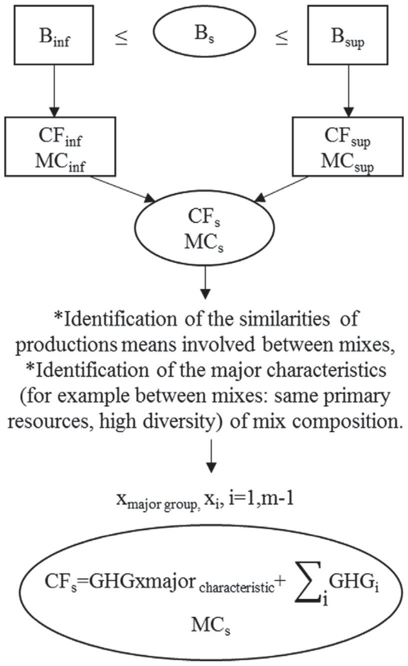

Fig. 2 – Determination of theoretical mixes from typology boundaries—B_{inf} and B_{sup} correspond respectively to the lower and upper bounds, that have been identified by the 2-tuple (GHG emissions CF; mix composition MC). The different steps allow determining (CF_S; MC_S) corresponding to the theoretical bound B_S.

2.3.2. Building theoretical typology boundaries

The typology must represent every possible mix. As mentioned in Section 2.2.2, the first step of our work only gives discrete values corresponding to the GHG emissions of the studied countries. The objective is here to determine the theoretical mixes that can represent general compositions as shown in Fig. 2, so that the evolution of GHG emissions can be viewed as a continuous function of the mix composition. Even if numerous combinations of mixes can correspond to identical values of GHG emissions, the theoretical mix has to correspond to the really observed ones that define potential boundaries.

For this purpose, the following methodology is proposed to determine theoretical mixes. For the sake of illustration, an arbitrary example supports the methodology: the numerical values do not represent the results that have been actually observed.

For each potential boundary defined in Section 2.2.2, the GHG emissions and mix composition can be obtained. For example, let us consider two consecutive values of potential boundaries for a same group, i.e., 450 gCO_2eq/kWh and 590 gCO_2eq/kWh respectively. The first emission value (respectively the second one) corresponds to a mix composed of 90% gas (which contributes to 422.1 gCO_2eq/kWh) and of a 10% contribution of diverse renewables (which contribute to 27.9 gCO_2eq/kWh). The mix corresponding to 590 gCO_2eq/kWh is also composed of 90% of gas (which contributes to 422.1 gCO_2eq/kWh as abovementioned) and of

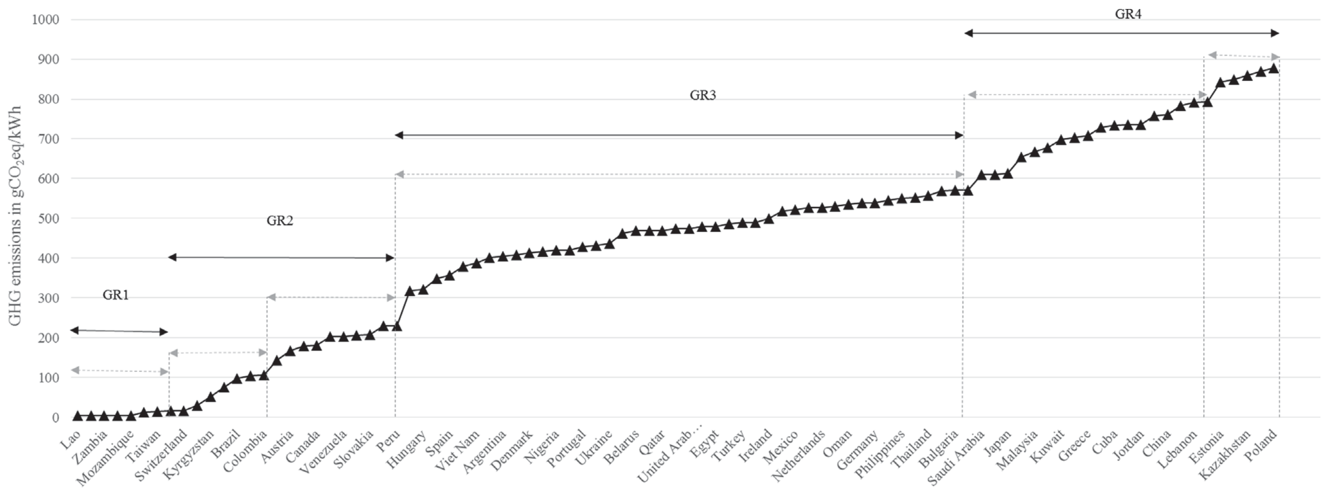

Fig. 3 – GHG emissions for the selected countries, GHG emissions are ranked in increasing order, the changes in curves identified. Grey arrows correspond to intervals delimiting boundaries before their evaluation regarding mix composition and leading to six potential groups: black arrows correspond to the finally selected intervals for boundary determination. The term GR is the abbreviation of the final group.

10% of a really diverse mix of fossil and renewables (which contributes to 167.9 gCO_2eq/kWh).

Similarities and differences between both mix compositions can thus be observed and the level of gCO_2eq/kWh that each contributor (i.e. energy primary source) gives can thus be highlighted. It must be also emphasized that the determination of a continuous function between two bounds is also motivated by the identification of a bound expressed as an integer rounded to hundred (here 500 gCO_2eq/kWh). In the example, both mixes have in common the gas contribution that will be kept for theoretical mix. The remaining energy sources then contribute to 77.9 gCO_2eq/kWh, which is consistent with the observed mixes, that are largely composed of renewables, so that low emissions are involved, yet with some percents of fossil fuels (for example to back up demand change). It can be thus deduced that the theoretical boundary of 500 gCO_2eq/kWh is reached with a mix composed of 90% of gas and 10% of a diverse mix, majorly composed of renewables, but also of some fossil fuels.

By definition, a lower bound of a group will be the upper bound of the previous one.

2.3.3. *Typology group description*

A qualitative analysis is performed for each country in order to identify the characteristics that can globally represent every mix belonging to a group. These general characteristics about mix composition must be applicable to every possible mix and will then define a typology group. A maximum number of three qualitative features is considered.

This qualitative assessment will be performed by histogram analysis (see Section 2.3.1) for each mix in order to detect which types of primary resources are significant. A primary resource is viewed as significant in mix composition for the typology if it represents at least 25% of the total mix composition. These observations will form the basis for the determination of major global characteristics of a group.

In order to avoid an exhaustive classification, i.e., limiting the number of features to 3, the primary resources that have similar values for GHG emissions and so a similar influence on mix are merged. This is typically the case for nuclear energy and hydropower, corresponding respectively to 4 and 16 gCO_2eq/kWh.

2.3.4. *Final typology*

The typology involves two items for group definition as defined in Sections 2.3.2 and 2.3.3:

- GHG emission range, defined by continuous quantitative data of GHG emission results delimited by group boundaries,
- Mix composition global characteristics, encompassing the identification of primary resources used to produce electricity and their quantitative contribution.

In order to represent all the cases taken into account in the typology, a spatial representation using a Geographic Information System (GIS) (Heywood et al., 1998) that is well adapted for a multifaceted description of complex systems and their dynamics is used. For this purpose, QGIS 2.6.1 (QGIS, 0000), a widely used open source software tool for GIS representation and modelling is selected.

For each country, two kinds of information are visualized, i.e., first total electricity production for 2012 (see Section 2.2.1 The Shift Project, 2015), and second, typology group.

The same tool will be further used to represent the temporal evolution of the mix dynamics that will also be studied in a perspective of energy transition.

3. Results and discussion

3.1. *Typology: results and map projection*

3.1.1. *Representation of GHG emissions and mixes*

Fig. 3 shows the GHG emissions of the different countries that exhibit a nonlinear behaviour.

Six ranges can be observed in the GHG emission curve corresponding to a change in the curve: [16–30], [30–100], [100–230], [230–317], [317–570] and [570–800] gCO_2eq/kWh, leading to six potential groups.

It can be seen from the coloured patterns in Fig. 4 that the mix composition histograms exhibit 3 major composition types, i.e., hydroelectric, gas and coal. Three characteristics can thus be highlighted for group definition and description.

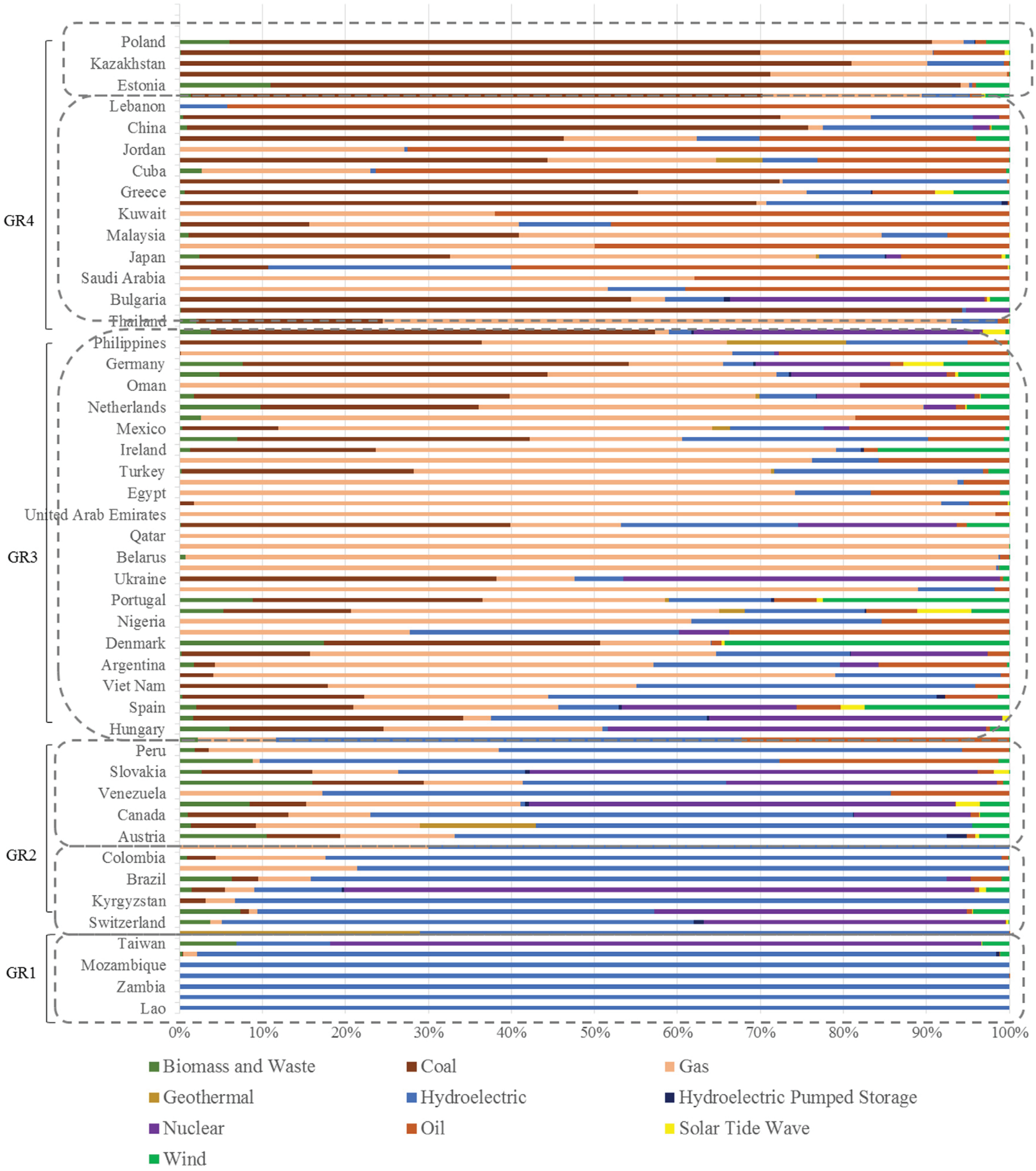

Fig. 4 – Mix composition for the selected countries, GHG emissions are ranked in increasing order. Each grey border corresponds to potential groups represented by grey arrows in Fig. 3. Black brackets on left side represent the selected groups (black arrows in Fig. 3). The term GR is the abbreviation of the final group.

3.1.2. *Group boundaries and mix composition*

Three of the observed changes in the GHG emission curve can be found consistent with the typology, i.e., the existence of a potential boundary matches with a significant change in mix composition. The first occurrence corresponds to a GHG emission of 16 gCO_2eq/kWh representing mixes that are largely composed of hydraulic and nuclear production (grey arrow in Fig. 3). A break into mix composition can be observed, affecting no major production, that is nuclear and/or hydropower, but the other modes that are composed largely of fossil fuels and renewables to a less extent. So the range [4–16] gCO_2eq/kWh can be kept as a group (Gr 1). Let us consider now the range [100–230] gCO_2eq/kWh, corresponding to the third grey arrow in Fig. 3. Even if a change in the curve can be observed at the upper bound, it does not correspond to a major change in mix composition. Indeed, hydropower plays an important role in mix. This explains why the two domains [30–100] and [100–230] gCO_2eq/kWh can be merged together to form group Gr 2. Indeed, the mixes in that group have a major production mode composed mainly of nuclear and/or hydropower, and of other production modes composed of various primary resources, from renewables to fossils fuels. The range [317, 570] gCO_2eq/kWh, corresponding to the fourth grey arrow in Fig. 1, is well representative of mixes composed of gas as major production, and of various other production mixes, so that the range [317–570] can be considered as group Gr3. Finally, the break occurring at 800 gCO_2eq/kWh, corresponding to the last grey arrow in Fig. 1, involves mixes with a majority of high emitting fossil fuel, i.e., coal and fuel so that it does seem necessary to distinguish between them.

Table 3 – World mix typology. Each group is characterized by boundaries defined by GHG emissions of kWh, major production, which represent predominant primary resources and other production mode that match total mix composition.

Group	GHG	Bounds (gCO_2eq/kWh)	Main characteristics	
			Major production	Other production
1	Very low	0–37	Hydraulic and/or nuclear	Predominantly renewables
2	Low	37–300	Hydraulic and/or nuclear	Diversification
3	Average	300–600	Gas	Diversification
4	High	>600	Coal, oil	Predominantly fossils

The identification of potential boundaries deduced from a graphical analysis is then followed by the analysis of theoretical mixes, so that the typology initiated from discrete values of carbon emissions of a set of countries could be extended to continuous values. Concerning the first group [4–16] (gCO_2eq/kWh), the mixes are mainly composed of hydraulic and nuclear production, as observed in Fig. 4. The lower bound has been taken equal to zero, so that the potential of new technologies that will be less emitting than hydropower (which is at 4 gCO_2eq/kWh) can be further considered. Clearly, a mix exclusively composed of either nuclear or hydraulic can be viewed as difficult to manage in a majority of cases, due to short-term demand management, for countries that do not have a strong grid connection with their neighbours or back-up generating capacity provided by others. So, to be consistent with this assumption, a bound with a theoretical mix composed of 75% of hydraulic or nuclear and 25% of a low emitting mean mix (composed of gas and renewables) has been selected, leading to an upper bound set at 37 gCO_2eq/kWh. For the second group ranging from [30–230] gCO_2eq/kWh from the graphical interpretation, the upper bound of the range has to represent mixes with high diversity in electricity generation, either from fossil or renewable sources, as it can be seen in Fig. 3. However, the value of carbon emissions of 230 gCO_2eq/kWh seems to be low compared to the following break observed at 317 gCO_2eq/kWh. A compromise solution involving a theoretical mix distributed between gas (50%) and a low emitting average mix (50%), including renewables, gas and only coal or fuel, leads to a bound of 300 gCO_2eq/kWh. For the third group, the observed upper bound (570 gCO_2eq/kWh) is determined by a theoretical mix mostly composed of gas and an average mix based on a variety of production means, (i.e., renewables, fossil fuels, hydropower etc.). A rounded value of 600 gCO_2eq/kWh is finally adopted and is consistent with the graphical observation and the principle of “continuity “for the carbon emission evolution vs. mix composition. No upper bound has been fixed for Gr 4.

3.1.3. *Final typology*

From the results mentioned above, the final topology can be proposed as follows (Table 3).

As suggested in 3.1.1, it can be first highlighted that the groups differ from each other by three major production types: hydraulic and/or nuclear, gas and coal that have been merged in the typology into fossil fuels (oil being scarcely represented).

At first look and without considering the typology, it can be said that only major production conditions group affiliation. So the other production modes, i.e., those representing less than half of total production are also key components in the affiliation to a group or another. For instance, the difference between Gr 1 and 2 is due to the diversity of those other production modes. The same comment is valid for Gr 3 and 4, but in that case, the diversity benefit to GHG emissions that can be observed is lower.

Then two supergroups corresponding to groups, which have the same characteristics about their major productions, i.e. Gr1, 2 and Gr 3,4, respectively can be observable in the typology. This assumption could imply different efforts for instance to move from the emitting supergroup 3–4 to the supergroup 1–2 or to move through a supergroup in a dynamic vision of mixes involved in an energy transition.

The country-level data are available in Appendix A, Table A.

3.1.4. *World representation of the typology*

The typology can also be visualized through a map representation to give more information about countries and their groups, as shown in Fig. 5. First, it can be observed that the main producers are also those belonging to Gr 4 with the highest GHG emissions, i.e., China and India, United States, Russia and some European countries such as Spain, Germany or United Kingdom. An energy shifting towards a more virtuous group can be achieved through a drastic change in their electrical mix. The Japan case requires special attention as 2012 corresponds to one year after Fukushima events: Japan had to replace its nuclear production by other modes, such as coal and oil, which are highly emitting production means. But this change is temporary, since the reactivation of some nuclear power plants in 2016 (Nuclear Energy Institute, 0000). So Japan could be a good candidate to observe a quick evolution from a highest emitting group to lower ones.

Latin America is the lowest emitting continent, with five among seven countries being part of low emitting supergroups 1–2, with significant electricity production in Brazil.

Africa is mostly not represented in typology, due to too low electricity production under 10 TWh for 2012.

The European case can also give some guidelines to analyse the United States dynamics. As Europe, the United States is composed of states with strongly different mixes. Indeed, even if the energy transition in the United States has to be considered globally, the way that each of the 50 states can achieve such a transition by 2050 has also to be taken into account.

3.2. *Understanding long-term dynamics of mixes*

3.2.1. *Uncertainty on group boundaries*

The analysis on the determination of group boundaries is based on median results (Section 3.1.2). The objective of this section is to show how uncertainty may affect results. For this purpose, a sensitivity analysis is carried out using the same methodology as the one presented in Section 2.3.2,

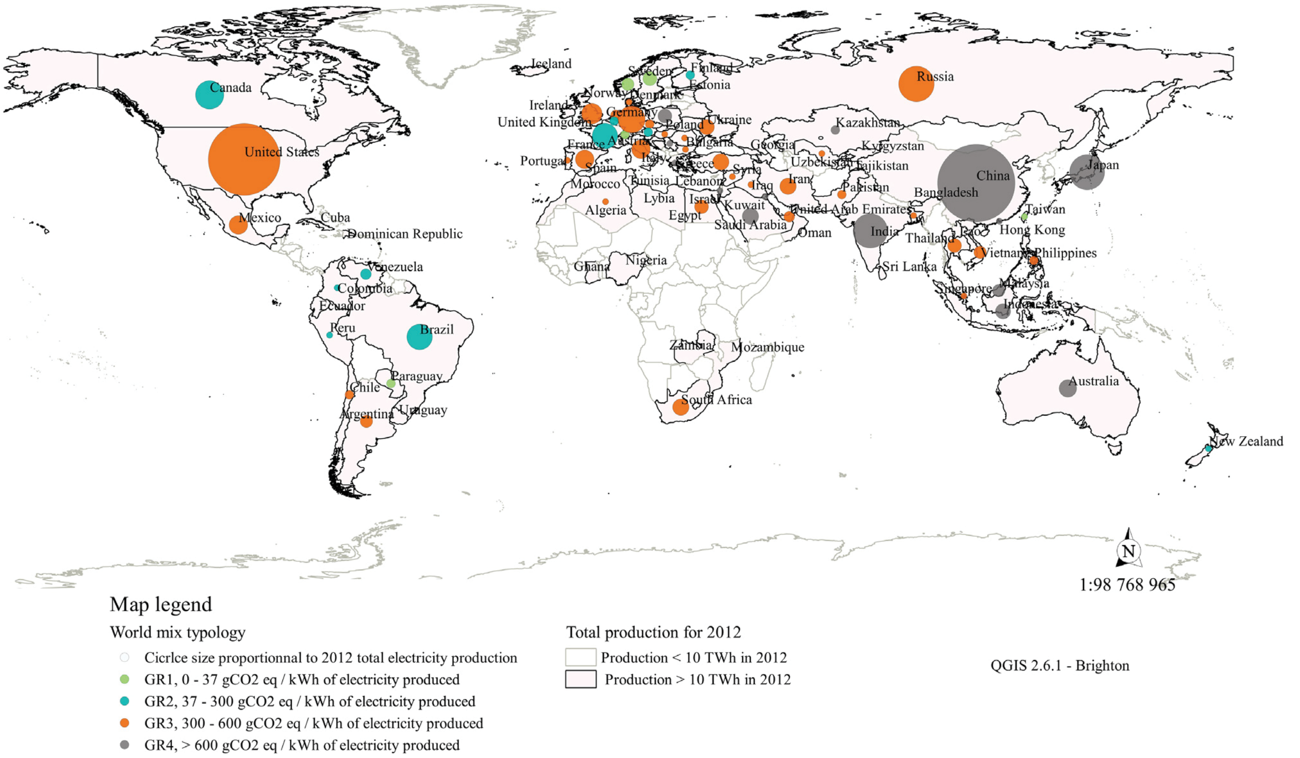

Fig. 5 – Typology and total production, per country. The circle size is proportional to total production in 2012 for countries, which produced more than 10 TWh as presented in Table 1.

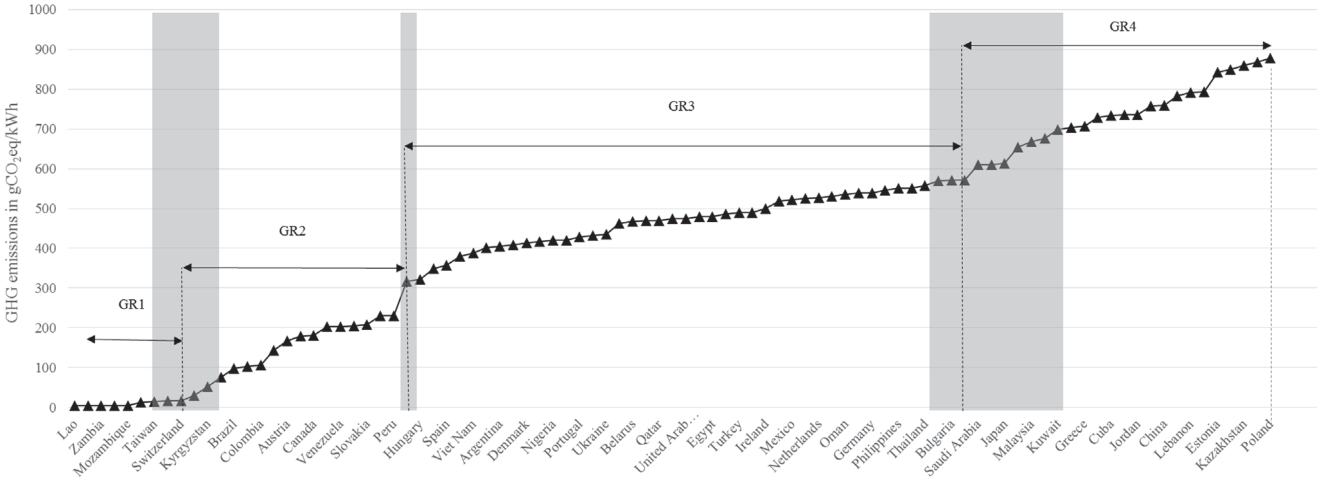

Fig. 6 – GHG emissions for the selected countries, ranked in increasing order. The dotted lines correspond to the previous bounds for the intervals determined from the median value. The black arrows correspond to the finally selected intervals for boundary determination. The grey zones correspond to the intervals calculated using the 25th and 75th percentiles for GHG emissions: transition zone 1 from Gr 1 to 2, [11; 71] covering 6 countries, transition zone 2 from Gr 2 to 3, [235; 311] covering 1 country and transition zone 3 from Gr 3 to 4 [536; 693] covering 15 countries.

with the 25th and 75th percentiles as respective lower and upper bounds for GHG emission. As before, the data from IPCC (Moonmaw et al., 2011) are used (see Table 4).

The obtained results are visualized in Fig. 6 and highlight the difference between the variation in major production and the one in other production mode. Transition zone 1 (corresponding to interval [11; 71]), with an amplitude of 60 gCO$_2$eq/kWh, (belonging to supergroup 1) exhibits the same major production but presents some variations in other production mode. The mix diversity leads in most cases to more emitting results. For example even if a variation of 1% or 2% in gas contribution seems insignificant, it has a significant influence on the total GHG emissions of the mix. The amplitude of 60 gCO$_2$eq/kWh may thus be viewed as the uncertainty embedded in the mass contribution of the mix, which may contribute significantly to total GHG emissions.

For transition zone 2 (corresponding to interval [235; 311]), major production changes from hydroelectric and/or nuclear to gas. So the results between those two groups are generally marked, and uncertainty appears to be low considering the relative values of GHG emissions. Moreover, it emphasizes the transition from supergroup 1–2 to supergroup 3–4.

Table 4 – Percentiles of GHG emissions vs. type of primary resources, from SREEN report (Moonmaw et al., 2011). GHG emissions represent the potential emissions in gCO_2eq/kWh, from LCA results.

Type of primary resource	GHG emissions in gCO_2eq/kWh	
	25th percentile	75th percentile
Biopower and waste	−360	37
Coal	877	1130
Gas	422	548
Geothermal	20	57
Hydroelectric (pump storage included)	3	7
Nuclear	8	45
Oil	722	907
Solar/Tide/Wave	29	80
Wind	8	20

Transition zone 3 (corresponding to interval [536; 693]) has an amplitude of 157 gCO_2eq/kWh (corresponding to the interval [536; 693]). The observed uncertainty is significant and comes from the uncertainty in GHG emissions of the dominant production means in Gr 3 and 4. Indeed, when technologies such as gas, coal or fuel exhibit a high uncertainty in their GHG emissions, the uncertainty calculated for a global mix which is majorly composed of those kinds of technologies will be also high.

These transition zones could be useful to be observed for implementing energy policies and for leading to a more comprehensive set of recommendations for future research and policy. Indeed, they allow to identify a state where mixes of a group start to have characteristics from another one. Then, those transition zones could lead to a better understanding of the implications of transitions. This can already be observed in two examples, Denmark and France.

Denmark has recently achieved a major change in its mix composition by introducing renewables (Mathiesen et al., 2009), especially wind power, moving from Gr 4 to Gr 3 in the 2000s. This transition is a result of energy policies established since the seventies to move from a mix majorly based on coal or oil to a more virtuous one composed of renewables. The transition zones constitute good tool to identify how long the transition has taken to move permanently from Gr 4 to Gr 3. In the case of France, since the first oil crisis in 1973, the French government has decided to introduce nuclear power into the electricity mix to decrease the national energy dependency (Percebois, 2012). This leads to a change in the proposed typology from Gr 3 to Gr 2, and the analysis of mix composition in this transition zone could give us insight to better understand how this change has been conducted. Then, from historical mix dynamics, the typology can thus serve as a tool to identify how much time countries will take to achieve major changes and how such a transition can be characterized.

3.2.2. *Influence of network*

It must be emphasized that the interconnection of electricity networks between countries is not taken into account in the typology. However, the grid interconnection across countries can be viewed as a key feature in mix evolution. Indeed, some countries have a small production in their territory and benefit from their neighbours' production. This situation can offer the opportunity to some countries to have a more virtuous mix: this corresponds typically to some countries from Gr 1 or 2 with a lot of intermittent renewables, for which most of their demand is produced by their neighbours and transported through existing networks. This can be in some cases explained by a lack in resources (either natural or technological) so that a real dependency on network supply is observed.

The ratio of net imports (US Department of Energy, 2016) compared to total production (The Shift Project, 2015) expressed in percentage is represented in Fig. 7. A majority of countries use grid connection with imports and exports: a value of 10% either for exports or imports is considered to be significant.

The exchanges that have been considered are available in Appendix A, Table B.

As it can be seen in Fig. 7, the most virtuous countries from Gr 1, are most of the time net exporters. So, clearly, the quality of their mix is due to their own electricity generation. Exporting such power can be beneficial to the grid-connected countries. Besides, major importers, i.e. countries importing more than 10% of their energy belong mostly to Gr 3 and 4. So, even if a switch from a group to a more eco-friendly one for these countries is not impossible, it can be viewed as difficult to steer their energetic policy onto a markedly different energy path. A closer look at Group 2 shows that importers and exporters, (respectively major and small ones) are equally involved. So the network dependency may not be significant for these countries.

Of course we are aware that Fig. 7 only gives the general trend about network influence. A more thorough analysis could be yet carried out in order to include over time small power producers, for example African countries, which could be highly network-dependent. In addition, indicators and performance measures of the interdependence of a country from the grid must be properly defined and included in the typology. This highlights to consider the energy infrastructure with a systems approach.

3.2.3. *Inertia in electricity power generation and resilience to energy change*

As emphasized in Section 3.1.3, major power generation systems play a key role in the typology by defining the supergroup in which mixes are, i.e., less emitting with major production of hydraulic and/or nuclear and higher emitting with major production based on gas and fossil fuels.

If those elements are now considered in a dynamic perspective, three types of changes could affect the existing mixes. In an energy transition point of view, every country will try to move to a less emitting group. So a shifting towards a higher-emission group could be viewed as a temporary situation due to an increase in power demand that cannot be provided by low-carbon emitting technologies.

The first evolution type that can be considered involves changes within either “major” or “other production” groups, but these changes are not enough significant to create a definitive change of group. In these conditions, mixes evolve in the same group, or move to another one, but not permanently, thus corresponding to an incremental dynamics.

The second evolution type is relative to changes in “other production” modes so that Gr 4 (respectively 2) moves to Gr 3 (respectively to 1).

Finally, the evolution type that can be considered leads to drastic changes in major production, so that groups 4 or 3 can move to group 2 or 1, so that a breakthrough change occurs.

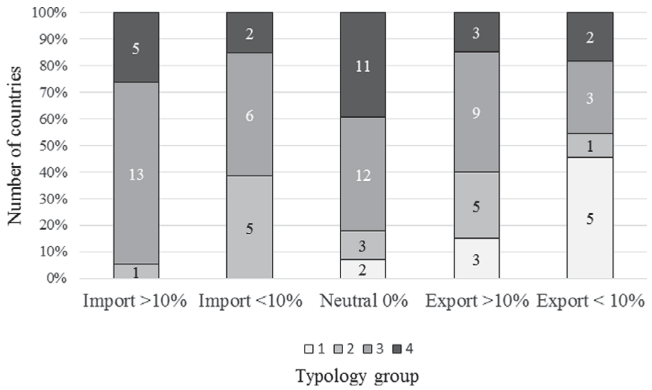

Fig. 7 – Comparison of imports and export by typology group. Countries considered are the ones selected for designing the typology presented in Table 1. 10% is the limit between a high/low exporter or importer.

Of course, such evolutions are subject to system inertia. For example, a predominantly fossil-oriented mix e.g. from Gr 4 will have to diversify gradually its "other production" mode to move to another group, and changes will require some years to finally reach Gr 3.

Furthermore, due to country specificities, inertia may be different for each group, depending on the strategy of each country concerning major electricity power generation. This aspect can be considered as a key feature for mix evolution. This criterion of inertia has to be further taken into account in the typology.

It is also important to consider flexibility and robustness. The guarantee of good resistance to shocks, sometimes referred to as resilience, is another parameter that must be considered in energy policies. It can lead to particular choices, not only in terms of diversification, or supply structures and energy system technologies, but also in terms of R&D, so that, a wide range of technologies and skills is available.

These elements are particularly important to be examined in a typology definition in order to determine the horizon time, which will be necessary for a country to shift to another group. This suggests that an indicator based on resilience of a country's energy system can be useful to measure the effectiveness of adaptation policies addressing such issues as energy generation.

3.2.4. A step towards a better understanding of global energy transition

As demonstrated in a previous work (Herbert et al., 2015), only major evolutions could lead to a lasting mix change. This dynamics can be initiated by modifying one or a range of static drivers, such as existing power plants, resources, technological developments (such as energy storage, carbon capture and storage), energy policy and public opinion. Some of these drivers can be considered formally in a dynamic modelling of the energy system to determine energy policies. Other criteria such as public opinion are yet more subjective but their influence may be significant on the other factors. For example, public opinion will strongly influence energy policy and can make it change, as observed in Italy concerning nuclear power (OECD/IEA, 2009).

Moreover, all countries are unequal face to those elements: there are among them differences in the way the possible mixes are assessed and thus in how an ideal or more practically an optimum mix (if it does exist) can be reached in terms of kWh GHG emissions (either both direct and indirect) and mix composition. Preferences vary widely from country to country, for example between levels of development (Northern and Southern countries) or domestic resources. As aforementioned, an indicator measuring the capacity to implement energy adaptation projects and how successful the proposed implementation measures will be in increasing energy system resilience will be particularly useful (Michaelowa et al., 2010).

This approach could also help to better understand energy transition communication with a clearer vision of the potential evolution of energy systems.

The use of generalized data in the proposed typology could thus strongly benefit in decision-making processes, especially for the development of new climate policy and related research. Indeed, for illustration purposes, the electricity production mix could be envisioned not as a compilation of production means, which would evolve with the addition or withdrawal of production means as "pieces", but rather as a single malleable entity, which would evolve by stretching. The typology could help identify which kind of mix is observed and which transition is possible from a group to another one and when the "malleable entity" will move to another type of mix with different main characteristics. As highlighted in Section 3.2.1, the transition zones could give an easy way to identify potential energy transition dynamics.

Finally whereas the typology is helpful, the importance of country-level results should not be downplayed. LCA results that are commonly used are likely to vary significantly by country depending on factors such as the vintage of the generation fleet as well as that of the supply chain infrastructure. Yet, the typology gives results and key tendencies at a high level of granularity and so does not take into account those specific country-level data. The typology can be viewed as a tool to identify the process dynamics and key evolutions tendencies, about an energy transition, with no specific insight of the country considered. The analysis of the mix dynamic evolution of some selected countries could thus give more insight to establish the limit between the use of typology and the one of specific country-level data at a lower level of granularity.

3.3. Typology use in Consequential inventories

Literature review highlights that CLCA studies have been carried out with data on case by case basis (Earles and Halog, 2011). Such an approach is both time and expertise consuming. Moreover, available techniques from Weidema et al. (1999, 2009) and Ecoinvent (Treyer and Bauer, 2013, 2014) do not make consensus for LCA practitioners (Fernandez Astudillo et al., 2015), especially concerning uncertainty management. In most studies, CLCA involves general equilibrium and partial equilibrium models to estimate economy-wide indirect emissions, which are subject to many types of uncertainty. In that context, all consequences that follow are not generally well taken into account. The literature review has shown that Consequential LCA suffers from a lack of knowledge of potential consequences from a policy examined, data gaps and large uncertainties, as well as from a lack of models that can capture the dynamic changes in land use patterns in different countries under specific economic drivers. Other indicators have been identified in the reported literature as relevant for electricity production impacts (Hauschild et al., 2013; PEFCR, 2015), such as resource depletion, water footprint, acidification and eutrophication. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR5) (Edenhofer et al., 2014) states, with very high confidence, that the observed changes in global climate are very likely due to the increase in anthropogenic greenhouse gas (GHG) concentrations. This is also emphasized in a recent SCORE LCA study (Alexandre et al., 2014) showing that according to practitioners responding to climate change involves to mitigate the emissions of greenhouse gases in the atmosphere.

The proposed typology can be considered as a first step to bridge this gap by considering typical groups of electricity power generation, in a worldwide and environmental vision. It must yet be strengthened by the development of indicators reflecting resilience to energy change and grid interconnection.

The development of the typology is interesting to represent the behaviour of some countries that share the same characteristics in a group. Then, data calculated from a mean mix representing each group could give easy to set data. With the selection of some countries in each group as a test bench, we could evaluate if global dynamics and data could be set by analysing the evolution of mixes through time in the typology, and otherwise what could be carried out to estimate them. This work will explore prospective data from public prospective studies available for each country selected. Conceptually, prospective studies estimate different future evolutions of current mixes (Pottier, 2014). Furthermore, in Consequential LCA thinking, mixes strongly evolve through time leading to allocation problems (Guiton and Benetto, 2013). Then, those results could constitute first methodological steps to establish Consequential LCI datasets.

4. Conclusions

Generalizing world electricity mixes production is a first step to evaluate the feasibility evaluation of Consequential specific inventory data. That is why a typology for mix assessment based on two criteria evaluated for 91 selected countries, i.e., mix composition (both qualitatively and quantitatively) and GHG emissions. Four groups have thus been established according to GHG emission range Gr1, very low (0–37 gCO_2eq/kWh); Gr2 low (37–300 gCO_2eq/kWh); Gr3 mean (300–600 gCO_2eq/kWh) and Gr4 high (>600 gCO_2eq/kWh) emitting countries. The GHG emissions have been associated with main characteristics of energy portfolio based on major and "other" modes for electricity power generation. Following this analysis, two supergroups {Gr 1; Gr 2} and {Gr 3; Gr 4} have been established based on major production mode. A map representation has shown the distribution of a set of countries (91) among the identified groups and subgroups and the possible path these countries are likely to carry out for achieving their energy transition. Moreover, this typology allows qualifying the change degree needed to achieve energy transition. Indeed, a transition is represented by a group change, involving either major or small productions, and the zone of uncertainty between groups could help identifying transition dynamics. The proposed typology can thus also be seen as an energy transition evaluation tool.

However, in order to use this typology in a Consequential LCI perspective, some criteria have to be developed in more depth. Firstly, national and cross-borders electrical grid networks are fundamental in electricity mix consumption, and this issue has to be considered in the further development of the typology by a so-called network indicator. Secondly, all the countries are not equal in terms of mix evolution inertia, so that an indicator based on energy sector resilience can be added. Lastly, linked to changing effort and inertia, tools to evaluate how mix can reach a so-called optimal group are required. These energy mix assessment criteria will be useful to evaluate Consequential inventory mix in order to reach a given target.

The proposed typology gives thus a macro-level vision of electricity production mixes that is more general than the country-level vision. Of course, to set reliable country-level dataset, additional factors have been completed to ensure reliable country-level datasets such as efficiency of country-level generation fleets, transmission and distribution losses, capacity factors, and higher-resolution generation detail (e.g. are natural gas plants peak or base-load for instance). The integration of grid modelling could constitute a further extension of this work. To support temporal dataset development, short-term (hourly) data from grid should be needed. The conciliation of short-term and long-term data will be probably required since in a long-term perspective. The influence that grid development and network may have on mix dynamics has to be investigated.

The next step towards the evaluation of typology to design generalized Consequential inventory data concerning electricity production is to study the dynamic evolution of some countries selected from each group of the proposed typology using historical data.

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Appendix

See Tables A and B.

Table A – Selected countries for typology design with associated code in manuscript, GHG emissions (calculated with Section 2.2.2 methodology), total production for 2012 and group in presented typology. Countries are alphabetically ranked.

Country	Code	GHG emissions (gCO_2 eq/kWh)	Total production 2012 (TWh)	Typology group
Algeria	P1	486	54	3
Argentina	P2	406	127	3
Australia	P3	793	240	4
Austria	P4	168	66	2
Azerbaijan	P5	432	19	3
Bangladesh	P6	479	13	3
Bahrain	P7	469	51	3
Belarus	P8	469	28	3
Belgium	P9	202	75	2
Bosnia and Herzegovina	P10	729	14	4
Brazil	P11	97	536	2
Bulgaria	P12	571	45	3
Canada	P13	182	646	2
Chile	P14	518	64	3
China	P15	760	4724	4
Colombia	P16	107	58	2
Croatia	P17	379	10	3
Cuba	P18	735	17	4
Czech Republic	P19	552	82	3
Denmark	P20	413	30	3
Dominican Republic	P21	677	14	4
Ecuador	P22	318	22	3
Egypt	P23	480	153	3
Estonia	P24	843	12	4
Finland	P25	206	68	2
France	P26	75	533	2
Georgia	P27	104	10	2
Germany	P28	539	579	3
Ghana	P29	144	11	2
Greece	P30	708	55	4
Hong Kong	P31	849	36	4
Hungary	P32	322	33	3
Iceland	P33	16	17	1
India	P34	783	931	4
Indonesia	P35	736	189	4
Iran	P36	546	238	3
Iraq	P37	491	57	3
Ireland	P38	500	26	3
Israel	P39	869	57	4
Italy	P40	420	288	3
Japan	P41	613	966	4
Jordan	P42	736	16	4
Kazakhstan	P43	859	85	4
Kuwait	P44	699	57	4
Kyrgyzstan	P45	52	15	2
Lao	P46	4	11	1
Lebanon	P47	792	16	4
Lybia	P48	655	28	4
Malaysia	P49	668	120	4
Mexico	P50	521	278	3
Morocco	P51	758	26	4
Mozambique	P52	4	18	1
Netherlands	P53	527	97	3
New Zealand	P54	180	43	2
Nigeria	P55	420	26	3
Norway	P56	13	146	3
Oman	P57	536	23	1
Pakistan	P58	416	87	3
Paraguay	P59	4	60	3
Peru	P60	231	39	1
Philippines	P61	551	69	2
Poland	P62	877	151	3
Portugal	P63	428	45	4
Qatar	P64	469	29	3
Romania	P65	475	57	3
Russia	P66	409	1003	3
Saudi Arabia	P67	610	237	3
Serbia	P68	704	32	4
Singapore	P69	526	45	4
Slovakia	P70	208	27	2
Slovenia	P71	349	15	3
South Africa	P72	569	239	3
Spain	P73	357	278	3
Sri Lanka	P74	611	11	4
Sweden	P75	30	163	1
Switzerland	P76	16	67	1
Syria	P77	571	39	3
Taiwan	P78	15	50	1
Tajikistan	P79	4	16	1
Thailand	P80	557	155	3
Tunisia	P81	462	16	3
Turkey	P82	490	228	3
United Kingdom	P83	538	341	3
Ukraine	P84	436	187	3
United Arab Emirates	P85	475	108	3
Uruguay	P86	230	10	2
USA	P87	530	4057	3
Uzbekistan	P88	402	50	3
Venezuela	P89	203	118	2
Viet Nam	P90	389	128	3
Zambia	P91	4	12	1

Table B – Net imports in TWh for selected countries of typology from 2009 to 2012 from EIA (eia.gov) with associated code in manuscript. Negative results correspond to exports and positive results to imports.

Country	Code	2009	2010	2011	2012	Country	Code	2009	2010	2011	2012	Country	Code	2009	2010	2011	2012	Country	Code	2009	2010	2011	2012
Algeria	P1	0.0	−0.1	−0.1	0.0	Estonia	P24	0.1	−3.3	−3.6	−2.2	Lebanon	P47	1.2	1.2	0.8	0.3	Slovakia	P70	1.3	1.0	0.7	0.4
Argentina	P2	6.2	8.6	9.7	7.6	Finland	P25	12.1	10.5	13.9	17.4	Lybia	P48	0.0	−0.1	−0.1	0.0	Slovenia	P71	−3.1	−2.1	−1.3	−0.9
Australia	P3	0.0	0.0	0.0	0.0	France	P26	−25.9	−30.7	−56.4	−44.5	Malaysia	P49	−0.1	−0.2	0.4	0.1	South Africa	P72	−1.8	−2.5	−3.1	−5.0
Austria	P4	0.8	2.3	8.2	2.8	Georgia	P27	−0.5	−1.3	−0.5	0.1	Mexico	P50	−0.7	−0.7	−0.6	−0.7	Spain	P73	−8.1	−8.3	−6.1	−11.2
Azerbaijan	P5	−0.3	−0.4	−0.7	−0.5	Germany	P28	−12.3	−15.0	−3.8	−20.5	Morocco	P51	4.6	3.9	4.6	4.8	Sri Lanka	P74	0.0	0.0	0.0	0.0
Bangladesh	P6	0.2	0.2	0.1	−0.2	Ghana	P29	−0.6	−0.9	−0.6	−0.5	Mozambique	P52	−5.1	−3.5	−3.4	−1.5	Sweden	P75	4.7	2.1	−7.2	−19.6
Bahrain	P7	0.0	0.0	0.0	0.0	Greece	P30	4.4	5.7	3.2	1.8	Netherlands	P53	4.9	2.8	9.1	17.1	Switzerland	P76	−2.2	0.5	2.6	−2.2
Belarus	P8	4.5	2.7	5.6	7.6	Hong Kong	P31	7.9	8.4	8.4	10.0	New Zealand	P54	0.0	0.0	0.0	0.0	Syria	P77	−0.1	−0.4	0.3	1.2
Belgium	P9	−1.8	0.6	2.5	9.9	Hungary	P32	5.5	5.2	6.6	8.0	Nigeria	P55	0.0	0.0	0.0	0.0	Taiwan	P78	0.0	0.0	0.0	0.0
Bosnia and Herzegovina	P10	−3.0	−3.8	−1.5	0.0	Iceland	P33	0.0	0.0	0.0	0.0	Norway	P56	−9.0	7.5	−3.1	−17.8	Tajikistan	P79	0.1	0.1	0.0	−0.7
Brazil	P11	40.0	34.6	35.9	40.3	India	P34	5.3	5.5	5.1	4.8	Oman	P57	0.0	0.0	0.0	0.0	Thailand	P80	1.1	6.0	9.7	9.0
Bulgaria	P12	−5.1	−8.4	−10.7	−8.3	Indonesia	P35	0.0	0.0	0.0	0.0	Pakistan	P58	0.2	0.3	0.3	0.4	Tunisia	P81	0.0	0.0	0.0	0.0
Canada	P13	−33.4	−25.3	−36.7	−46.6	Iran	P36	−4.1	−3.7	−5.0	−7.1	Paraguay	P59	−45.0	−43.4	−46.1	−47.7	Turkey	P82	−0.7	−0.8	0.9	4.3
Chile	P14	1.3	1.0	0.7	0.0	Iraq	P37	5.6	6.2	7.3	8.2	Peru	P60	−0.1	−0.1	0.0	0.0	United Kingdom	P83	2.9	2.7	6.2	12.0
China	P15	−11.4	−13.5	−12.8	−10.8	Ireland	P38	0.8	0.5	0.5	0.4	Philippines	P61	0.0	0.0	0.0	0.0	Ukraine	P84	−5.4	−4.1	−6.3	−5.9
Colombia	P16	−1.1	−0.8	−1.5	−0.7	Israel	P39	−3.8	−4.0	−4.2	−4.4	Poland	P62	−2.2	−1.4	−5.2	−2.8	United Arab Emirates	P85	0.0	0.0	0.0	0.0
Croatia	P17	5.1	4.1	7.4	11.5	Italy	P40	45.0	44.2	45.7	43.1	Portugal	P63	4.8	2.6	2.8	7.9	Uruguay	P86	1.2	−0.3	0.5	0.5
Cuba	P18	0.0	0.0	0.0	0.0	Japan	P41	0.0	0.0	0.0	0.0	Qatar	P64	0.0	0.0	0.0	0.0	USA	P87	34.1	26.0	37.3	47.3
Czech Republic	P19	−13.6	−14.9	−17.0	−17.1	Jordan	P42	0.2	0.6	1.7	0.7	Romania	P65	−2.3	−2.3	−1.9	−2.8	Uzbekistan	P88	−0.1	−0.1	−0.1	−0.1
Denmark	P20	0.3	−1.1	1.3	5.2	Kazakhstan	P43	−0.7	1.2	0.8	1.3	Russia	P66	−14.9	−17.4	−22.6	−16.5	Venezuela	P89	−0.4	−0.4	−0.5	−0.2
Dominican Republic	P21	0.0	0.0	0.0	0.0	Kuwait	P44	0.0	0.0	0.0	0.0	Saudi Arabia	P67	0.0	0.0	0.0	0.0	Viet Nam	P90	3.7	4.6	1.8	2.2
Ecuador	P22	1.1	0.9	1.3	0.2	Kyrgyzstan	P45	−1.2	−1.7	−2.7	−1.7	Serbia	P68	−1.4	−0.3	−0.3	0.4	Zambia	P91	−0.6	−0.6	−0.6	−0.6
Egypt	P23	−0.9	−1.4	−1.6	−1.4	Lao	P46	−1.1	−5.1	−9.0	−8.4	Singapore	P69	0.0	0.0	0.0	0.0						

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