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Nuclear Power Plants As a Solution for Reducing Carbon Footprint and Achieving Sustainable Energy System

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ABSTRACT

The paper presents the current requirements and practice of carbon footprint reporting, with the aim of reducing greenhouse gas emissions while following legislation and ESG (Environmental, Social, and Governance) framework. The practice of calculating the carbon footprint is presented and, as an example, a general overview of the importance of nuclear facilities for reducing the carbon footprint is given.

The calculation of carbon footprint is a new element of a comprehensive environmental impact management system, as it enables monitoring of progress and comparisons within similar activities. By calculating an accurate and verifiable carbon footprint, organizations identify their activities that are the most burdensome with greenhouse gas emissions. Nowadays purchased electricity presents a significant part of those emissions and organizations need to follow the trend of reducing emissions, resource consumption and costs to achieve the greatest possible progress. In practice, customers or users, companies and other stakeholders demand more and more such statements from the companies they work with. One of the key indicators of an organization's efforts to transition to sustainable operations is also the timely preparation of a quality carbon footprint report.

All the above are reasons why companies want to reduce their carbon footprint. By switching to a fossil-free electricity therefore enables companies to lower its indirect emissions and show their dedication to be more environmentally friendly. The need for fossil-free electricity will therefore increase shortly and nuclear power plants are a solution to deliver such electricity.

1 CARBON FOOTPRINT

The carbon footprint of an individual company, organization, group or community (e.g. country) is defined as the mass or the amount of emitted carbon dioxide or the sum of all the emissions of various greenhouse gases (GHGs) that is directly or indirectly caused through activities. It is a measure of impact on climate change and can be used as a tool for planning measures to reduce emissions and monitor effectiveness. The carbon footprint is calculated and expressed in tons of CO_2 equivalent (CO_2e), because we consider the appropriately weighted impact of emissions of various greenhouse gases together with one quantity.

The main versions of the carbon footprint calculation are organizational and product footprint. With the organizational footprint, we calculate the emissions of a company (or office buildings, municipalities, countries, etc.), which are based on average data for individual energy sources, materials, processing processes, transport routes and other existing data in a

certain period of time. In the case of a product footprint, we calculate emissions caused by a product, service, event, etc. in its lifetime.

1.1 THE IMPORTANCE OF CARBON FOOTPRINT REPORTING

Calculating one's own carbon footprint can enable a company to reduce and control emissions, control one's own footprint and find possible savings, to report accurately, to meet the requirements of business partners, customers or investors, to allow customers to choose a more environmentally friendly product or service, to obtain the necessary input data for decision-making procurement, selection of materials and development of products in production, to show social responsibility and potentially have competitive advantage.

Companies include carbon footprint as an integral part of their sustainability reports. At the EU level, the *Corporate Sustainability Reporting Directive (CSRD)* was adopted in 2022. Reporting in accordance with the CSRD directive must also comply with the *European Sustainability Reporting Standards (ESRS)*, which are currently still in draft form, but with disclosed contents where no major deviations are expected. The CSRD directive defines who and when must report, while the ESRS standards define what must be reported. Within the ESRS standards, the content standards are ESG (Environmental, Social, and Corporate Governance). The environment content standard (E) covers climate change and mandatory reporting on greenhouse gas emissions, i.e. reporting on the organization's carbon footprint.

The practice is such that the companies, banks and other stakeholders, demand more and more such sustainable reports from their business partner, even within their organizational units in their own organizations.

2 GHG PROTOCOL (WRI/WBCSD)

The GHG protocol is the most widely used international tool for measuring, reporting, and managing GHG emissions and is a good basis for other carbon footprint calculation methodologies. It was created in 2001 in collaboration with the associations WRI (World Resources Institute) and WBCSD (World Business Council for Sustainable Development) and facilitates the preparation of emissions inventories with standardized approaches and principles. The GHG protocol is the most accurate of the protocols for calculating greenhouse gas emissions. It is widely used and recognized, as it is used by the majority of companies that report emissions, including some major, world-renowned companies from various fields of activity (Shell, Tokyo Gas, Green Mountain Energy, Unilever, Johnson, IBM, Sony, Gap, IKEA, etc.) [1].

The GHG protocol consists of several standards. The most widely used for calculating the organizational footprint is *A Corporate Accounting and Reporting Standard* (mandatory reporting of scope 1 and scope 2) [2], supplemented by the *Corporate Value Chain (Scope 3) Accounting and Reporting Standard* (mandatory reporting of scope 3) [3]. The *Product Standard* (mandatory reporting of emissions throughout the product life cycle) is used to calculate the products footprint [4].

If the company refers to reporting according to the *A Corporate Accounting and Reporting Standard* of the GHG protocol, reporting of scopes 1 and 2 is mandatory. Reporting of scope 3 is voluntary, based on the data that can be easily accessed. If there is a need for further development of reporting, the company can refer to the *Corporate Value Chain (Scope 3) Accounting and Reporting Standard* of the GHG protocol, which specifies mandatory reporting of scope 3. This must then be properly evaluated in all 15 categories of scope 3.

According to the protocol, greenhouse gases CO_2, CH_4, N_2O, SF_6, HFC, PFC, NF_3 aggregated to CO_2e [t] are reported. When reporting, it is necessary to follow principles such as relevance, completeness, consistency, transparency, and accuracy.

2.1 SETTING ORGANIZATIONAL BOUNDARIES

A company must decide whether to report on equity share or the control approach. An agreement with the other co-owners is required for uniform reporting (i.e., if an agreement is reached on equity share approach, one company reports 10 % of emissions, other companies 90 %). The same reporting method is then also used in subsidiary companies, at all other levels of the organization.

If a company chooses to report on equity share, then it reports the subsidiary's releases only in the proportion equal to its ownership part. Under the control approach, a company accounts for 100 percent of the GHG emissions from operations over which it has control. No emissions are reported for subsidiaries in which it owns an interest but does not have control. Control can be defined in either financial or operational terms. When using the control approach to consolidate GHG emissions, companies shall choose between either the operational control or financial control criteria [2][5].

2.2 SETTING OPERATIONAL BOUNDARIES

After a company has determined its organizational boundaries in terms of the operations that it owns or controls, it then sets its operational boundaries. This involves identifying emissions associated with its operations, categorizing them as direct and indirect emissions, and choosing the scope of accounting and reporting for indirect emissions. To help delineate direct and indirect emission sources, improve transparency, and provide utility for different types of organizations and different types of climate policies and business goals, three “scopes” (scope 1, scope 2, and scope 3) are defined for GHG accounting and reporting purposes [2].

2.2.1 SCOPE 1 - direct emissions

Scope 1 includes emissions that occur from sources owned or controlled by the company. Examples are:

- Emissions occurring in production of electricity, steam, or heat by burning fossil fuels in immovable assets,
- Emissions occurring in transport of materials, products, waste, or workers due to the combustion of fossil fuels by vehicles owned or controlled by the company,
- Emissions from chemical production or processing,
- Fugitive emissions originating from intentional or accidental releases [2][5].

2.2.2 SCOPE 2 - indirect emissions

Scope 2 includes emissions resulting from the consumed energy supplied by another provider. The company therefore reports on purchased energy that is consumed by equipment or activities owned or controlled by the company. This includes purchased electricity, heat, steam, or cooling [5].

As stated in the GHG Protocol Scope 2 Guidance, companies can use two methods to calculate GHG emissions, market-based and location-based method. Using the market-based method, the company provides the emissions that occur during the production of the consumed electricity, for which the company has explicitly decided, e.g. by purchasing certificates. The market-based method refers to the emissions created by the individual electricity provider from which the company buys energy. The company obtains the emission factors from the provider. With the location-based method, the company provides the average emissions that occur

during the production of electricity for the power grid to which the company is connected. The emission factors represent the average value of a certain area and a certain period of time and differ from the emission factors of an individual provider. A company located in an area where market-based method can be used must report using both methods, even if it does not have leased certificates itself [1].

2.2.3 SCOPE 3 - indirect emissions

Scope 3 includes all indirect emissions that are not included in the reporting of the second scope and appear in the company's value chain. Within *A Corporate Accounting and Reporting Standard*, reporting is optional, so only available data from the following 15 categories can be defined and reported: purchased products and services, investment goods, activities related to fuel and electricity not specified in scope 1 and 2, transport and distribution up the supply chain, waste, business trips, transportation of workers to and from work, leased assets, transport and distribution down the supply chain, processing of sold products, use of sold products, disposal of end-of-life products, leasing of assets, franchises and investments.

Scope 3 can provide more realistic results than reporting by scopes 1 and 2 only, despite the lower quality. In certain cases, it may be more cost-effective to reduce indirect emissions than to reduce scope 1 emissions. The GHG protocol suggests that companies make a rough estimate of the emissions of each potential category in scope 3 and, based on the estimation, decide on reporting [5].

2.3 CHOOSING A BASE YEAR

The company needs to choose base year for reporting and explain the reason for choosing this year exactly. A company may also select an average of several consecutive years if a single year does not reflect the company's normal emissions and represents an unusual deviation from expected results.

2.4 COLLECTION OF QUALITY PRIMARY AND SECONDARY INPUT DATA

To calculate CO_2e emissions, the company can collect data in the form of direct measurements, can make stoichiometric calculations or make an estimate of emissions with the help of emission factors. The latter approach is the most widely used [6]. The easiest way to obtain basic data is, for example, from received invoices and own databases.

2.5 IDENTIFICATION OF EMISSION FACTORS

Emission conversion factor or in short, the emission factor allows us to obtain information about the corresponding amount of carbon dioxide emissions from the input data (e.g. in the unit of kWh, m^3, l, kg, km). The latest emission factors are used for the calculations. These are usually reported with a lag of some years. With each new edition, to calculate the carbon footprint of that year, it is necessary to take updated values or latest possible emission factors [6].

2.6 DATA COLLECTION AND EMISSIONS CALCULATION

The emissions of each GHG (CO_2, CH_4, N_2O, etc.) are calculated separately and then converted to CO_2 equivalents on the basis of their global warming potential (GWP). For the conversion to CO_2e, it is necessary to use the latest checked and confirmed global warming potential of each gas.

2.7 PREPARATION OF A METHODOLOGICAL REPORT WITH ACCOUNTING FOR GHG REDUCTIONS

A public report on GHG emissions that complies with *A Corporate Accounting and Reporting Standard* of the GHG Protocol must contain the following information:

- DESCRIPTION OF THE COMPANY AND INVENTORY BOUNDARY, such as an outline of the organizational boundaries, including the chosen consolidation approach. An outline of the operational boundaries, and if scope 3 is included, a list specifying which types of activities are covered. The reporting period.
- INFORMATION ON EMISSIONS, total scope 1 and 2 emissions independent of any GHG trades such as sales, purchases, transfers, or banking of allowances. Emissions data separately for each scope. Emissions data for all six GHGs separately (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) in metric tonnes and in tonnes of CO_2 equivalent. Year chosen as base year, and an emissions profile over time that is consistent with and clarifies the chosen policy for making base year emissions recalculations. Appropriate context for any significant emissions changes that trigger base year emissions recalculation (acquisitions/divestitures, outsourcing/insourcing, changes in reporting boundaries or calculation methodologies, etc.). Emissions data for direct CO_2 emissions from biologically sequestered carbon (e.g., CO_2 from burning biomass/biofuels), reported separately from the scopes. Methodologies used to calculate or measure emissions, providing a reference or link to any calculation tools used. Any specific exclusions of sources, facilities, and / or operations.

2.8 OBTAINING INDEPENDENT VERIFICATION OF METHODOLOGY AND RESULTS

Companies order verification of the carbon footprint report to confirm the approach, the chosen methodology and the validity of the calculation. This is done by individual independent experts and a few independent institutions.

3 EMISSIONS IN NUCLEAR POWER PLANTS

Emissions in nuclear power plant (NPP) occur during the construction, operation and in decommissioning phase. The greater part of the emissions occurs also during fuel production and fuel reprocessing.

3.1 DIVISION OF EMISSIONS FROM NPPs BY SCOPES

It is important to note that nuclear power plants emit practically zero GHGs during operation itself, as opposed to fossil fuel generators that generate the most of their emissions during this stage.

3.1.1 CALCULATING SCOPE 1 EMISSIONS IN NPPs

During the operation of NPPs the scope 1 stationary emissions can occur mainly from consumption of fossil fuels for heating in office buildings. Another factor can be safety systems, which are fossil fuels based, such as backup generators. These emissions generally arise only during testing of equipment. Scope 1 mobile emissions are created because of fossil fuels consumption by fleet vehicles and worksite equipment, such as security vehicles, maintenance vehicles, fire trucks, etc. Scope 1 fugitive emissions occur because of SF_6 and coolant leaks. Electricity production itself emits no GHGs.

3.1.2 CALCULATING SCOPE 2 EMISSIONS IN NPPs

Scope 2 indicates indirect emissions associated with purchased electricity, heating, steam or cooling. In NPP these emissions can differ depending on its planned own use and the need for purchase. Most of the emissions in scope 2 occur during the regular outages when NPP doesn't produce electricity and heat itself. Some emissions in scope 2 can also appear on different locations.

3.1.3 CALCULATING SCOPE 3 EMISSIONS IN NPPs

In many companies, and NPPs as facilities for the production of electricity, are no exception, the bulk part are identified in scope 3. The fuel chain ("front-end") contributes most to the overall emissions, such as extraction, conversion, enrichment of uranium and fuel fabrication.

3.2 CASE STUDY - NPP

In the case study, a conventional NPP is used as a model, with nameplate capacity of 1000 MW, 60 years of lifetime, 34 % efficiency and burnup rate of 42 GWd/t. Included in the analysis are fuel element supply chain (from extraction to fuel fabrication), core processes (construction and decommissioning of power plant, as well as operation), back-end processes (spent fuel management, storage, and final repository) and connection to grid. Excluded in the analysis are potential recycling of dismantled equipment and reprocessing of spent fuel (conservative assumption that all fuel is primary is used).

The nuclear power fuel cycle involves the following steps:

- uranium mining and milling, extracting ore and then separating out the uranium for transport as a uranium oxide
- uranium conversion and enrichment, converting the solid uranium oxide into gaseous UF6 for enrichment, which increases the concentration of the useful isotope ^{235}U
- fuel fabrication, converting the enriched uranium into a highly stable compound before loading into manufactured assemblies
- power generation at nuclear power plant
- used fuel management
- high-level radioactive waste management and disposal

The first steps, from mining to fuel fabrication, are commonly called "front end". Energy use on site, mainly from diesel generators, are the main cause of GHG emissions for mining and milling processes. "Back end" refers to the retreatment of the used fuel. It is also possible to "reprocess" used fuel to recover useful isotopes and recycle uranium and plutonium as new fuel, however for simplicity reprocessing was not included in this study. All of these emissions fall under scope 3 in GHG protocol reporting. "Core" processes generally refer to all operations occurring at the nuclear power plant site and at this point scope 1 and scope 2 emissions occur. The distribution of GHG emissions for whole NPP operating cycle and its total sum are shown on the Figure 1 [7].

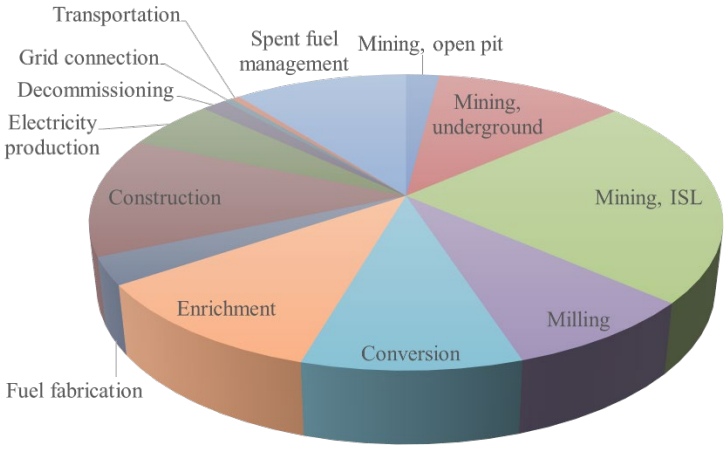

Figure 1: Distribution of emissions in global average reactor, per kWh and activity [7]

For NPPs, general emissions are expected to even decrease for 25 % by 2050, due to the projected reduced use of fossil fuels and its emissions in the process of extracting uranium ore. This would be the biggest decrease in all of available electricity generation sources, as shown on Figure 2 [7].

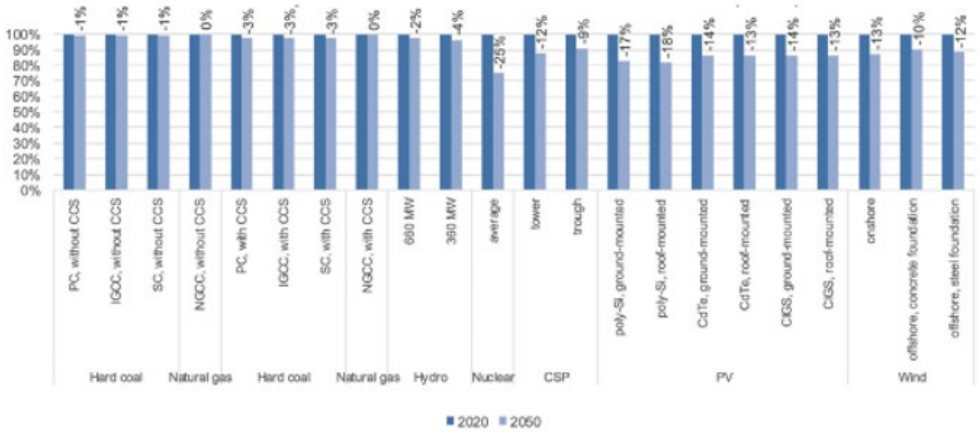

Figure 2: Difference in lifecycle GHG emissions between 2020 and 2050 [7]

4 COMPARISON OF EMISSION VALUES BETWEEN DIFFERENT POWER PLANTS

The most reliable and easily comparable way of reporting greenhouse gases between different power plants is to report emissions of CO_2e on produced kWh. A detailed comparative analysis on different power plants was made.

Results for greenhouse gas (GHG) emissions are reported on Figure 3. Coal power shows the highest scores, with a minimum of 751 g CO_2e/kWh (IGCC, USA) and a maximum of 1095 g CO_2e/kWh (pulverised coal, China). Equipped with a carbon dioxide capture facility, and accounting for the CO_2 storage, this score can fall to 147–469 g CO_2e/kWh (respectively).

A natural gas combined cycle plant can emit 403–513 g CO_2e/kWh from a life cycle perspective, and anywhere between 92 and 220 g CO_2e/kWh with CCS. Both coal and natural gas models include methane leakage at the extraction and transportation (for gas) phases; nonetheless, direct combustion dominates the lifecycle GHG emissions.

On the renewable side, hydropower shows the most variability, as emissions are highly site-specific, ranging from 6 to 147 g CO_2e/kWh. As biogenic emissions from sediments accumulating in reservoirs are mostly excluded, it should be noted that they can be very high in tropical areas.

Solar technologies generate GHG emissions ranging from 27 to 122 g CO_2e/kWh for CSP, and 8.0–83 g CO_2e/kWh for photovoltaics, for which thin-film technologies are sensibly lower-carbon than silicon-based PV. The higher range of GHG values for CSP is probably never reached in reality as it requires high solar irradiation to be economically viable (a condition that is not satisfied in Japan or Northern Europe, for instance).

Wind power GHG emissions vary between 7.8 and 16 g CO_2e/kWh for onshore, and 12 and 23 g CO_2e/kWh for offshore turbines.

Nuclear power shows less variability because of the limited regionalisation of the model, with 5.1–6.4 g CO_2e/kWh. The absence of operational emissions, a long asset lifetime, and high load factors make nuclear perform relatively well regarding the GHG metric. Nuclear power's lifecycle emissions are than estimated at 5.5 g CO_2e/kWh on a global average, with most of the emissions occurring in the front-end processes. This value is comparable to the lower range of literature values because of the following assumptions: revised energy inputs for mining and milling, including electricity inputs for ISL, centrifugation-only enrichment, longer lifetime assumed for nuclear power plant (60 years instead of 40).

While the technology description is identical across regions, the site of operation plays a role for all technologies. The varying electricity mixes and industrial process efficiencies across world regions influence the environmental impacts of all systems, as energy inputs are a main contributor of infrastructure production as seen on Figure 3 [7].

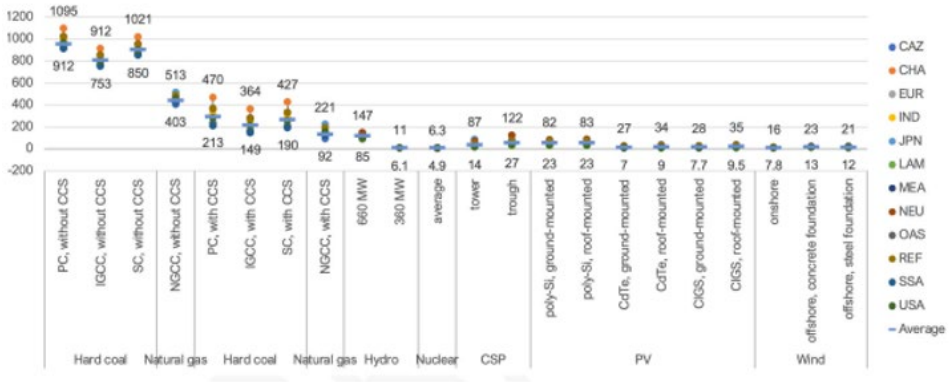

Figure 3: Lifecycle GHG emissions, in g CO_2e/kWh, regional variation, 2020 [7]

5 CONCLUSION

Calculating the carbon footprint will be an inevitable practice for all European and global companies in a few years, so it is necessary for companies to get familiar with the topic as soon as possible and prepare the ground for a quality calculation. Companies that already prepare carbon footprint calculations share information, that the most demanding part of calculation is obtaining quality data. The information about *which* data to collect is straightforward. Organizations themselves must then develop a process of *how* to access this data from their databases and maybe even set up a system in advance to make access to this data as easy and as fast as possible in the years to come. According to all predictions, the carbon footprint will become one of the criteria of the company's quality in the coming years, so it is necessary to approach the calculation as soon as possible and with greater reliability,

even if on a smaller scale, and thus prepare a good basis for a possible upgrade of the future calculations.

As the legislation requiring reporting of the carbon footprint is widely accepted, the desire of companies to reduce their carbon footprint will naturally follow as well. Nuclear power plants have one of the lowest carbon footprints of all power plants. Many companies will most likely want to buy electricity produced in nuclear power plants to lower their scope 2 emissions in their sustainability reports. Very low carbon footprint, in addition to the other advantages that nuclear power plants already show anyway, will be one of the main reasons why there will be an increased need for nuclear newbuilds in EU and around the world. A practice that had already begun significantly.

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