Co-funded by the Intelligent Energy Europe Programme of the European Union

Best practice of collection and provision of environmental data for electricity disclosure

Deliverable 5.2 of the RE-DISS II Project

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1 Introduction and background

This paper reports the environmental data for electricity disclosure provided by the RE-DISS II project as well as the methodology and data sources that have been used.

As described in RE-DISS II (2013), the two major approaches for calculating environmental impacts relate to whether or not upstream, and eventually downstream, impacts (throughout the whole electricity generation value chain) or only direct impacts from the generation (conversion) step are included in the calculation approach. If the approach includes the entire ("cradle to grave" or "cradle to gate") value chain of electricity generation, it should be based on the Life Cycle Assessment (LCA) methodology, which is an internationally standardised (ISO 14044) method for quantifying environmental impacts that are associated with any products. If only direct emissions, resulting from the electricity conversion step, are included, this approach reflects for example how the national inventories' according to the Kyoto protocol are calculated. In this case upstream and downstream emissions are covered by other sectors. This differentiation in principle also applies to the second type of environmental indicators required for electricity disclosure besides CO_2 emissions, the radioactive waste related to the generation of electricity. However, as the production of radioactive waste is clearly dominated by the direct waste production in the conversion step in nuclear power plants, the differences between direct and LCA-based data are only addressed further in this paper in relation to carbon emissions.[1]

When determining CO_2 emissions in general, it is important to be clear about whether the data represent only emissions of the single substance CO_2 or total GHG (Greenhouse Gas) emissions. If total GHG emissions are presented, the emissions of CO_2 have been summarised with other GHG gases, such as methane and N_2O, which usually are converted into CO_2 equivalents according to their Global Warming Potential.

The RE-DISS II project has calculated the environmental indicators for electricity disclosure as shown in Table 1. The mark "XX" highlights the new indicators when compared to data provided by the former RE-DISS project.

[1] It should be noted that for a complete LCA assessment of nuclear energy, the whole value chain of nuclear power generation would have to be taken into account, starting with uranium mining and fuel enrichment and ending with final storage of different types of radioactive waste. However, based on the stipulations of Article 3 (9) of Directive 2009/72/EC, disclosure usually focuses on indicators relating only to radioactive waste from nuclear power plants. See section 2.3 for a discussion on alternative indicators for nuclear energy in electricity disclosure.

Environmental indicator		Unit	Direct emissions	Emissions based on LCA (life cycle assessment) methodology
GHG emissions	Single substance	g CO_2 per kWh	X	XX
	GWP*	g CO_2-equiv. per kWh	XX	XX
High-level radioactive waste (RW)		mg RW per kWh	X	

*GWP: Global Warming Potential

Table 1: Environmental indicators for electricity disclosure.

The different environmental indicators can shortly be summarised as follows:

- Direct greenhouse gas emissions given as the single greenhouse gas CO_2 emissions (this is equivalent to the CO_2 content usually displayed in disclosure statements in previous years)
- Greenhouse gas emissions given as the single greenhouse gas CO_2 emissions based on the life-cycle perspective (LCA) and thus including up- and downstream impacts throughout the electricity generation value chain
- Direct greenhouse gas emissions, expressed as Global Warming Potential (GWP) and given as CO_2 equivalents (CO_2e), which also includes the effects of other greenhouse gases than CO_2
- Greenhouse gas emissions based on the LCA approach, expressed as Global Warming Potential (GWP) and given as CO_2 equivalents (CO_2e). This is the most comprehensive emission figure as it contains CO_2 and other greenhouse gases and the full electricity generation value chain
- High-level radioactive waste given as mg (milligrams) high-level radioactive waste per kWh generated electricity, and only provided by the direct perspective (this is equivalent to the radioactive waste displayed in previous years in most countries).

None of the above described GHG indicators are more correct or more wrong than the others. They simply represent different value chain perspectives and the inclusion of different GHG emissions. However, the choice of one indicator above another is dependent on which perspective end-consumers want to take for their disclosed electricity. In addition, if end-consumers want to go beyond disclosure, and use the disclosed parameter for carbon accounting, the scope of their chosen carbon accounting standard/guideline determines which indicator to be used. As an example, carbon accounting according to the GHG Protocol's Scope 2 standard requires the direct GWP indicator[2], while carbon accounting according to LCA-guidelines requires the LCA-based GWP indicator. Therefore, suppliers are recommended to disclose the different GHG indicators and the leave the choice for a potential use beyond disclosure purposes to the end-consumers.

2 The GHG Protocol Scope 2 Guidance (http://ghgprotocol.org/scope_2_guidance) requires companies operating in markets providing product or supplier-specific data in the form of contractual instruments (e.g. Guarantees of origin) to report scope 2 emissions according to two parallel methods: the location-based method (using grid average emissions in the case of electricity) and the market-based method (using the emissions of the product used, based on the environmental indicators of disclosure in the case of electricity)..

2 Data sources and methodology

2.1 Electricity generation data

The country specific electricity generation data separated into the different energy sources in the EU 28 + CH, NO, IS countries are mainly based on data from ENTSO-E for the year 2013 (ENTSO-E). From this database, the electricity generation data is separated into the following energy sources: hydro (storage, run-of-river, pumped), fossil fuels (of which lignite, hard coal, gas, oil, mixed fuels), renewables (of which wind, solar, biomass), unknown.

The major challenges with regard to data quality for the electricity generation data have been:

1. The ENTSO-E data source reports some data as unknown energy sources. This has been solved by adding/supporting data from other relevant statistics for electricity generation in (Itten et al., 2014) as well as adding specific data input from data collection related to the Residual Mix Work Packages (WP 2 and 7) in order to complete the data set.
2. The ENTSO-E data source only reports the energy source/fuel and not the specific technology being used for producing the electricity from the energy source. This challenge relates specifically to combined heat and power (CHP) plants, as the allocation of emissions to the generated heat and power depends the share of generated heat/electricity. According to the EU Energy Efficiency Directive (2012/27/EC), general principles and reference values are given for the calculation of generated electricity and heat from cogeneration. On this basis, the emissions and environmental burdens from the total power and heat generation can be allocated to the generated heat and power. According to LCA methodology, this is normally done on the basis of exergy, energy or economic values. According to Eurostat (2014) the average share of combined heat and power (CHP) generation in the EU (28 countries) in 2013 was 11,7% (provided as % of gross electricity generation). The share in the different countries varies from 0 to 77% with Slovakia (77%), Denmark (50,6%) representing the largest shares. However, as the country specific CHP shares are not specified for the different energy sources, it is not possible to determine which energy sources and the respective share of the electricity generation from these sources that have been produced by CHP technology. Therefore, the reported energy source, has, in general, been used as the basis for the country specific electricity generation emissions factor (more detailed described in the next section 2.2).

2.2 Emissions of CO_2 and CO_2 equiv. – direct and LCA perspectives

2.2.1 Direct CO_2 emissions

The data for direct CO_2 emissions for the different electricity generation technologies/sources in the respective countries have been based on the following references: Treyer and Bauer (2013), Dong Energy A/S, Energi.dk, Vattenfall (2010), Fritsche and Rausch (2009), Bauer (2008) and GEMIS database (GEMIS, 2015).

The article “Life cycle inventories of electricity generation and power supply in version 3 of the ecoinvent database — part I: electricity generation” (Treyer and Bauer, 2013) represents the major data source, covering 25 of the total 31 countries included in RE-DISS II and all the fossil energy sources (hard coal, lignite, natural gas and oil) covered by RE-DISS II. The article is based on the ecoinvent 3.01 database (ecoinvent v. 3.01 Database) which is the world's leading database of consistent and transparent, up-to-date Life Cycle Inventory (LCI) data and which is integrated in the life cycle software tool SimaPro (http://www.ecoinvent.org).The ecoinvent Association was originally known as the ecoinvent Centre, the Swiss Centre for Life Cycle Inventories. Since June 2013 ecoinvent is a not-for-profit association founded by institutes of the ETH Domain and the Swiss Federal Offices. The founding members are namely the Swiss Federal Institute of Technology Zurich (ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Science and Technology (Empa), and Agroscope, Institute for Sustainability Sciences.

Data from Treyer and Bauer (2013) have been compared with data from other data sources, such as the GEMIS (Global Emissions Model for integrated Systems) database. This is a public domain life-cycle and material flow analysis model and database that the German institute IINAS (The International Institute for Sustainability Analysis and Strategy) provides freely (www.iinas.org/gemis-de). GEMIS was first released in 1989, and is continuously updated and extended since then. It is used by many parties in more than 30 countries for environmental, cost and employment analyses of energy, materials and transport systems. In addition, the reports "Life Cycle Assessment of Fossil and Biomass Power Generation Chains" (Bauer, 2008) and "Life Cycle Analysis of GHG and Air Pollutant Emissions from Renewable and Conventional Electricity, Heating, and Transport Fuel Options in the EU until 2030" (Fritsche and Rausch, 2009) have been used to a large extend. When data from the different data sources were diverging, qualified choices based on relevant input and/or average data have been used.

With regard to the lack of specific data for CHP generation, the reported energy source for the different countries has, in general, been used as the basis for the country specific electricity generation emissions indicators. This means the indicators for some energy sources may be overestimated to some extent in the countries with the largest shares of CHP technologies (Slovakia, 77%, Latvia: 38.3%, Lithuania: 35%, Netherlands: 34.5% and Finland: 34.2%). However, for Denmark (50.6%), specific emissions data for CHP from natural gas data (Dong Energy A/S, Energi.dk, Vattenfall (2010) have been used as this study represents specific data for Denmark and because the major part of electricity from natural gas in Denmark is generated on the basis of such CHP plants.

The country and energy source/technology specific environmental indicators for direct CO_2 emissions are shown in Table 3 in Chapter 3.

2.2.2 Direct emissions GWP (CO_2-equiv.) and life cycle based (LCA) emissions CO_2 and GWP

In contrast to the data for direct CO_2-emissions, which have been based on a different comparable data sources, the direct emissions data for Global Warming Potential (GWP) from other greenhouse gases (in CO_2 equivalents) and the life cycle based (LCA) emissions data for CO_2 and GWP (CO_2-equivalents) have been calculated solely based on the ecoinvent database (ecoinvent v3.01 Database). The reason for this choice is that it was very difficult and time consuming to find published life cycle data, as well as direct data for GWP from other greenhouse gases (CO_2 equivalents) for all the different countries and technologies. When country specific data were missing in the ecoinvent database, data for the relevant energy source/technology representing another country have been chosen (based on the direct emissions profile) and adapted in order to represent the country specific fuel/technology. Due to restrictions from the ecoinvent database with regard to publishing country and technology specific data, the results for these three indicators are shown as weighted European average values across all European countries (see Table 4 in Chapter 3). These average values are based on the electricity generation energy source/technology and volumes in the respective countries (2013) multiplied with the emissions indicators for the respective electricity generation technologies.

It should be mentioned that specific country and energy source/technology emission factors have been used for the Residual Mix calculations for these additional environmental indicators.

2.3 High-level radioactive waste

The environmental indicator for radioactive waste is given as mg high-level radioactive waste per kWh of generated electricity, and only provided by the direct perspective.

As annual data on the fuel consumption and waste production of the individual reactors in Europe is not publicly available, the data is mostly based on best estimates for the specific production of high-level radioactive waste of five different types of nuclear reactors used in Europe, shown in Table 2.

Reactor type	Typical burn-up [GWd/t]	Typical net efficiency [%]	Typical waste factor [mg/kWh]	Reactor type used in
Pressurized water reactor (PWR), Western Type	47	33%	2,7	BE, CH, DE, ES, FR, GB, NL, SE, SI
Boiling water reactor (BWR)	47	33%	2,7	CH, DE, ES, FI, SE
Pressurized water reactor Eastern Type (WWER)	40	30%	3,5	BG, CZ, FI, HU, SK
Canadian Deuterium Uranium pressurized heavy water reactor (CANDU)	7	33%	18	RO
Advanced gas-cooled reactor (Magnox/AGR)	*)	*)	8,0	GB

*) no information available
Note: the burn-up is the thermal heat generated during the fission process of a specific mass of nuclear fuel expressed in Gigawatt-days of thermal energy produced per ton of heavy metal in the reactor core.
Sources: Expert estimates by Öko-Institut. Data for PWR and BWR are adapted to the waste factor provided in BDEW (2015). Data for Magnox/AGR are derived from DECC (2014).

Table 2: Estimates for the production of high-level radioactive waste per reactor type.

The RE-DISS II figures on the specific high-level radioactive waste production per country as shown in Table 3 in Chapter 3.1 are based on the estimates given in Table 2. For those countries which are operating only reactors of a single type, or of types with identical typical waste factors, the corresponding factors were allocated directly to the nuclear electricity generated in that country. Given that the estimates for PWR and BWR reactors are identical, this applies to all countries covered by the analysis except Finland and the United Kingdom. For the United Kingdom, DECC is publishing a Fuel Mix Disclosure Data Table on an annual basis, which provides an average factor for the production of high-level radioactive waste by power reactors in the UK. For 2014, this data as provided in the DECC publication from 2014 has been used in Table 3 directly.[3] This leaves Finland as the only country for which a weighted average of the typical waste factors of the reactors in use had to be calculated.

For this analysis, the list of reactors used in Europe, their allocation to the reactor types and their annual electricity production in 2014 was derived from the Platts World Electric Power Plants Database and from the IAEA Power Reactor Information System (PRIS).[4]

The two factors determining the specific production of high-level radioactive waste in a reactor, the burn-up of the nuclear fuel and the net efficiency of electricity generation, usually do not vary much over time for a given power plant. Therefore, the estimates shown in Table 2 may also be suitable for calculations of environmental indicators in future years. However, the annual power production per reactor may vary significantly, depending on planned or unplanned outages and other events. This may have an impact on the weighted average calculated for Finland. Therefore, an annual update of this calculation should be performed for Finland based on the actual electricity production per reactor.

From a scientific point of view, the mass of spent nuclear fuel (in milligrams) may not be the most meaningful indicator. According to the Product Category Rules (PCR) for electricity generation (The International EPD System 2015), nuclear waste shall be reported as follows in detailed LCA analyses:

From nuclear power plants:

- Spent nuclear fuel reported as total weight specified in weight units (g) of spent fuel assemblies unloaded from the reactor during the reference period
- Uranium in spent nuclear fuel (expressed as initial uranium content in the fuel assemblies unloaded (g uranium atoms (U))

To final repository:

- High-level radioactive waste (HLW; consisting of spent fuel or parts of spent fuel, demolition waste, etc. including any containers, according to legislation and nuclear core components) specified as volumes (m^3)
- Low- and intermediate level radioactive waste (LLW/ILW, consisting of conditioned operational waste, demolition waste, etc., including binding matrix (cement, bitumen or other) and containers, according to legislation) specified as volumes (m^3)

Generally spoken, all those indicators have not much to do with environmental impacts nor are they a linear function of impacts. Impacts are those effects that lead to doses posed to individuals, groups of individuals or larger collectives. Masses and volumes are only relevant for the size of interim or final storages that are necessary to store and dispose those wastes,

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[3] Note that a new publication from August 2015 specifies a slightly lower value of 7 mg/kWh for the disclosure period 01/04/2014 – 31/03/2015. This figure was published after the RE-DISS Residual Mix calculations for the calendar year 2014 had been completed and published.

[4] See the Platts website http://www.platts.com/products/world-electric-power-plants-database and the PRIS website https://www.iaea.org/pris.

not for their impacts to man and the environment. Storage and disposal is irrelevant as long as this does not contribute to doses posed. The perfect indicator that would be directly related to impacts would have the dimension of a dose: e.g. Sv/GWa (individual dose) or man·Sv/GWa (collective dose).

However, the disclosure regulation in Article 3 (9) Directive 2009/72/EC focuses on "radioactive waste" only. Thus, an environmental disclosure indicator relating to radioactive doses would not be following the wording of the Directive. Therefore it might be better to disclose the risks associated with high-level radioactive waste in units of generated radioactivity in the radioactive waste from nuclear power plants. European lawmakers could consider whether generated radioactivity expressed in MBq/kWh should be communicated towards final consumers of electricity as the indicator for high-level radioactive waste in the future, rather than volumes or masses of spent fuel or other waste. This indicator would be a linear measure for the

- nuclear fissions that have been triggered in the fuel to generate heat,
- generation of long-lived fission products such as iodine-129, selenium-79 and technetium-99 in the fuel that can
    - diffuse over technical and geological barriers of repositories,
    - leave the repository towards groundwater pathways and can cause doses to individuals,
    - dominate individual doses posed downstream of repositories, and can
    - cause collective doses by the spreading and circulation of long-lived iodine-129 in the environment,
- total risks associated with the generation of long-lived radioactive waste and the necessary measures to control and limit exposures.

This indicator can be calculated quite easily. Most importantly, it does not differ much in relation to the burn-up in different reactor types. In a range of burn-ups between 20 and 50 GWd/t, the proposed indicator only varies between 87 and 100 MBq/kWh. Thus it is much less dependent from the reactor type used in a country and for a rough estimate (within $^{+}/_{-}$ 7,5 % accuracy) even a uniform figure could be used for all nuclear energy produced in Europe.

As a downside argument to this proposal, it must be noted that the unit of Becquerel[5] may not be easily understood by many consumers. Based on these arguments, a potential revision of the environmental indicator for high-level radioactive waste should be considered in future modifications of legislation on electricity disclosure in Europe. A further potential shortfall of this indicator is the fact that it is focused on spent fuel only and does not cover the generation of low- and intermediate level wastes (LLW/ILW). If not properly disposed (e.g. in a simple surface disposal and without effective geologic barriers, or associated with a high content of long-lived radionuclides) repositories for so-called "short-lived" LLW can even pose higher doses than a repository in clay/salt/hardrock in 500 m depth with HLW.

The country and fuel/technology specific environmental indicators for radioactive waste are shown in Table 3 in Chapter 3.1.

[5] Becquerel = Bq = radioactive decays per second.

3 Results environmental indicators

3.1 Direct CO_2 emissions and radioactive waste

The country and energy source/technology specific environmental indicators for direct CO_2 emissions and radioactive waste are given in Table 3. Note that the data provided is relating to electricity produced from the energy source/technology specified, not to any generation mix.

Environmental indicator		Energy source/technology		AT	BE	BG	HR	CZ	DK	FI	FR	DE	GB	GR	HU	IE	IT	LU	NL
mg/kWh		Nuclear		n/a	2,7	3,5	n/a	3,5	n/a	3,0	2,7	2,7	8,0	n/a	3,5	n/a	n/a	n/a	2,7
CO2 (kg/kWh)	Direct	Fossil	Hard Coal	0,8380	0,9480	1,0570	0,9490	1,1350	0,8140	0,8140	0,9490	0,9220	1,0040		1,0040	1,0040	0,9070		0,9490
			Lignite (or brown coal)			1,1000	1,2600	1,1300				1,1800		1,2500	1,1350	1,1800			
			Natural Gas	0,4751	0,4416	0,6092	0,5497	0,4992	0,3430	0,4172	0,3980	0,4610	0,4640	0,4397	0,4992	0,4616	0,4586	0,3430	0,4719
			Oil	0,7040	0,7900	0,7930	0,8270	0,8509	0,7120	0,4480	0,6500	0,9830	0,9890	0,7460	1,0074	0,7400	0,7610		0,6070
			Unspecified (fossil)	0,4861	0,4609	1,0933	0,5720	1,1340		0,4329		0,9220	0,4642	1,2546		1,0044	0,4609		0,6090

Environmental indicator		Energy source/technology		NO	PL	PT	RO	SK	SI	ES	SE	CH	CY	EE	IS	LV	LT	MT
mg/kWh		Nuclear		n/a	n/a	n/a	18,0	3,5	2,7	2,7	2,7	2,7	n/a	n/a	n/a	n/a	n/a	n/a
CO2 (kg/kWh)	Direct	Fossil	Hard Coal	0,8140	1,0040	0,9020	1,0040	0,8720	0,8480	0,9600	0,8140							
			Lignite (or brown coal)		1,0800		1,1000	1,1640	1,1700	1,1800				0,9596				
			Natural Gas	0,4860	0,4992	0,4397	0,6500	0,4910	0,5310	0,4330	0,4860	0,3483		0,6029		0,6029	0,6029	
			Oil	0,4480	0,8513	0,7830	0,8160	0,7930	0,7070	0,8320	0,5190	0,6694	0,8301	0,9273		0,9273	0,9273	0,8178
			Unspecified (fossil)	0,4861		0,4609	1,1025	0,8723		0,4329	0,4861	0,3982		1,0447	0,4861	0,6201	0,6201	0,8265

Table 3: Country and energy source/technology specific environmental indicators (direct CO_2 emissions and nuclear waste).

3.2 Direct GWP (CO_2-equiv.) and life cycle based (LCA) emissions CO_2 and GWP

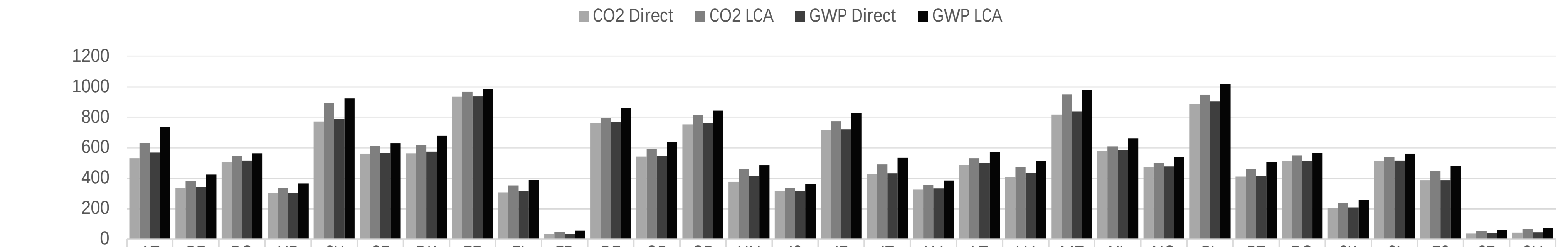
The weighted average environmental indicators for direct GWP (CO_2-equivalents) and life cycle based (LCA) emissions CO_2 and GWP are given in Table 4.

Energy source/technology		Weighted average		
		LCA	Direct	LCA
		CO2 (kg/kWh)	GWP (kg CO2-eqv/kWh)	
Renewable	Solar	0,0624		0,0708
	Wind	0,0182		0,0200
	Hydro & Marine	0,0053	0,0002	0,0058
	Geothermal	0,0549		0,0590
	Biomass & Biogas	0,1181	0,0460	0,1762
	Unspecified (renewable)	0,0299	0,0206	0,0535
Fossil	Hard Coal	1,0382	0,9660	1,1626
	Lignite (or brown coal)	1,1986	1,1641	1,2192
	Natural Gas	0,5258	0,4614	0,5658
	Oil	0,8869	0,7844	0,9142
	Unspecified (fossil)	0,8060	0,7785	0,8981

Table 4: Weighted average environmental indicators (Direct GWP (CO_2-equivalents) and life cycle based (LCA) CO_2 and GWP).

3.3 Environmental indicators for the Residual Mixes

The environmental indicators for the Residual Mixes in the respective countries have been calculated on the basis of the country and energy source/technology specific data presented in Table 3 and Table 4. For the indicators CO2 LCA, GWP Direct and GWP LCA indicators, the country and fuel/technology emission factors create the basis for the Residual Mix calculations even though these indicators are not presented in detail in this report, but only as weighted average data (Table 4).



	AT	BE	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GB	GR	HU	IS	IE
CO2 Direct	530	334	503	303	772	562	564	934	307	32	762	542	753	376	314	717
CO2 LCA	631	382	545	334	894	610	619	968	352	48	795	592	812	457	334	774
GWP Direct	569	343	517	302	786	567	575	936	314	33	768	544	761	412	317	721
GWP LCA	735	424	563	366	923	630	678	986	387	55	862	639	844	486	360	825

	IT	LV	LT	LU	MT	NL	NO	PL	PT	RO	SK	SI	ES	SE	CH
CO2 Direct	427	325	487	409	818	578	473	887	410	513	204	514	387	36	43
CO2 LCA	490	356	530	474	950	608	498	949	461	550	238	539	446	53	65
GWP Direct	432	333	498	436	839	585	477	906	416	515	208	515	387	41	45
GWP LCA	535	385	572	515	981	662	537	1020	506	567	255	562	480	61	76

Figure 1: CO_2 content in Final Residual Mixes 2014 [gCO_2(e)/kWh]

Environmental indicator	**Data source**
CO_2 Direct *= Direct onsite CO_2 emissions [g CO_2/kWh].*	Treyer and Bauer (2013), Dong Energy A/S, Energi.dk, Vattenfall (2010), Fritsche and Rausch (2009), Bauer (2008), GEMIS database (GEMIS, 2015)
CO_2 LCA *= Life Cycle Assessment CO_2 emissions [g CO_2/kWh].* ***GWP Direct*** *= Direct onsite Global Warming Potential emissions [g CO_2e/kWh].* ***GWP LCA*** *= Life Cycle Assessment Global Warming Potential emissions [g CO_2e/kWh].*	ecoinvent v. 3.01 Database

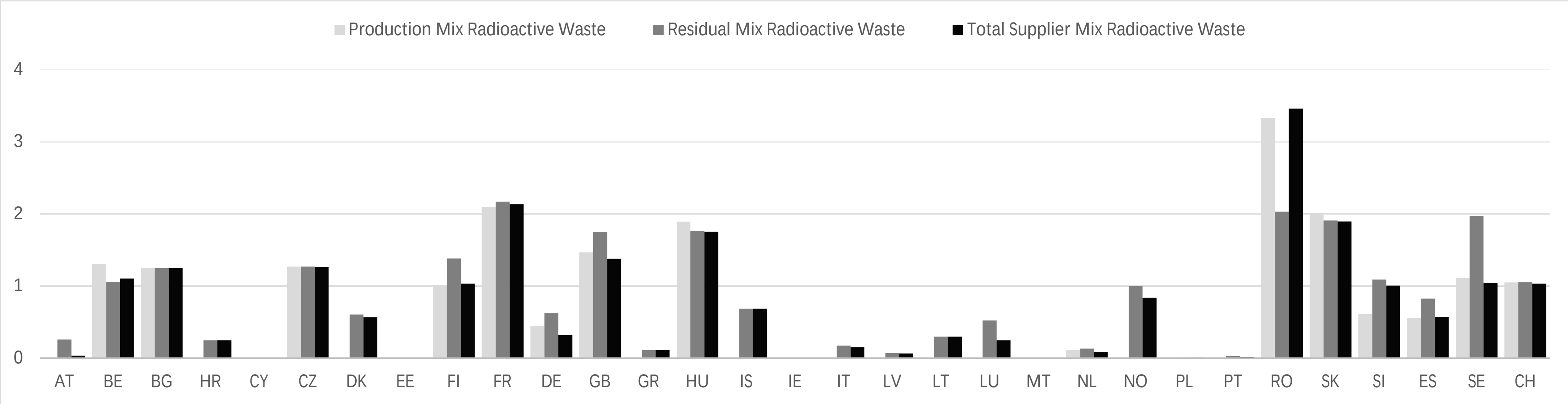


Figure 2: High-level radioactive waste (RW) content in the Production Mix (PM), the Residual Mix (RM) and the Total Suppler Mix (TSM) 2014 [mg RW/kWh]

Detailed information about the 2014 Residual Mixes can be found in the RE-DISS II paper on European Residual Mixes 2014 (RE-DISS 2015).

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