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Modelling electricity in environmental footprints

Tentative suggestions for the general guidelines and EU regulations

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Summary

The European Commission developed a framework for life cycle assessment (LCA) denoted Product Environmental Footprint (PEF) in collaboration with representatives from the EU Member States, industry, and researchers. The PEF framework is now being used in a Regulation for photovoltaics (PV) within the Ecodesign Directive. It may become a precedent for future use of PEF in a policy context.

The PEF Guidance and the draft PV Regulation both state that production of electricity should be modelled using as specific information as possible. Input data on a specific technology or supplier should be used in the calculations when contractual instruments give a valid basis for this. The calculation rules include a description of what is required from a valid contractual instrument. When no such instrument is in place, the rules stipulate that the electricity supply should be modelled using data on the residual consumption mix in the country.

However, the calculation rules in the draft PV Regulation are not based on the latest version of the general PEF methodology. Concern has also been raised that the use of contractual instruments such as Guarantees of Origin entail a risk for greenwashing that can put European PV producers at a disadvantage. The general PEF methodology is in addition interpreted and applied in diverging ways by different actors and countries. The PEF rule to use a national residual mix is, for example, in Sweden interpreted to refer to a Nordic or Scandinavian residual mix, while other countries follow this rule to the letter.

This project aims to investigate the need for revised methods and revised text on the modelling of electricity supply in PEF as given by the general PEF guidelines and in the draft PV Regulation. We also aim to present tentative suggestions for amended text, when revisions are called for. The project involves a literature study that includes PEF documents and several other frameworks for LCA and carbon footprint. We also interviewed representatives from the Swedish Energy Agency and the Swedish Environmental Protection Agency, researchers at institutes and industry with experience from applying the PEF methodology, and representatives from relevant governing bodies. The outcome from literature studies and interviews was analyzed and forms the basis for our suggestions for amendments in the method and text.

Our interviews and analysis confirm that key concepts such as contractual instruments, Guarantees of Origin, tracking and tracking systems, residual mix, etc. are not fully defined or sufficiently explained. This makes it difficult for PEF practitioners to apply the method. It also invites subjective choices into the interpretation and application of the PEF rules.

Several of our interviewees share the concern that Guarantees of Origin and similar instruments indicate that the electricity is renewable even when there is no increase in renewable electricity production. This gives companies an incentive to buy Guarantees of Origin rather than investing in electricity efficiency.

We also find that the use of national residual data overestimates the significance of national borders between countries with interconnected electricity grids, particularly if the countries form a common electricity market. Electricity users in a country with a good residual mix get little incentive to invest in energy efficiency, even when a reduced electricity consumption means that more electricity can be exported to a country where the domestic electricity production has a poor environmental performance.

The principles in the current PEF approach for modelling electricity fits in the context of attributional LCA. It also corresponds to how the production of other goods is typically modelled in LCA. However, to make PEF results accurately indicate what actions and decisions reduce climate and environmental impacts, it would be better to choose a different approach for modelling the electricity supply. Elements that can be used in such an approach can be found in other existing frameworks. Ideally the electricity supply should be modelled using marginal data, i.e., data that reflect how a small change in the electricity demand affects the electricity production. However, marginal data depend strongly on the method and model used for identifying marginal impacts on the electricity supply. To avoid making PEF calculations highly subjective, the rules should include a specific method to identify the marginal electricity supply. Here, the method used by the Ecoinvent team is an interesting option: each unconstrained technology is part of the marginal mix in a country to the extent that it contributes to the projected future increase in electricity production.

Less accurate but still reasonable results would probably be obtained if electricity supply is modelled using average data for the electricity market where the electricity is used. To acknowledge that electricity users can contribute to increased production of renewable or fossil-free electricity production, exemptions from the rule to use average data should be made when:

- the electricity is produced at the site where it is used, and contractual instruments are not sold to a third party,
- the electricity is produced in a directly connected power plant, if this power plant was built after or at the same time as the production plant where the electricity is used, and contractual instruments are not sold to a third party,
- the electricity user built or had a power plant built elsewhere after or at the same time as the production plant where the electricity is used, and contractual instruments are not sold to a third party,
- the electricity user enters a long-term power purchase agreement that enables investment in new electricity-production capacity that would not otherwise have been viable, or
- the electricity is used only when the price is low enough to indicate that wind, hydro, solar, or nuclear power supplies the marginal electricity.

If the existing PEF approach based on contractual instruments and tracking systems is retained, the rule to always use data on supplier-specific electricity products in countries with a 100% tracking system should still be removed. Data on specific electricity-production technologies cannot be used when the electricity supply to a specific process is unknown, even if the country has a 100% tracking system.

To reflect the most recent version of the general PEF rules, the PV Regulation should allow for the use of data reflecting the residual mix of a region (e.g., EU+EFTA) as a last option.

The Swedish use of Scandinavian residual data instead of Swedish residual data should also be changed, since the use of national residual data is explicitly stipulated in the PEF rules. It is difficult to defend a contradiction to this rule, since Sweden stands alone in this position: national data are used in other Scandinavian countries.

The current PEF rules would also benefit from clarifications on how to interpret and apply the rules. We present several suggestions for clarifications in the text.

Regardless of which approach is selected for modelling electricity in future PEFs, the feasibility and robustness of the method would benefit from a database with electricity data. Hence, we recommend that such a dataset is developed, published, and regularly updated. The content of this task depends on the approach used for modelling electricity:

- If electricity production is modelled using marginal data developed through the Ecoinvent approach, data on 40 countries already exist in the Ecoinvent database. Marginal data for other countries need to be developed from existing or new generated plans or projections on the future electricity production.
- The essentially location-based approach recommended in this report would require a significant effort to identify to what extent different countries and price areas form common markets. The average data for each country and electricity-price area would then be calculated based on the results of this investigation.
- If the current, market-based approach remains, a major task is to check the validity of tracking systems in countries outside Europe. Such an assessment, which requires both legal and language expertise, would help deciding whether to calculate and publish residual or average data for each country.

In a possible second stage of the project, we hope to discuss these suggested changes with actors and other stakeholders in Sweden and other Nordic countries to refine the proposals and investigate to what extent we can reach consensus on them.

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Project title

Modelling electricity in Product Environmental Footprints

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Aim

This project aims to investigate the need for revised texts on the modelling of electricity supply in Product Environmental Footprints as given by the general Environmental Footprint guidelines and in the EU Ecodesign Regulation for photovoltaics.

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Coordination of the project

This project in coordinated within the Swedish Life Cycle Center.

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About Swedish Life Cycle Center

Swedish Life Cycle Center is a collaboration platform for universities, industries, research institutes and government agencies for competence building and the exchange of experience to move the life cycle field forward. Current partners are Chalmers University of Technology (host of the Center), KTH Royal Institute of Technology, Swedish University of Agricultural Sciences, Swedish Environmental Protection Agency, CEVT, Electrolux, Essity, Höganäs, Polestar, Vattenfall, Volvo Car Group, Volvo Group, IVL Swedish Environmental Research Institute, RISE Research Institutes of Sweden, Scania and CEVT. The Center hosts a dialogue group with Government agencies in Sweden. For more information about Swedish Life Cycle Center, please visit www.lifecyclecenter.se.

1. Introduction

1.1 Background

The European Commission developed a framework for life cycle assessment (LCA) called Product Environmental Footprint (PEF) in collaboration with representatives from the EU Member States, industry, and researchers. This framework is now becoming part of EU legislation. An early example is the Regulation for photovoltaics (PV) within the EU Ecodesign Directive. This Regulation will contain requirements for the maximum climate impact of solar cells throughout their life cycle, and stipulate that the climate impact be calculated using the PEF methodology. To be more specific, the draft PV Regulation (EC 2022a) includes calculation rules based on the Product Category Rules (PEFCR) for solar cells that were developed during the PEF pilot phase.

On December 10th 2020, the EU Commission also presented a proposal for a new Regulation on batteries (EC 2020a). According to the proposal, there are requirements for a carbon footprint for batteries over 2 kWh. This must also be calculated according to the PEF methodology (EC 2020b, pp. 3-6).

This is the first time that PEF is used in EU instruments. Therefore, it may become a precedent for future use of PEF in a policy context.

The calculation rules proposed in the draft PV Regulation raises concern. The calculation rules in the draft Regulation do not reflect the latest version of the general PEF methodology (EC 2021a). The European Solar Manufacturing Council (ESMC 2021) states the rules entail a risk for greenwashing that can put European producers at a disadvantage. The global production of PV cells and modules is dominated by China. European production is currently very small in comparison (Masson & Kaizuka 2020). This means Europe is dependent on imports for its growing use of PV.

The general PEF methodology (EC 2021a), in turn, is interpreted and applied in diverging ways by different actors and countries. The rule to use a national residual mix is, for example, in Sweden interpreted to refer to a Scandinavian residual mix (based on EMI 2013). Meanwhile, in other Scandinavian countries, the rule of national data is interpreted literally. In summary, there might be a need to both modify and clarify the rules for how to model electricity supply in the PV Regulation and in the general PEF rules.

It is possible to contribute to revising the text in the PV Regulation and in the general PEF guide if we develop good proposals for changes. The proposal should ideally be developed in dialogue with partners within the Swedish Life Cycle Centers and actors in other Nordic countries to increase the quality, relevance, and significance of the suggestion.

1.2 Aim of project

This project aims to investigate the need for revised methods and texts on the modelling of electricity supply in PEF as given by the general Environmental Footprint guidelines and in the EU Ecodesign Regulation for PV. We also aim to present tentative suggestions for amended text, when revisions are called for. These amendments will also have an impact on the battery regulation, since this refers to the PEF method.

We focus on the following questions:

1. How can and should the rules for electricity modelling in the draft PV Regulation be updated to reflect the most recent version of the PEF rules?
2. What are the arguments for and against these rules, accounting also for European competitiveness?
3. How can and should the rules be clarified to simplify application and increase robustness?
4. Can alternative calculation rules be more appropriate for the PEF framework?
5. Can and should Scandinavian countries differ in the interpretation of the of national residual mix?

1.3 Methods

The project involves a literature study and interviews with Swedish and European key actors. The literature study includes a comparison of the draft Ecodesign Regulation for PV to the general PEF guideline and the Product Environmental Footprint Category Rules (PEFCR) for PV (Chapter 2). This part of the analysis serves the purpose to better understand the origin of the text in the draft PV Regulation and to investigate how this text should be revised to reflect the current PEF methodology (Question 1).

The literature study also includes a discussion of the rules for modelling electricity supply in several other frameworks for life cycle assessment (LCA) or carbon-footprint calculations (Chapter 3). We survey frameworks that are closely related to PEF, frameworks that are otherwise important to industry and policymakers in Sweden and the EU, and other frameworks that are easily accessible to us. This literature survey contributes to the discussion of the pros and cons of the current PEF rules (Question 2), how these rules can a should be clarified (Question 3), and if alternative calculation rules can be more appropriate for the PEF framework (Question 4).

Interviews are held with representatives for the Swedish Energy Agency and the Swedish Environmental Protection Agency to better understand their concerns. The interviews also cover researchers at institutes and industry with experience from applying the PEF

methodology, and representatives from relevant governing bodies. The results from the interviews (Chapter 4) contribute to the basis for responding to Questions 2-5.

The outcome from literature studies and interviews is analyzed and forms the basis for our suggestions for amendments in the method and text.

In a possible second stage of the project, these tentative proposals can be refined through communication with actors and other stakeholders in Sweden and other Nordic countries.

2. Electricity modelling in PEF documents

This chapter cites the text on electricity modelling in the draft Ecodesign Regulation for PV and compares it to the corresponding text in other PEF documents: the current general guidelines for PEF and the Product Environmental Footprint Category Rules (PEFCR) for PV.

2.1 EU draft PV Regulation

The draft Ecodesign Regulation for PV includes recommendations for how to allocate electricity use in production plants with more than one product (EC 2022a, pp. 46-47). When possible, allocation should be avoided through subdivision, i.e., by separate metering the electricity use of different processes or products.

When subdivision is not possible, the electricity use should be allocated to different PV cells or different PV modules in proportion to their area. If PV cells and modules are produced in the same factory, the area of the cells and modules should be weighted by a default specific electricity use: 51.8 MJ per m^2 cells and 13.4 MJ per m^2 modules.

The draft PV Regulation calls the area and the weighted area physical relationships. This hints that the allocation procedure in the international standard (ISO 2006, p. 14; ISO 2020), where allocation based on underlying physical relation is the recommended approach when allocation cannot be avoided. However, the standard explains this approach to be allocation that reflects the way emissions are affected by a change in the production volume of the products. Allocation of electricity demand based on cell or module area does not accurately reflect such a causal relationship. Instead, allocation based on product area is a case of allocation based on other relationships, which can be used when no underlying physical relationship exists. Hence, denoting area and weighted area physical relationships is somewhat misleading in the context of allocation. More accurate would be to call them bases for allocation.

When a production plant uses electricity from different suppliers and/or grids, each product should be assigned the same mix of electricity sources, with two exceptions. One is when the products have separate electricity metering, purchase records or electricity bills that specify what electricity is used in the production of specific products. The other exception is when PEF studies have been produced, verified, and made available on all products. Then the use of a specific electricity source can be allocated to a specific product (EC 2022a, p. 47).

On the modelling of electricity supply, the draft PV Regulation includes the following text (EC 2022a, pp.47-50):

"The guidelines in this section shall only be used for the processes where company-specific information is collected.

The following electricity mix shall be used in hierarchical order:

I. Supplier-specific electricity product shall be used if:
- *a) available, and*
- *b) the set of minimum criteria referred to in the section below to ensure the contractual instruments are reliable is met.*

II. The supplier-specific total electricity mix shall be used if:
- *a) available, and*
- *b) the set of minimum criteria referred to in the section below to ensure the contractual instruments are reliable is met.*

III. As a last option the 'country-specific residual grid mix, consumption mix' shall be used. Country-specific means the country in which the life cycle stage occurs. This may be an EU country or non-EU country. The residual grid mix characterizes the unclaimed, untracked or publicly shared electricity. This prevents double counting with the use of supplier-specific electricity mixes in (I) and (II).

Note: if for a country, there is a 100% tracking system in place, case (I) shall be applied.

Set of minimum criteria to ensure contractual instruments from suppliers are reliable:

A supplier-specific electricity product/mix may only be used when the applicant ensures that any contractual instrument used meets the criteria specified below. If any of the contractual instruments do not meet the criteria, then 'country-specific residual grid mix, consumption mix' shall be used in the modelling.

A contractual instrument used for electricity modelling shall:

1. Convey attributes:
- *Convey the energy type mix associated with the unit of electricity produced and include an explanation of the calculation method used to determine this mix.*
- *The energy type mix shall be calculated based on delivered electricity, incorporating certificates sourced and retired on behalf of the relevant company (for the supplier-specific electricity product) or on behalf of the supplier's customers (for the supplier-specific electricity mix). Electricity from facilities for which the attributes have been sold off (via contracts or certificates) shall be characterized as having the environmental attributes of the country residual consumption mix where the facility is located.*

2. Be a unique claim:

- *Be the only instruments that carry the environmental attribute claim associated with that quantity of electricity generated.*
- *Any certificates incorporated in the energy type mix*

shall be redeemed, retired, or cancelled by or on behalf of the company (e.g. by an audit of contracts, third-party certification, or may be handled automatically through other disclosure registries, systems, or mechanisms).

- *A certificate may only be incorporated if it:*
  a. *allows for the unambiguous identification of the type, age and location and capacity of the energy generation facility to which it refers;*
  b. *the energy generation facility to which it refers is located in a country with a tracking system in place that meets the minimum criteria for tracking systems listed in the section below;*
  c. *in case the energy generation facility to which it refers is located in a country with a multi-certificate tracking system, it is accompanied by any additional contractual instrument necessary to show and ensure there is no risk of double counting.*

3. Be as close as possible to the period to which the contractual instrument is applied.

Set of minimum criteria for tracking systems

A supplier-specific electricity product/mix may only incorporate certificates redeemed, retired, or cancelled by or on behalf of the relevant company if those certificates stem from a tracking system that:

- *has a share of untracked production below 95%;*
- *is based on objective, non-discriminatory and transparent criteria for the issuing certificates;*
- *allows certificates to be valid no longer than 12 months after the production of the relevant energy unit;*
- *relies on accurate, reliable and fraud-resistant mechanisms for the issuance, transfer and cancellation of certificates;*
- *entrusts the issuance of certificates, as well as the supervision of their transfer and cancellation of certificates, to an entity or entities:*
  1) *that are independent from energy production, trade and supply activities, and of any commercial interest of customers on whose behalf certificates are redeemed, retired, or cancelled;*
  2) *whose activities are governed by transparent rules and procedures laid down by law;*
  3) *whose decisions may be challenged and reviewed in the context of proceedings before an independent judiciary.*

Modelling 'country-specific residual grid mix, consumption mix':

Datasets for residual grid mix are available in the nodes listed in the spreadsheet "CF_Annex_PV_modules-Life_cycle_inventory", sheet Data sources. If no dataset is available, the following approach may be used:

Determine the country consumption mix (e.g. X% of MWh produced with hydro energy, Y% of MWh produced with coal power plant) and combine them with LCI datasets per energy type and country/region (e.g. LCI dataset for the production of 1MWh hydro energy in Switzerland):

- *Activity data related to non-EU country consumption mix per detailed energy type shall be determined based on:*
  - *Domestic production mix per production technologies*
  - *Import quantity and from which neighbouring countries*
  - *Transmission losses*
  - *Distribution losses*
  - *Type of fuel supply (share of resources used, by import and / or domestic supply)*
- *Available LCI datasets per fuel technologies in the node. The LCI datasets available are generally specific to a country or a region in terms of:*
  - *Fuel supply (share of resources used, by import and / or domestic supply),*
  - *Energy carrier properties (e.g. element and energy contents)*
  - *Technology standards of power plants regarding efficiency, firing technology, flue-gas desulphurisation, NOx removal and de-dusting.*

On-site electricity generation:

If on-site electricity production is equal to the site own consumption, two situations apply:

- *No contractual instruments have been sold to a third party: the own electricity mix (combined with LCI datasets) shall be modelled.*
- *Contractual instruments have been sold to a third party: the 'country-specific residual grid mix, consumption mix' (combined with LCI datasets) shall be used.*

If electricity is produced in excess of the amount consumed on-site within the defined system boundary and is sold to, for example, the electricity grid, this system can be seen as a multifunctional situation. The system will provide two functions (e.g. product + electricity) and the following rules shall be followed:

- *If possible, apply subdivision.*
- *Subdivision applies both to separate electricity productions or to a common electricity production where you can allocate based on electricity amounts the upstream and direct emissions to your own consumption and to the share you sell out of your company (e.g. if a company has a wind mill on its production site and export 30% of the produced electricity, emissions related to 70% of produced electricity should be accounted in the carbon footprint).*
- *If not possible, direct substitution shall be used. The country-specific residual consumption electricity mix shall be used as substitution.*
- *Subdivision is considered as not possible when upstream impacts or direct emissions are closely related to the product itself."*

The criticism from the European Solar Manufacturing Council (ESMC 2021) focusses on the use of certificates as basis for using technology- and supplier-specific data on electricity production. They argue that this means a "dirty" PV producer can buy themselves free, claiming this implies a risk for greenwashing. Instead, ESMC (2021) recommends the use of national average data only. They

refer to a few other frameworks, e.g., EPD International, as good examples.

The substance in the ESMC criticism seems to be that PV producers in a country where the electricity mix has a high climate impact, such as China, can buy electricity certificates and not be burdened by the poor national electricity system. This reduces the competitive advantage of PV producers in countries with cleaner electricity. To be more concrete, a system with certificates can allow Chinese PV producers into the European market that would otherwise be excluded from this market – depending on the maximum climate impact allowed by the PV Regulation, and the electricity use of the producer.

2.2 General PEF guidelines

An early version of the guidelines for environmental footprints was published a decade ago (Manfredi et al. 2012) and presented as an official recommendation from the European Commission soon after (EC 2013). The official recommendation was recently replaced by an updated version (EC 2021a). In between these official versions, the Commission made available guidelines for the development of PEFCRs (EC 2018a). They also published a report that both presented the state-of-the art in the PEF framework and identified need for further development in the PEF framework (Zampori & Pant 2019). As the PEF framework evolved over time, the methods and the words describing these methods vary between these documents.

The first official version of the PEF framework describes the modelling of electricity in relatively brief terms (EC 2013, p. 31):

"*5.4.8 Accounting for Electricity Use (including Use of Renewable Energy)*

Electricity from the grid consumed upstream or within the defined PEF boundary shall be modelled as precisely as possible giving preference to supplier-specific data. If (part of) the electricity is renewable it is important that no double counting occurs. Therefore, the supplier shall guarantee that the electricity supplied to the organisation to produce the product is effectively generated using renewable sources and is not put into the grid to be used by other consumers (e.g., Guarantee of Origin for production of renewable electricity ([69])).

Requirement for PEF studies

For electricity from the grid consumed upstream or within the defined PEF boundary, supplier-specific data shall be used if available. If supplier-specific data is not available, country-specific consumption-mix data shall be used of the country in which the life cycle stages occur. For electricity consumed during the use stage of products, the energy mix shall reflect ratios of sales between countries or regions. Where such data are not available, the average EU consumption mix, or otherwise most representative mix, shall be used.

It shall be guaranteed that the renewable electricity (and associated impacts) from the grid consumed upstream or within the defined PEF boundary is not double counted. A statement of the supplier shall be included as an annex to the PEF report, guaranteeing that the electricity supplied is effectively generated using renewable sources and is not sold to any other organisation."

This text highlights Guarantees of Origin (GOs) as a means to justify the use of supplier-specific data, instead of the three minimum criteria listed in the draft PV Regulation. Note 69 refers to the contemporary version of the EU Renewable Energy Directive (EC 2009, pp. 34-35), where GOs are discussed in some depth. This discussion, in turn, builds on an earlier Directive on the EU electricity market (EC 2003). Neither of these Directive are valid anymore, but GOs is still an important concept in the current Renewable Energy Directive (EC 2018b, pp. 117-119). It is not mentioned in later versions of the general PEF rules, however (EC 2018b; Zampori & Pant 2019; EC 2021a). These are more similar to the text in the draft PV Regulation.

Even though the text on electricity modelling in the most recent version of the general PEF rules (EC 2021a, Section 4.4.2, pp. 36-40) resembles the text in the draft PV Regulation, there are several differences in details:

a) The beginning of Section 4.4.2 includes a short text that is essentially the same as the first paragraph from 2013, except that it does not mention GOs. No corresponding text is included the draft PV Regulation. However, this text does not affect the calculation rules but mainly explains their purpose.

b) The general PEF rules and the draft PV Regulation both require that data for supplier-specific products be used when there is a 100% tracking system in the country. The PEF rules define electricity tracking as the process of assigning electricity generation attributes to electricity consumption (EC 2021a, p. 9). This is consistent with the draft PV Regulation, which defines tracking system as a system that assigns electricity generation attributes to electricity consumption (EC 2022a, p. 35). However, the two documents differ on how to decide whether a tracking system is valid. The draft PV Regulation includes a set of criteria for the tracking system (ibid., p 49, and Section 2.1 above). The general PEF rules (EC 2021a, p. 38), instead, state that information from the Association of Issuing Bodies (AIB 2022a) should be used. However, the PEF rules do not specify any document to be consulted.

c) When country-specific electricity data cannot be found or used, the general PEF rules allow, as a last resort, for the use of data representing the average consumption mix in the EU+EFTA area, or whatever region where the electricity is used. This option is not available in the draft PV Regulation, nor in the previous guidelines for PEFCR development (EC 2018b). It was part of the first version of the general PEF guidelines (EC 2013), reintroduced in the PEF framework by Zampori & Pant (2019, p. 50) and remains in the most recent general guidelines (EC 2021a, p. 36). This option can have a substantial impact on the calculation results, when the country where the electricity

is used has a very different electricity mix, compared to the greater region where the country is located.

d) Subsection 4.4.2.1 ends with a short text that explains why the calculation rules includes minimum criteria to ensure that contractual instruments are met. is not in the draft Regulation. This text originates from the previous guidelines for PEFCR development (EC 2018b, p. 89). It does not affect the calculations.

e) The criterion to convey attributes (Subsection 4.4.2.2) differs from the draft PV Regulation:

"*The energy type mix shall be calculated based on delivered electricity, incorporating certificates sourced and retired (obtained, acquired or withdrawn) on behalf of its customers. Electricity from facilities for which the attributes have been sold off (via contracts or certificates) shall be characterised as having the environmental attributes of the country residual consumption mix where the facility is located.*"

This text does not distinguish between supplier-specific electricity products and mixes. This distinction is also not part of any previous version of the general guidelines but added specifically in the draft PV Regulation (EC 2022a, p. 48).

On the other hand, the most recent PEF guideline specifies what is meant by "sourced and retired": obtained, acquired or withdrawn. This information was introduced by Zampori & Pant (2019, p. 50) and remains in the most recent general guidelines (EC 2021a, p. 37). It is not included in the draft PV regulation.

f) The criterion to be a unique claim, and the conditions to meet this claim, are described with more words in the general PEF guidelines (EC 2018b, pp. 90-92; Zampori& Pant 2019, pp. 50-52, EC 2021a, pp. 37-38). There seems to be no difference in substance, however, when compared to the more condensed text in the draft PV Guidelines (EC 2022a, pp. 48-49).

g) The conditions to meet the criterion of a unique claim are in the general PEF guidelines presented in a table that repeats all criteria and expands also the criterion to convey attributes (EC 2018b, pp. 90-92; Zampori& Pant 2019, pp. 50-52, EC 2021a, pp. 37-38). This table adds practical information on how to apply the criteria, but also quite a bit of redundancy.

h) The recommendations of data sources for modelling country-specific residual grid mix vary between different versions of the PEF guidelines. The guidelines for PEFCR development refer to a data set produced by Sphera (formerly Thinkstep) and available at http://lcdn.thinkstep.com/Node/ (EC 2018b, p. 92). The draft PV Regulation points at data in a spreadsheet at https://ec.europa.eu/docsroom/documents/50174 (EC 2021a, p. 40), which in turn refers to the Thinkstep node for electricity data.

Other versions of the PEF guidelines (EC 2013, p. 31; Zampori & Pant 2019, p. 52; EC 2022a, p. 38), in contrast, do not point at a specific database or data provider. This reduces the robustness of the LCA results, which is important in the context of the Regulation.

i) When a production plant produces more than one product, all recent general PEF guidelines (EC 2018b, pp. 92-93; Zampori & Pant 2019, p. 53; EC 2021a, p. 39) state "*...the subdivision of electricity supply used among multiple products is based on a physical relationship (e.g. number of pieces or kg of product).*" This description of the allocation approach is problematic for two reasons. First, allocation based on the number or kg of products is not subdivision. Subdivision requires that input data is separately collected for the subprocesses in the production plant (ISO 2006, p. 14). This fact is accurately reflected in the draft PV Regulation (EC 2022a, p. 46).

Second, stating that this allocation is based on physical relationships invites misinterpretations, because it reads almost the same as allocation based on *underlying* physical relationships. The latter is what the international standard for LCA recommends when allocation cannot be avoided (ISO 2006, p. 14; ISO 2020). Allocation based of the number or kg of products does not reflect the causal relationship required for this approach. Instead, allocation based on the number or kg of products is a case of allocation based on other relationships, which can be used when no underlying physical relationship exists. The general PEF guidelines share this risk of misinterpretation with the draft PV Regulation (EC 2022a, p. 47).

j) The general PEF guidelines (EC 2021a, p. 39) state that when the same product "*...is produced in different locations or sold in different countries, the electricity mix shall reflect the ratios of production or the ratios of sales...*" This seems to mean that the user of a product cannot use country-specific electricity data for modelling the production of that piece of product even if the country of origin is known and well documented. This rule appears at odds with the general rule to model electricity as precisely as possible and using supplier-specific data when these are well documented (e.g., EC 2021a, p. 36). This contradiction was already indicated in the PEFCR guidelines (EC 2018b, p. 89 & p. 93), but is more explicit in the most general PEF guidelines. It is not included in the draft PV Regulation.

k) The general PEF guidelines requires that the consumption grid mix be used for modelling the supply of electricity to the use phase of products (EC 2018, p. 93; Zampori & Pant 2019, pp. 53-54; EC 2021a, p. 39). This rule is not part of the draft PV Regulation. It also seems to be at odds with the general rule to model electricity as precisely as possible. When the electricity supply in the use phase is unknown, it seems reasonable to use data that reflect this supply. Allowing for this would require a modification of the general PEF rules.

2.3 PV PEFCR

In the PEF pilot phase, a case study on five different PV modules was carried out to pave the way for the development of PEF Category Rules (PEFCR) for PV. In this case study, the electricity supply was modelled using data on specific technologies (natural gas combined heat and

power production, hydroelectric power)" when companies reported the purchase of such electricity (Stolz et al. 2016, p. 75). It seems no check was made regarding the validity of such claims.

When no claim on specific electricity sources was made, Stoltz et al. used data on the national consumption mix based on OECD statistics from the year 2011.

Two versions of the PEFCR for photovoltaics were then produced and published; however, of them are currently valid: Version 1.1. (Anon. 2019) was valid until the end of 2020, and Version 1.2 (Anon. 2020) was valid until the end of 2021. Both versions were also published before the most recent version of the general PEF guidelines (EC 2021a).

The text in the two PEFCR documents is identical when it comes to modelling electricity supply. They are also similar to the recent general rules for PEF and to the draft Ecodesign Regulation for PV. When the general PEF rules and the draft PV Regulation deviate, the PV PEFCR resembles the draft PV Regulation (EC 2022a) more than the most recent version of the general PEF guidelines (EC 2021a). This is consistent with the view that the methodology in the draft PV Regulation is influenced more by the PV PEFCR than by the most recent PEF methodology.

Relating to the list of items in the previous section, the PV PEFCR include the following:

Re a) The PEFCR are similar to the draft PV Regulation in that they do not include the short initial text on electricity data.

Re b) Like both compared documents, the PEFCR require that data for supplier-specific products be used when there is a 100% tracking system in the country (Anon. 2020, p. 72). Similar to the most recent PEF guidelines, the PEFCR do not explain what this means.

Re c) The PEFCR are similar to the draft PV Regulation in that they do not allow for the use of data representing the average consumption mix in the EU+EFTA area, or whatever region where the electricity is used.

Re d) The PEFCR include a text that is similar, but not identical, to the explanatory text in Section 4.4.2.1 of the general PEF guidelines. As stated above, the draft PV Regulation does not include such a text.

Re e) The PEFCR are similar to the draft PV Regulation in that they do not specify what is meant by "sourced and retired": On the other hand, they are similar to the most recent PEF guidelines in that they do not distinguish between supplier-specific electricity products and mixes (Anon. 2020, p. 73).

Re f) The PEFCR differ from both the draft PV Regulation and the most recent PEF guidelines by not including any conditions to meeting the criterion of a unique claim.

Re g) The PEFCR are similar to the draft PV Regulation in that they do not include a table that repeats and expands on the criteria for the use of supplier-specific data.

Re h) The PEFCR include the same recommendation as the guidelines for PEFCR development and the draft PV Regulation: to model country-specific residual electricity with a data set produced by Sphera (formerly Thinkstep).

Re i) The guidelines in the PEFCR for modelling production plants with more than one product is essentially the same as in the draft PV Regulation.

The approach for modelling co-production is in the PECRF complemented by a rule for modelling PV modules at a regional storage (Anon. 2020, p. 74). This rule is not included in the draft PV Regulation.

Re j) The rule in the general PEF guidelines (EC 2021a, p. 39) for how to model a product that is produced or sold in different countries is not part of the PEFCR. However, the PEFCR requirement for modelling of PV modules at regional storages resembles this rule in the general PEF guidelines.

Re k) The PEFCR are similar to the general PEF guidelines in that electricity in the use stage of PV units has to be modelled with input data representing the "consumption grid mix" (Anon. 2020, p.72). The draft EU Regulation on PV does not include such a requirement.

3. Electricity modelling in other frameworks

This chapter presents and discuss the rules for modelling of electricity production in several other frameworks for LCA or carbon-footprint calculations. These include:

- frameworks that are closely related to PEF:
  - the ILCD Handbook, which preceded PEF, and
  - Environmental Product Declarations, which shares important applications and the structure of detailed rules for different product categories;
- frameworks that are otherwise important to industry and policy-makers in Sweden and the EU:
  - the Greenhouse Gas Protocol,
  - international and European standards,
  - the EU Renewable Energy Directive (RED), and
  - the Ecoinvent database;
- a framework on LCA of photovoltaics:
  - guidelines of the International Energy Agency; and
- other frameworks that are easily accessible to us:
  - the UK Transport Fuels Obligation,
  - the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA),
  - the US Fuel Standard, and
  - the California Fuel Standard.

3.1 ILCD Handbook

The predecessor to the Environmental Footprint initiative was the International Reference Life Cycle Data System (ILCD) developed by the EU Joint Research Center (JRC) in Ispra on behalf of the European Commission. The ILCD initiative had an emphasis on developing a database with consistent LCA data. For this purpose, but also to contribute to more consistent LCA methods overall, JRC developed instructions on how to perform LCA calculations in a handbook (EC 2010). This handbook distinguishes between attributional and consequential LCA. It also distinguishes between three different decision contexts:

A. "Micro-level decision support": Life cycle based decision support typically for questions related to specific products,
B. "Meso/macro-level decision support": Life cycle based decision support at a strategic level, and
C. "Accounting": Purely descriptive documentation of the system's life cycle.

In attributional LCA (ALCA) in general, the ILCD Handbook states that you should ideally use producer-specific LCI data where specific producers in the background system provide a good or service. Average data is often used where the goods and services stem from a wide mix of producers or technologies. For electricity consumed by a consumer product in a country, the consumption mix in that country would be used. However, this change from specific to average or generic data is only done for practicality reasons (EC 2010, p. 71).

If an ALCA is done to support decisions – context A or B above – producer-specific should not be used if their technology is constrained, which it is for hydropower in many countries (EC 2010, p. 125). In such cases, the ILCD Handbook states that data reflecting the consumption mix are more adequate.

The ILCD Handbook (EC 2010, pp. 128-129) claims that the average typically relates to a market and points out that this market can be equal, smaller or larger than a country. Markets can be distinguished not only geographically, but also depend on when the electricity is used, and can differ between customer-segments. The ILCD Handbook suggests that the market can be defined such that there is no significant trade over the borders of the market. Otherwise, the trade should be accounted for when calculating the consumption mix.

In a consequential LCA (CLCA), the ILCD Handbook states that data should reflect how the production system is affected by a change. However, if the LCA is done to support a micro-level decision, the handbook states that this effect is best modelled using the consumption average, i.e., the same data that are used for ALCA (EC 2010, pp. 169-173 & p. 82). This is different from the conventional wisdom that small-scale changes are best modelled using marginal data; these by definition reflect how the electricity supply is affected by a small change in the electricity demand (e.g., Ekvall et al. 2016).

To conclude, the ILCD Handbook and the PEF framework indicate that specific input data is typically the ideal data, and that average data can be used as a fallback option. However, the ILCD Handbook is different in that it:

- distinguishes between attributional and consequential LCA,
- does not include requirements for proof that specific data can be used,
- states that specific data should not be used for constrained technologies, if the LCA is to support decisions, and
- indicates that averages should be calculated over a market, which can be larger or smaller than a country, and vary depending on when the electricity is used.

3.2 EPD

An Environmental Product Declaration (EPD) is an LCA-marketing format primarily intended to facilitate business-to-business transactions. Such product declarations are also an important application for PEF. It requires detailed calculation rules to make EPDs for competing products comparable. Such detailed rules cannot be given in a general framework, and EPD systems, just like the PEF framework, include specific rules for different product categories. Hence, the EPD and PEF frameworks have overlapping applications and a

similar structure that include a set of general rules and complementary Product Category Rules.

The EPD framework was established long before PEF. EPD International, the first and longest operational EPD programme, was originally founded in 1998 as the Swedish EPD System. The 4th version of the general rules of EPD international was recently published (EPD International 2021).

The general calculation rules of EPD International (2021, p. 64) states that data on the electricity supply shall be chosen with the following ranking order:

1. Specific electricity mix as generated, or purchased from an electricity supplier, demonstrated by a Guarantee of Origin (GO) or similar as provided by the electricity supplier.
2. Residual electricity mix of the electricity supplier on the market.
3. Residual electricity mix on the market.
4. Electricity consumption mix on the market.

The framework defines residual electricity mix as the mix when all contract-specific electricity that has been sold to other customers has been subtracted from the total consumption mix. The framework also states that the market is not necessarily national. On the contrary, using data for a national system requires that it can be shown to correspond to a market.

Hence, EPD International agrees with the PEF rules in that specific data should be used if possible and that average data are a fallback option. It is different in that it:

- emphasizes GOs as a contractual instrument, where PEF emphasizes tracking,
- allows for the use of data on the consumption mix and not just the residual mix, and
- recognizes that the average should be made over a market rather than a country.

Other EPD programmes have different calculation rules. The Norwegian EPD programme, for example, does not specify what electricity data should be used. However, it states that data on national electricity production is available in the Ecoinvent database (epd-norge, p. 28). This indicates that national average data is at least an uncontroversial option in this EPD programme.

3.3 Greenhouse Gas Protocol

The Greenhouse Gas (GHG) Protocol is an initiative of the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). They have developed a series of standards aiming to establish global standardized frameworks to measure and manage greenhouse gas (GHG) emissions from private and public sector operations, value chains and mitigation actions.

The GHG Protocol standard for products states (WRI/WBCSD 2011, p. 52):

"*When an electricity supplier can deliver a supplier-specific emission factor and these emissions are excluded from the regional emission factor, the supplier's electricity data should be used. Otherwise, companies should use a regional average emission factor for electricity to avoid double counting.*"

The standard on accounting for organizations recommends that "*companies obtain source/supplier specific emission factors for the electricity purchased. If these are not available, regional or grid emission factors should be used*" (WRI/WBCSD 2015a, p. 87):

The standard on accounting for organizations has an amendment focusing on Scope 2, i.e., on how to model the energy supply to a company. This amendment distinguishes between location-based and market-based methods (WRI/WBCSD 2015b, p. 26). Location-based methods model the energy supply with the use of average data for a geographical area, which can have local, subnational, or national boundaries. Market-based methods model the energy supply with supplier- or technology-specific data based on contractual instruments, or with residual data if the electricity used is not connected to a valid contractual instrument.

If the electricity is used in an area with contractual instruments, companies must report their Scope 2 GHG emissions both with the location-based and with the market-based approach (WRI/WBCSD 2015b, p.8). This seems to contradict at least the GHG Protocol standard for products, where location-based data are used only when market-based data are unavailable (see above).

Contractual instruments include certificates, direct contracts (such as Power Purchase Agreements), certificates, or supplier-specific information (e.g., green energy tariffs) (WRI/WBCSD 2015b, p. 48). To be valid in the context of the GHG Protocol, they must meet the Scope 2 Quality Criteria (ibid., p. 60): "

1. *Convey the direct GHG emission rate attribute associated with the unit of electricity produced.*
2. *Be the only instruments that carry the GHG emission rate attribute claim associated with that quantity of electricity generation.*
3. *Be tracked and redeemed, retired, or canceled by or on behalf of the reporting entity.*
4. *Be issued and redeemed as close as possible to the period of energy consumption to which the instrument is applied.*
5. *Be sourced from the same market in which the reporting entity's electricity-consuming operations are located and to which the instrument is applied.*

In addition, utility-specific emission factors shall:

6. *Be calculated based on delivered electricity, incorporating certificates sourced and retired on behalf of its customers. Electricity from renewable facilities for which the attributes have been sold off (via contracts or certificates) shall be characterized as having the GHG attributes of the residual mix in the utility or supplier-specific emission factor.*

In addition, companies purchasing electricity directly from generators or consuming on-site generation shall:

7. *Ensure all contractual instruments conveying*

emissions claims be transferred to the reporting entity only. No other instruments that convey this claim to another end user shall be issued for the contracted electricity. The electricity from the facility shall not carry the GHG emission rate claim for use by a utility, for example, for the purpose of delivery and use claims.

Finally, to use any contractual instrument in the market-based method requires that:

8. *An adjusted, residual mix characterizing the GHG intensity of unclaimed or publicly shared electricity shall be made available for consumer Scope 2 calculations, or its absence shall be disclosed by the reporting entity.*"

These conditions are similar in content and wording to the conditions for using technology- or supplier-specific data in the PEF framework. However, the GHG Protocol that includes these criteria is valid for organizations and not for products. It also states that location-based and market-based results should both be calculated and presented, when the electricity is used in areas where valid contractual instruments exist.

The GHG Protocol standard on products, on the other hand, agrees with the PEF rules in that specific data should be used if possible and that average data are a fallback option. We have not found Scope 2 Quality Criteria for product assessments, but it seems reasonable to apply the eight criteria listed above also in this context.

Note that the market-based approach in the GHG Protocol is quite different from using the residual or average data in a market, as recommended by EPD International. The location-based approach in the GHG Protocol does not allow for geographical areas that include more than one country, such as Scandinavia or the Nordpool area. Otherwise, the geographical area in the location-based approach could be an electricity market and, hence, consistent with EPD International.

3.4 ISO standards

Several global and European standards relate to life-cycle calculations: LCA in general, LCA of bio-based plastics, Life cycle inventory analysis (LCI) of steel products, EPD in general, EPD in the construction sector, carbon footprint, water footprint, etc. Here we cover only two of these standards. One is ISO 14044, the international standard that includes calculation rules for LCA in general. The other is ISO 14067. This is a standard for carbon footprint and not for LCA. However, several actors we talked to during this project referred to this specific standard.

ISO 14044

The International standard for LCA, ISO 14044, says little about how to model the electricity supply. It just states that account shall be taken of the electricity mix (ISO 2006, p. 13). This indicates that the standard stipulates what the GHG Protocol calls a location-based approach.

This interpretation is not contradicted but rather strengthened by the ISO Technical Report 14049, which gives illustrative examples on how to apply ISO 14044 in the goal & scope definition and the LCI. When discussing representativeness (ISO 2012, p. 42) and uncertainty (ibid., p. 44), this report mentions average data only.

ISO 14067

The international standard for carbon footprints of products, ISO 14067, has ISO 14044:2006 as a normative reference. This means everything in this version of ISO 14044 is valid also in ISO 14067. However, while ISO 14044 seems to stipulate a location-based approach, ISO 14067 includes market-based rules for the modelling of electricity production. These rules resemble the PEF rules in the sense that they require specific data to be used whenever there is a basis for this, and that the basis can be a guarantee through a contractual instrument (ISO 2018, p.36). The standard still diverges from the PEF methodology on several points (ibid.):

- If the electricity is produced at a power plant with a dedicated transmission line to the site where it is used, ISO 14067 states that data on this production shall be used in the calculations, as long as no contractual instruments for this power production have been sold to a third party. No contractual instrument between the electricity producer and the electricity consumer is required in this case.
- ISO 14067 does not distinguish between supplier-specific products and supplier-specific mixes, but only mentions supplier-specific electricity products.
- ISO 14067 requires that the contractual instrument concerns electricity produced in the country where it is used or in the same, grid-connected market. An exception is made for electricity that is used in small island developing states. However, this rule means a GO for Icelandic electricity production cannot be used on the European continent.

3.5 EU Renewable Energy Directive

The Renewable Energy Directive (RED) was developed by the EU to promote the use of energy from renewable sources. It was originally established in the year 2009. A revised version was published in 2018 (EC 2018c). A new revision has been proposed by the Commission (EC 2021b).

The RED includes a methodology for calculating the climate impacts of fuels. In this methodology, electricity bought from the grid should be modelled to reflect the average emissions from "*the production and distribution of electricity in a defined region*" (EC 2018c, p. 154). The only exception from this rule is when the electricity is produced at a power plant that is not connected to the grid.

The RED does not specify how the region should be defined. Tracking, certificates, or GOs are not mentioned in its carbon-footprint methodology.

In summary, the carbon-footprint methodology in the RED differs clearly from the PEF framework in that:

- average and not specific data are the first option, and
- the average is calculated over a defined region and not necessarily for each country.

However, the RED includes another set of rules for calculating the renewable share of electricity used in road and rail vehicles or for producing fuel of non-biological origin (EC 2018c, pp. 127-128). Here, "*...the average share of electricity from renewable sources in the country of production, as measured two years before the year in question, shall be used to determine the share of renewable energy.*" Although not explicitly stated, this indicates that the average is calculated based on the national *production* mix, measured two years before the year for which the renewable share of energy is reported.

An exception from the use of average data is given when the electricity used for producing non-biological fuel is produced in a directly connected power plant that was built after or at the same time as the production of non-biological fuel started. Another exception from the use of average data is given when it can be uniquely demonstrated that electricity taken from the grid is produced from renewable sources.

The RED states that GOs should be used by energy suppliers for demonstrating to final customers the share renewable sources in the energy supplier's energy mix (EC 2018c, pp. 117-119). A GO can be issued for each MWh produced. It is valid for 12 month after the electricity has been produced and can be transferred between countries. This means it is only loosely connected in time and space to the actual electricity production.

The current RED (EC 2018c, p. 128) states that the European Commission shall develop a framework to ensure that the expected increase in electricity used in the transport sector is met with an increase in the production of renewable energy. It is also given the task to develop methods for measuring such additionality. However, this part of the RED is deleted in the proposed revision of the Directive (EC 2021c, p. 44).

In summary, the approach for calculating the share of renewable electricity in the RED is similar to the PEF framework, but with slight variations:

- RED emphasizes GOs and does not mention contractual instruments in general, and
- the average seems to be a production mix and not a consumption mix.

A supplement to RED is being developed that includes calculation rules for the carbon footprint of renewable transport fuels produced from non-biological sources and recycled carbon (EC 2022b). Such fuels are often produced with electricity as the main energy input. This means that the modelling of electricity supply is particularly important for the carbon footprint.

The draft Supplement refers to the approach used in the RED for calculating the renewable share of electricity. However, it includes does additional exceptions from the use of average data (EC 2022b, p. 3). The carbon footprint of electricity from the grid is set to zero if this electricity is used only when the marginal electricity supply is renewable or fossil free. The draft Supplement consider such a claim to be credible, if the number of full load hours of the electricity use "*is equal or lower than the number of hours in which the marginal price of electricity was set by installations producing renewable electricity or nuclear power plants in the preceding calendar year for which reliable data are available.*"

In addition, "*the greenhouse gas emissions value of the marginal unit generating electricity at the time of the production of the renewable liquid and gaseous transport fuels of non-biological origin in the bidding zone may be used if this information is publicly available from a reliable source.*"

In summary, the carbon-footprint methodology in the RED supplement for fuels produced from non-biological sources and recycled carbon is similar to PEF, but differs in that:

- it emphasizes GOs and does not mention contractual instruments in general,
- it does not specify over what region average data should be calculated, nor if it should be a production mix or a a consumption mix, and
- data on the marginal technology, identified by the electricity price, can be used instead of average data.

3.6 Ecoinvent

The Ecoinvent database is the most important commercial database in Europe and possibly in the world. It includes electricity data that reflect the production average for many countries. In the recent Version 3.9, the residual average as presented by the Association of Issuing Bodies (AIB) were added for the countries that are AIB members (Ecoinvent 2023).

Since Version 3.4, the consequential part of Ecoinvent also includes a set of marginal data for the electricity supply in 40 countries, representing 77% of the global electricity production. The marginal electricity data are calculated based on public plans or projections of the future electricity production in each of these countries. Each unconstrained technology for electricity production is included in the marginal mix to the extent that it contributes to increasing electricity production in the country (Vandepaer et al. 2019).

3.7 IEA Guidelines for LCA of PV

The International Energy Agency (IEA) developed and published guidelines on LCAs on photovoltaic (PV) electricity generation systems to help improving their consistency, balance, quality, and credibility (Frischknecht et al. 2016). These guidelines include advice on how to model electricity supply in four types of PV LCA (ibid., pp. 5-8):

A. Reporting environmental impacts of PV currently installed in a utility's network, comparisons of different PV systems, or of electricity-generating technologies. This is a retrospective and attributional LCA. In this case,

current average data for a region or country (such as Europe, the US, China, Korea, or Japan) is the default option. However, data for a specific electricity supplier or a specific country within Europe (e.g., Norway) can also be used.

B. Choice of a PV electricity supplier, or switch of raw material or energy suppliers. This is a short-term prospective study of the kind that Frischknecht et al. call decisional LCA. In this case, marginal data should be used. These should be developed based on scenarios for the national or regional electricity system, with an approach demonstrated by Frischknecht & Stucki (2010).

C. Future energy supply situation: comparison of future PV systems or of future electricity-generating technologies. This is a long-term prospective attributional type of LCA. The electricity supply should be modelled using data that represent the future average grid mix in the country or region where the electricity is used. These data should account for the fact that the environmental performance of different electricity-supply technologies can improve over time.

D. Large-scale, long-term energy supply transition: large scale-up of PV in electricity grids of nations and regions. This is what Frischknecht et al. call consequential LCA. The consequences for the electricity supply, and the economy as a whole, should be estimated using economic equilibrium models, back-casting, or other tools.

The purpose of the calculation rules EU Ecodesign Regulation for PV is to ensure that solar cells produced in the near future to not cause too much GHG emissions. This could be considered a Case A or Case B situation. Here the IEA Guidelines differ from the PEF Guidelines in that they:

- do not include strict conditions for when to use specific data in Case A, and
- consider marginal data more appropriate than average data in Case B.

The purpose of PEF in general is much broader: it can be used as basis for strategic decisions on energy policy, etc. and, hence, be applied in any of the four situations described by the IEA. An important difference between the IEA and PEF Guidelines in this broad perspective is that IEA states that the method for modelling electricity supply depends on the type of LCA.

3.8 UK Transport Fuel Obligation

The UK Renewable Transport Fuel Obligation (RTFO) scheme was developed by the UK government under the EU's Renewable Energy Directive to support the development of renewable transport fuels and reduce emissions. The scheme includes rules for calculating the GHG emissions of biofuels, which in general are quite similar to the calculation rules in the EU Renewable Energy Directive.

For electricity not produced within the fuel production plant, the UK RTFO stipulates that average data for a defined region must be used. The only exception from this rule is when the electricity is produced at a power plant that is not connected to the grid (UKDfT 2022, p. 85).

3.9 CORSIA

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is an emission mitigation instrument to address the climate impact of aviation. It has been developed by the UN agency International Civil Aviation Organization (ICAO). The CORSIA initiative aims to offsetting the amount of international aviation CO2 emissions that cannot be reduced through aircraft technologies, operational improvements, and sustainable aviation fuels.

CORSIA entered a pilot phase in 2021. During this phase, ICAO updated a series of guidance documents. These include, but are not limited to, default values of the life cycle emissions from a broad range of fuels and production pathways (ICAO 2022a), the methodology used to calculate the default values (ICAO 2022b), and a brief description of the methods that can be used for calculating actual life cycle emissions if these are lower than the default values (ICAO 2022c).

The CORSIA framework does not discuss in detail how the electricity supply should be modelled. However, when the calculation rules talk about the electricity supply, they mention the generation mix for grid electricity (ICAO 2022b, p. 26), or the average carbon intensity of grid electricity in the region where the electricity is used (ICAO 2022b, p. 41; ICAO 2022c, p. 17 & p.19). This indicates that regional average data is at least an uncontroversial option in the CORSIA calculations.

3.10 US Renewable Fuel Standard

The Renewable Fuel Standard (RFS) program was originally established in the year 2005 and expanded in 2007. It is a national policy in the US that sets targets for the use of renewable fuels for transports. To qualify as renewable within the RFS, a fuel must, among other things, have life cycle GHG emissions that are significantly lower than the emissions of a 2005 petroleum baseline.

The US Environmental Protection Agency (EPA) carries through life cycle calculations to investigate what fuel pathways meet the GHG requirements. The methodology for these calculations were developed in an ambitious process that included hundreds of meetings with experts from various governmental agencies, academia, industry, and non-profit organizations; a 120-day open consultation period; and an external review conducted by experts on LCA, economic modelling, remote sensing imagery, biofuel technologies, soil science, agricultural economics, and climate science (USEPA 2010, pp. 393-394). The resulting methodology applies the GREET (Greenhouse gases, Regulated Emissions, and Energy use in

Technologies) model developed at Argonne National Laboratory.

Electricity supply is generally modelled with data representing the grid average electricity in the US (USEPA 2022). However, the production of ethanol from sugarcanes is modelled both with average data and with data reflecting the marginal electricity supply (USEPA 2020).

3.11 California Fuel Standard

The California Low Carbon Fuel Standard (LCFS) was originally adopted by the California Air Resources Board (CARB) in 2009. It was re-adopted in 2015 and amended in 2018. The amended version stipulates a gradual decline of the life-cycle climate impact of energy carriers used for transportation in California. The climate impact of renewable fuels is calculated with the model CA-GREET3.0 (CARB 2018). This is a California-specific version of the GREET model.

The electricity supply is modelled with data representing the regional or national grid average (CARB 2018, pp. 22-26; CARB 2022, p. 20).

4. Interview responses

As input to the recommendations from the project, we have interviewed representatives for different organizations and professions to understand their view of what needs to be clarified in the draft PV regulation (EC 2022) and to suggest changes in the text. We have also received some comments on the EU methodology for Product Environmental Footprints (EC 2021a). The interviewees were:

Eva Lotta Lindholm, administrator Product unit, and Eva Nordlander, administrator Renewable energy instruments, both at the Swedish Energy Agency;

Björn Spak, administrator at the Swedish Environmental Protection Agency (Swedish EPA), Swedish representative in the Technical Advisory Board of the Product Environmental Footprint steering organization at EU level;

Torun Hammar, LCA researcher and practitioner, and Michiel van Noord, researcher and engaged in sustainable applications of solar PV, both at RISE;

Ellen Riise, senior environmental specialist at Essity.

We have also had e-mail conversations with The Swedish Energy Markets Inspectorate (Bianca Kasemi) and (via Eva Nordlander at the Swedish Energy Agency) Grexel (Markus Klimscheffskij)[1].

Below, we describe the overall findings from these interviews, starting with some perspectives that are relevant to the draft PV Regulation but not explicitly needs for clarification.

4.1 Opinions on the PEF methodology

The representative from the Swedish EPA stresses that PEF rules (EC 2021a) should be completely mirrored in the final PV Regulation since they are intended for application to any product category. Furthermore, they are the most recent ones.

A couple of interviewees recommend the adoption of a perspective where electricity is considered as any other product.

The representative from Essity anticipates that carbon footprint methodology for a product will most likely have to comply with ISO 14067 (ISO 2018) in order to be internationally accepted; the development of ISO14067 required considerable efforts and is now widely referred to in different frameworks. This standard means that life cycle data from a supplier specific contractual instrument shall be used when the electricity product is produced within the country, or within the market boundaries where consumption occurs if the grid is interconnected. This is according to Paragraph 6.4.9.4.4 Electricity from the grid in ISO 14067 (ISO 2018, p. 24; see also Section 3.4 above):

"Life cycle data from a supplier-specific electricity product shall be used when the supplier is able to guarantee through a contractual instrument that the electricity product:

- *conveys the information associated with the unit of electricity delivered together with the characteristics of the generator;*
- *is assured with a unique claim (see 5.12);*
- *is tracked and redeemed, retired or cancelled by or on behalf of the reporting entity*
- *is as close as possible to the period to which the contractual instrument is applied and comprises a corresponding timespan;*
- *is produced within the country, or within the market boundaries where consumption occurs if the grid is interconnected."*

The representatives from Essity and the Swedish EPA believe that ISO 14067 give general support for a market-based approach (where supplier- or technology-specific data are used, or residual data if the electricity used is not connected to a valid contractual instrument). Otherwise, only location-based electricity should be used.

As a general position from all interviewees, high climate ambitions substantiated through *additional* investments and/or procurement in renewable energy facilities must be rewarded and encouraged wherever they take place.

The representative from Grexel noted that the Internal Energy Market directive 2009/72/EC, Art.3(9) clearly advocates for supplier mixes whereas in the recent update 2019/944/EC, Annex 1(5) clearly advocates for product mixes. Thus, prioritizing supplier specific electricity product before supplier-specific total electricity mix in the PEF rules (EC 2021a) seems consistent with this update. However, since the second hierarchy level is supplier *total* mix (and not the "residual product" of the supplier), there is a risk of double counting within the supplier's own portfolio. So, one supplier should always disclose I) both of these values (product of the customer and total supplier mix) or II) just one of them, but in the latter case it should be the same approach for all customers. National legislation should provide clarity here, but it is often lacking in detail. This is backed by the best practice recommendation 39b from the Reliable Disclosure Systems for Europe project – phase II (AIB 2022b), further on referred to as RE-DISS II.[2] The

1 Currently, Grexel calculates the residual mix for e.g. the Nordic countries, applying the recommendations from RE-DISS, a European project/cooperation for recommendations for the implementation of guarantees of origin and other tracking systems for disclosure in the electricity sector in Europe. The residual mix is made publically available by The Swedish Energy Markets Inspectorate.

2 These recommendations are intended to provide guidance to competent bodies and legislators which are implementing and managing systems of

representative from Grexel concludes that this is in line with the tracking hierarchy Table 6.3 in (WRI/WBCSD 2015b).

Contractual instruments

One of the main concerns raised by several interviewees is that the PEF methodology allows for producers to claim they use a renewable "supplier specific electricity product" without contributing to creating additional renewable power production. Producers in countries where the grid mix has a large climate impact can benefit greatly from buying guarantees of origin (GOs) in other countries. Norwegian GOs are, for example, exported to other European countries, dominated by fossil-based power production. However, according to Grexel, it is less likely, but not prohibited, that this would occur to non-EU countries since such ex-domain cancellation[3] is allowed by only a few EECS®[4] domains[5]. It is up to every EECS® domain to decide whether they allow ex-domain cancellations and to which countries. As an example, Sweden allows ex-domain cancellation to UK (until April 2023). Statistics on cancellations made elsewhere for customers in Sweden are incomplete, since not all members of AIB report this, and when they do, this is only done for EECS GOs, not for, e.g., national GOs.

According to Grexel GOs are most likely a reliable instrument, since they are governed by EECS and European directives, while tracking systems outside EU are probably less robust.

4.2 Clarity of the text

Tracking system

In the draft PV regulation, as well as in the PEF rules, the concept "tracking system"[6] is introduced. In the draft PV regulation, annex IV, a tracking system is defined as the "system applying the process of assigning electricity generation attributes to electricity consumption", but, as highlighted by one interviewee, it does not say whether this refers to the system in a country or to the entire system within the cooperation of AIB.

The interviewees find the requirement regarding the supplier-specific electricity product/mix, where certificates must stem from a system with less than 95% of untracked production, too low and that it is either a typo or must be rephrased.

From an LCA practitioner perspective, the application of the criterium is also associated with challenges:

How to get a verification of a 100 % tracking system from, e.g., non-EU-countries? Is it always a *country* that is responsible for a tracking system? How to calculate the supplier specific total electricity mix? Is this based on information from the electricity supplier? If you are not able to account for the advantages of good electricity is there any point in buying it?

Modelling country-specific residual grid mix, consumption mix

A couple of the interviewees raised the question of what is meant by consumption mix, a question that indicates risks for misinterpretations and potentially double counting. In addition, quality assured data must be made available to enable these calculations. Furthermore, it was questioned whether it is always the *country* specific electricity mix that is the most correct choice. For example, Ecoinvent has data from different Chinese provinces.

The draft PV regulation, as well as the PEF rules, uses the term residual mix. As was mentioned by Grexel, the RE-DISS II Best Practice recommendations (AIB 2022b) could be referred to:

"All countries should provide a Residual Mix as a default set of data for disclosure of energy volumes for which no attributes are available based on cancelled GOs or based on other Reliable Tracking Systems."

Thus, the residual mix represents all "untracked electricity attributes" and it is applied to such electricity for which no claims are made with GOs on the origin of the energy; untracked attributes from the pool which is applied to untracked/unclaimed consumption

Regarding the Swedish use of Nordic or Scandinavian residual mix and the use of national residual mix in the other Nordic countries, Grexel points out that a regional approach can only be recommended if there is a consensus for using it among all countries in the region. That is not the case, and therefore it would be recommended to use the Swedish national mix to avoid possible double counting. This is also described in RE-DISS II Best Practice Recommendation (AIB 2022b). The representative from The Swedish Energy Markets Inspectorate explained that when the recommendations were developed, several other projects were running in parallel in the Nordic countries, aiming at harmonization of the Nordic end customer market, and that the inspectorate at that time found the Nordic residual mix to be the better option. However, since then, the

Guarantees of Origin (GO) for electricity and other tracking systems for purposes of electricity disclosure in Europe.

3 Ex-Domain Cancellations are GO cancellations that take place in one country, for use of the GO in another. These are not supported between AIB (Association of Issuing Bodies) member countries, which always transfer GOs via the AIB hub for cancellation in the destination country, where this is technically possible. (Ex-domain cancellation is therefore not a transfer of GOs.) Best Practice Recommendations for the implementation of Guarantees of Origin and other tracking systems for disclosure in the electricity sector in Europe (AIB 2022b) admits that "the implications of a coexistence of electronic GO transfers within EECS and outside of EECS are not fully clear yet and require further assessments." (AIB 2022d)

4 European Energy Certificate System. Certificates, e.g. GO, are created, change owners and are eventually made untransferable under a carefully developed and managed control infrastructure, the EECS® Rules, as interpreted by each country or region according to its "Domain Protocol". The adequacy of this interpretation is assured by the other AIB members as a condition of membership. The EECS Rules provided the foundation of the CEN standard EN 16325 (AIB 2022).

5 Country or region providing a domain protocol, interpreting the EECS rules (AIB 2022c).

6 Also ISO 14067 uses the concept tracking system but does not define it.

development has not continued as expected, and thus, the other Nordic countries still use the national residual mixes. The Swedish Energy Markets Inspectorate awaits the updated European standard on GOs related to energy (SS-EN 16325:2013+A1:2015) and will then assess the need for updates of their regulation.

As an observation, it should be mentioned that the Excel file from Grexel, provided by The Swedish Energy Markets Inspectorate, listing the residual mixes in the Nordic countries (except Iceland) and in Norden (except Iceland) as a whole [7], the term "untracked" does not signify the residual mix as such, only the share of the total electricity use that has no GOs.

The interviewee from Grexel made valuable comments on the PEF rules (EC 2021a). The introduction to Subsection 4.4.2.1 (ibid., p. 36) states that:

" *The following section introduces two types of electricity mixes: (i) the consumption grid mix which reflects the total electricity mix transferred over a defined grid including green claimed or tracked electricity, and (ii) the residual grid mix, consumption mix (also named residual consumption mix), which characterizes the unclaimed, untracked or publicly shared electricity only."*

This categorization is analogous to the distinction between location-based and market-based data in GHG Protocol (WRI/WBCSD (2015b). The sentence under ii) suggests that the residual mix could be three different things: the unclaimed, the untracked or the publicly shared electricity. This might introduce ambiguities. The representative from Grexel believes that residual grid mix is best described by the word "untracked".

With regards to Criterion 2 (Unique Claims) to ensure contractual instruments from suppliers in the PEF Guidance, the representative from Grexel identified the following two needs for clarifications:

[...] Be tracked and redeemed, retired, or cancelled by or on behalf of the company [...].

It should be added a "selling the electricity" after "company".

[...] 1. Is the plant located in a country with no tracking system? Information provided by the 'Association of issuing bodies' should be used. [...]

Data from the Association of Issuing Bodies (AIB) cannot be used in this case. AIB presents data on countries that are AIB members and have tracking systems. However, tracking systems can exist also in other countries.

Furthermore, the authors of the report would like to replace "plant located" with "electricity used".

7 "Residualmix" at Energimarknadsinspektionens hemsida

5. Discussion

5.1 Updating the PV Regulation

It is clear from Section 2.3 that the draft PV Regulation (EC 2022a) resembles the PV PEFCR (Anon. 2020) more than the most current general PEF guidelines (EC 2021a). However, in some cases, the draft Regulation deviates from the PEFCR to the advantage of the general guidelines. For example, the draft Regulation includes conditions for certificates used to demonstrate the uniqueness of claims associated with a specific electricity source. These are a more concise version of the conditions in the general guidelines, and they are not included in the PEFCR.

When the draft Regulation deviates from the general PEF guidelines, they differ not only compared to the most recent version of the general guidelines but often also compared to previous versions of these guidelines (EC 2018b and/or Zampori & Pant 2019). In some cases, the deviation is just the exclusion of explanatory text. In other cases, the authors of the draft Regulation appear to have made deliberate deviations with an aim to improve the methodology. For example, the PEFCR and the draft Regulation both use the term subdivision in a more correct manner than the general guidelines. The draft PV Regulation excludes the rule to model products produced in multiple countries by the use of a weighted average over these countries. It also excludes the rule to model electricity supplied in the use phase with data that represent the grid average.

It seems there is a single case only, where the draft PV Regulation missed a deliberate substantial update of the general PEF methodology. The most recent version of the general PEF guidelines allows, as a last resort, for the use of data representing the average consumption mix in the EU+EFTA area, or whatever region where the electricity is used (EC 2021a, p. 36). This option is not available in the draft PV Regulation (EC 2022a, p. 48). Allowing for the use of continental average data or similar risks reducing the robustness of the PEF results. However, if it is allowed only as a last option when national data cannot be obtained, the loss of robustness is probably small and the advantage of making PEF calculations possible is probably more important.

5.2 Clarity and interpretation

Tracking and tracking systems

The concepts of tracking and tracking systems is important both in the draft PV Regulation (EC 2022a) and in the most current general PEF guidelines (EC 2021a). A tracking system must be in place for supplier-specific data to be used. In countries with a 100% tracking system in place, supplier-specific data should always be used. For this reason, the concepts of tracking, tracking system, and 100% tracking system must be clearly understood by the PEF practitioners performing the calculations.

The documents define electricity tracking as the process of assigning electricity generation attributes to electricity consumption (EC 2021a, p. 9) and a tracking system as a system that assigns electricity generation attributes to electricity consumption (EC 2022a, p. 35). What this means is not necessarily clear to the average PEF practitioner. The general PEF rules (EC 2021a, p. 9 & p. 38) refer to Fazio et al. (2020) and state that information from the Association of Issuing Bodies (AIB 2022a) should be used to establish if a national tracking system is in place. Fazio et al. (2020) does not seem to explain the concepts further, but a more precise reference to AIB (2022b) could be useful, both in the PEF rules and in the PV Regulation, to make the concepts a bit clearer.

The main limitation of AIB (2022a-d) is that it covers a number of European countries only. The PEF rules give little guidance on how to decide if countries outside Europe have a tracking system, if this tracking system is valid, and if it covers 100% of the electricity. Here, the draft PV Regulation at least includes criteria for valid tracking systems (EC 2022a, p. 49):

- at least 5% of the electricity must be tracked;
- certificates must be based on objective, non-discriminatory and transparent criteria;
- certificates can be valid no longer than 12 months after the electricity is produced;
- the mechanisms for issuance, transfer and cancellation of certificates must be accurate, reliable and fraud-resistant; and
- the issuance of certificates, as well as the supervision of their transfer and cancellation of certificates, are made by a body that:
  1) is independent from energy production, trade and supply activities, and of commercial interest of electricity customers using the certificates;
  2) is governed by transparent rules and procedures laid down by law; and
  3) whose decisions may be challenged and reviewed in the context of proceedings before an independent judiciary.

The problem with these criteria is that it is a cumbersome process to check whether they are met. It is likely to require language skills and legal expertise that cannot be expected from the average PEF practitioner. The process also depends on subjective judgements regarding, for example, the transparency of certificate criteria and the fraud-resistance of the tracking system. A global list of countries with valid tracking systems would make the PEF methodology more applicable and robust. This list could be published together with information on the level of tracking in the valid systems, and with data on the residual mix.

For supplier-specific data to be used, the draft PV Regulation (EC 2022, p. 49) and the most current general

PEF guidelines (EC 2021a, p. 38) both require that at least 5% of the electricity in the country is tracked. The PEF guidelines somewhat misleadingly describe the case when less than 5% is tracked as the case "where consumption is partly untracked (>95%)". It would be clearer to state "...where the share of tracked electricity is very small (<5%)". Alternatively, the text can be a typo, as suggested by our interviewees, and should simply be corrected.

Other aspects

As stated by the representative from Grexel (see Section 4.1), there is a risk of double-counting data on supplier-specific products and mixes, if an electricity supplier offers contractual instruments for both a specific electricity product and for the supplier mix. This risk can be alleviated if the calculation rules stipulates that the supplier mix should be the residual supplier mix, i.e., the part of the supplier mix that is not separately sold as a specific electricity product.

Subsection 4.4.2.5 in the general PEF guidelines (EC 2021a, p. 39) states that when the same product "*...is produced in different locations or sold in different countries, the electricity mix shall reflect the ratios of production or the ratios of sales...*" This rule makes sense when applied to PEF calculations on the full production volume of the product, for example all sheet steel produced in the world. It also makes sense when in a PEF where of a product where the origin or use is unknown. However, when applied on a specific part of the production volume, for example the sheet steel used to produce a Volvo, and the steel supplier is known, the rule is at odds with the general rule to model electricity as precisely as possible and using supplier-specific data when these are well documented (e.g., EC 2021a, p. 36). A small amendment can be made to Subsection 4.4.2.5 to avoid this contradiction.

Subsection 4.4.2.6 in the general PEF guidelines (EC 2021a, p. 39) deals with modelling of electricity in the use phase of a product. It requires the use of electricity data representing the consumption grid mix for the use phase. This contradicts the general rule that specific data should be used when valid contractual instruments and tracking systems are in place. There is no apparent reason to treat electricity in the use phase differently from electricity in the production or waste-management phases. Hence, there seems to be no need for a subsection on electricity in the use phase.

5.3 Pros and cons of the method

The PEF rules stipulate that the electricity data should be as specific as possible. This is an attractive aim from an attributional perspective. It also corresponds well to how the production of other goods is modelled in LCA.

However, the conditions given for the use of technology- or supplier-specific data requires applying several concepts that are not well understood by the typical LCA practitioner: tracking, tracking system, contractual instruments, certificates, etc. These concepts are vague or unclear also to at least some experts on energy systems.

As indicated by our interviewees (Chapter 4) and by The European Solar Manufacturing Council (ESMC 2021), the possibility to base PEF results on data reflecting GOs gives PV producers and other companies in any country incentives to buy such guarantees rather than investing in energy efficiency. However, the environmental benefit of guarantees of origin is unclear and likely to be near zero in the foreseeable future (Brander et al. 2018). The quantity produced of renewable and fossil-free electricity is much greater than the quantity of guarantees of origin in Europe and internationally. This means that even a significant increase in the demand for GOs is not likely to affect the production of renewable or fossil-free electricity. The environmental benefit of investments in energy efficiency, however, is immediate. Buying GOs instead of making actual improvements can be called greenwashing. This appears as a major concern of the PEF rules for modelling electricity.

Data on the residual mix are difficult to come by for countries outside Europe. In such cases, the PEF practitioner should calculate the consumption mix. Such a fallback option is necessary to make the methodology applicable. However, it also makes the data from different countries inconsistent: the use of residual electricity in Europe will be modelled with data representing the residual consumption mix, but the use of residual electricity in other parts of the world is likely to be modelled with data representing the total consumption mix. Since any electricity sold as a separate electricity product is likely to have good environmental performance, the residual mix in any country with trade of specific electricity products is likely to have a greater environmental impact than the total mix in the same country. This puts European producers (that use residual consumption data) in a disadvantage compared to producers in other countries (that use the total consumption mix).

The choice of national average data overestimates the importance of the country where the electricity is used. Using electricity in Sweden instead of Poland is not nearly as important for the environment as national data would suggest. This is because electricity that is not used in Sweden most of the time can be exported to, e.g., Poland and used there. The use of national average data increases the competitiveness of countries with a lot of hydropower and a lot of space for wind-power, for example Sweden and Norway. It reduces the competitiveness of countries such as Poland. The main drawback, however, is that PEF results will indicate that energy-efficiency measures in Norway and Sweden are not important for the environment. Moving a process to Sweden or Norway instead of making it more energy-efficient can also be considered greenwashing.

The rule to always use data on supplier-specific electricity products in countries with a 100% tracking system is not feasible. If the country has a 100% tracking system, the electricity supply to a specific process in the life cycle can still be unknown. The electricity supply to the waste management is likely to be unknown in a PEF study,

particularly if the product investigated has a long service life. The electricity supply to the production processes is likely to be unknown in a PEF study aiming to compare different waste-management options. In general, the electricity supply is often unknown to processes in the background system and almost never known in future processes.

5.4 Alternative methods

Alternative methods are available in other guidelines and standards. Elements from these methods can be combined to design a method that greatly reduces the risk of greenwashing but instead gives a reasonable indication of the importance of saving electricity in different parts of the world. The method presented here is also designed with an aim to make the modelling of electricity feasible and less cumbersome than with the current PEF rules.

Marginal data

The most accurate data to describe the consequences of using or saving electricity are data that reflect a marginal change in the electricity supply. The ILCD Handbook stipulates the use of marginal data in some cases (see Section 3.1). The database Ecoinvent includes marginal electricity data for 40 countries (Section 3.6). The US Renewable Fuel Standard applies marginal electricity data in some calculations (Section 3.10). However, the use of marginal data is still contested and might be difficult to agree on at a European level.

A distinction can be made between short-term and long-term marginal electricity, where the former is generated through a change in the utilization of existing power plants, but the latter is generated by a change in the production capacity that, over time, is made to adapt to the new electricity demand. The long-term marginal electricity is more relevant from the perspective of environmental sustainability, because the long-term impacts will dominate in the long run (Ekvall & Weidema 2004). However, the long-term marginal is highly uncertain (Mathiesen et al. 2009). It can be identified using different methods and models, but the results will depend strongly on the method or model used. The real long-term consequences of a change in electricity use will never be known.

A relatively robust approach for modelling marginal electricity can be established by selecting a specific method for identifying the long-term marginal electricity, for example the approach used in the consequential part of the Ecoinvent database (Vandepaer et al. 2019): each unconstrained electricity technology is included in the marginal mix to the extent that it contributes to the projected increase in electricity production in the country. This approach is straightforward and allows for transparent calculations.

However, the Ecoinvent approach is applicable only in countries where plans or projections on the future electricity production are available. When multiple projections are available, the marginal data will depend on a subjective choice of projection.

On a more theoretical level, the marginal data in Ecoinvent do not necessarily reflect how a change in the electricity use affects the electricity supply. This is because a projected increase in electricity from a specific source is not necessarily caused by a projected increase in electricity use. For example, an increase in wind and solar power might instead be driven by an ambition to reduce the use of fossil and nuclear fuel. Vandepaer et al. (2019) observe that renewable energy sources often dominate the marginal mixes in their results. This might depend on a green bias in the approach and not fully represent the share of renewable energy sources that is used to meet an increasing electricity demand.

A location-based approach

Several frameworks recommend or stipulate what the GHG Protocol calls a location-based approach, using average data for a specific country, region, or market. This avoids the greenwashing implied when an electricity user buys contractual instruments instead of investing in energy efficiency.

As stated in the previous section, the use of national average data overestimates the importance of national borders between countries that with interconnected electricity grids. Instead of national averages, the GHG Protocol, the RED, the UK Transport Fuel Obligation, and CORSIA all recommend calculating the average over a region. This allows for flexibility in the calculations, since a region can be anything from the area around a municipality to a continent. Such flexibility is an advantage in some LCA applications. In the PV Regulation, however, the calculation rules must be specific and robust; they should not allow for subjective choices when such choices can be avoided. The same goes for applications of the PEF methodology in the regulation on batteries, and other similar applications. It also holds for the use of PEF in marketing. In fact, a subjective choice of region is a weakness also in the GHG Protocol, the RED, the UK Transport Fuel Obligation, and CORSIA.

The ILCD Handbook and EPD International state that the averages should be calculated over a market. This is more relevant than national averages since it accounts for the interconnectedness of grids between countries. The geographical area of a market is also more well-defined than an undefined region.

However, the boundaries of a market can also be difficult to identify as the different European markets grow more integrated. The electricity market Nord Pool originally included just Sweden and Norway, but has expanded to also include Denmark, Finland, the Baltic states, Poland, Germany, the UK, the Netherlands, Belgium, Luxembourg, France, and Austria. These countries in turn, have grid connections to and trade arrangements with countries outside Nord Pool. On the other hand, bottlenecks remain between and within countries because of limited transmission capacity and/or administrative obstacles. These bottlenecks constrain the trade between different

countries and even within countries, for example Sweden and Norway. When such constraints are active, they become apparent by differences in the electricity price between regions on opposite side of the bottleneck.

This indicates that boundaries of the market can be identified by using the electricity price as indicator. A significant difference in price between two adjacent regions indicates a bottleneck in the trade, for example because of limited transmission capacity. A small or moderate change in the electricity use on one side of the bottleneck has little impact on the price or electricity production on the other side. When the electricity price is similar between two regions, it indicates a smooth trade of electricity between these regions – in other words that the regions jointly form an effective market.

Figure 1 shows the electricity prices and flows a cold winter evening when several nuclear power plants in Sweden had technological problems. Using the price as indicator, South Sweden and South Norway at this moment formed a market together with Denmark, Finland, the Baltic States, and possibly beyond (at or near EUR 500/MWh). Mid Norway and North Sweden formed another market (EUR 176/MWh), and Northern Norway was effectively an isolated market (EUR 95/MWh) because of limited transfer capacity between regions in Sweden and Norway.

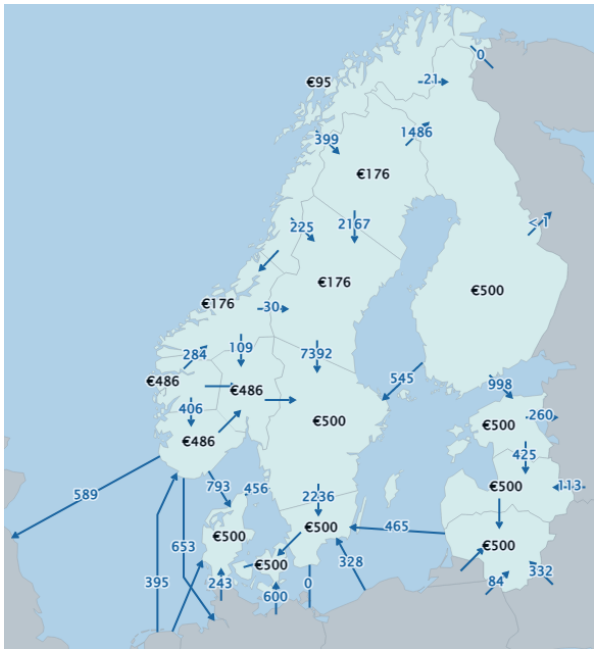

Figure 1: *Map of electricity prices (in EUR/MWh) and flows (in MWh) at 17:00, December 15th, 2022. Source: Svenska Kraftnät (https://www.svk.se/om-kraftsystemet/kontrollrummet/).*

Figure 2 shows the prices and flows a relatively mild winter night with good winds and part of the broken nuclear power back in business. Using the price as indicator, most of Sweden at this moment formed a market together with North and Mid Norway, and Finland (EUR 56 MWh/MWh). Southernmost Sweden, Eastern Denmark and the Baltic states formed another market, possibly including Germany and/or Poland (at or near 105 EUR/MWh). West Denmark was a market of its own or together with Germany and/or the Netherlands (EUR 120/MWh). The southern parts of Norway formed a market with a slightly higher price (EUR 153/MWh).

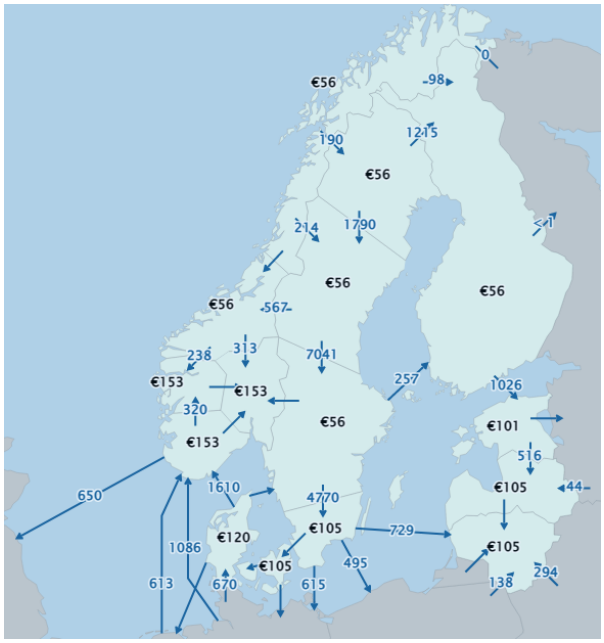

Figure 2: *Map of electricity prices (in EUR/MWh) and flows (in MWh) at 00:30, December 19th, 2022. Source: Svenska Kraftnät (https://www.svk.se/om-kraftsystemet/kontrollrummet/).*

As the figures illustrate, the bottlenecks and, hence, the markets shift over time. Ideally, the average should be calculated hour-by-hour using the boundaries of the market that are valid at that time. This would also allow for assigning different emissions to electricity used at peak hours and electricity used during the night. However, such an approach would require too much from the PEF practitioners. They would need to:

1. Find data on how the electricity use is distributed over time.
2. Identify the market boundaries for each hour electricity is used, and
3. Calculate or find data on the average electricity production in that region at that hour.

A less accurate but more feasible location-based approach would be to have a group of researchers or consultants investigate to what extent different countries and electricity-price areas form a common market. They would then calculate and publish the market-average data for each country and electricity-price area. PEF practitioners could then use this as a database in their calculations. The database would need to be updated now and then to remain valid.

To illustrate the approach for calculating the market-average data, consider the following simple example:

Area 1 is only connected to Area 2, which in turn is connected to other areas. For 75% of the time, the price in Area 1 is significantly lower compared to Area 2. The two regions have the same electricity price during the

remaining 25% of the time, but then a much lower price than other regions connected to Area 2. The emissions assigned to electricity used in Area 1 is then calculated as X = 0.75*{production average of Area 1} + 0.25*{production average over Areas 1+2}.

The production average in each area can be used as input to the calculation, since the bottlenecks between regions means that a change in the electricity use in Area 1 does not affect the imports from other regions.

Acknowledging additionality

A pure location-based approach fails to reflect the fact that electricity users can contribute to investments and increased utilization of power plants with a low environmental impact. To better reflect such cases, exceptions from the location-based approach can be made for electricity users to the extent that they can point at a causal link to increased production of renewable or fossil-free electricity. Such additionality can be indicated, if:

- the electricity is produced at the site where it is used, and contractual instruments are not sold to a third party (element from the current PEF methodology and ISO 14067),
- the electricity is produced in a directly connected power plant, if this power plant was built after or at the same time as the production plant where the electricity is used, and contractual instruments are not sold to a third party (inspired by elements in the RED and in ISO 14067),
- the electricity user built or had a power plant built elsewhere after or at the same time as the production plant where the electricity is used, and contractual instruments are not sold to a third party (generalized from elements in the RED and in ISO 14067),
- the electricity user enters a long-term power purchase agreement that enables investment in new electricity-production capacity that would not otherwise have been viable (suggestion from Brander et al. 2018), or
- the electricity is used only when the price is low enough to indicate that wind, hydro, solar, or nuclear power supplies the marginal electricity (element from the RED Supplement on renewable fuels of non-biological origin or recycled carbon).

5.5 National or Scandinavian data?

The PEF methodology states that data representing a national residual mix should be used when there is no solid basis for the use of more specific data. The Swedish Energy Market Inspectorate decided that the national residual mix should be interpreted to mean a Scandinavian residual mix (EMI 2013). This decision was made assuming that other Scandinavian countries would make similar decisions since the Scandinavian electricity market had become a single integrated market. However, other Scandinavian countries still apply a literal interpretation of the PEF rule to use national data. This means that Sweden stands alone in contradicting the PEF rule, which makes the Swedish position difficult to defend. The interview responses from Grexel and the Energy Market Inspectorate also indicate that Sweden should not use Scandinavian data when the other Scandinavian countries use national data.

With the marginal approach described above, there is no choice between different kinds of residual data. However, the question still remains if the marginal data should be calculated separately for each country, as in the Ecoinvent approach, or over a smaller or greater region.

If the essentially location-based approach described in previous section is used, the choice between national or Scandinavian data disappears. The average is instead calculated over the market where the electricity is used. This market will be likely to include at least parts of other countries, as indicated by Figures 1-2.

6. Conclusions

This section includes our answers to the five questions in focus of this project:

1. How can and should the rules for electricity modelling in the draft PV Regulation be updated to reflect the most recent version of the PEF rules?
2. What are the arguments for and against these rules, accounting also for European competitiveness?
3. How can and should the rules be clarified to simplify application and increase robustness?
4. Can alternative calculation rules be more appropriate for the PEF framework?
5. Can and should Scandinavian countries differ in the interpretation of the of national residual mix?

6.1 Need for updates

To reflect the most recent version of the general PEF rules, the PV Regulation should allow for the use of regional data as a last option. This means that the hierarchical order presented in the draft Regulation (EC 2022a, p. 48) needs to be amended:

In Option III, the beginning "*As a last option, the 'country-specific residual grid mix…*" should be replaced by just "*The 'country-specific residual grid mix…*""

An Option IV should be added that reads (cf. EC 2021a , 36):

"*As a last option, the average EU residual grid mix, consumption mix (EU+EFTA), or region representative residual grid mix, consumption mix, shall be used.*"

The option to use regional data is the only substantial update we found. Minor changes can be made to more accurately reflect the text in the current general PEF Guide. For example, a small addition (underscored below) could be made in the first sentence describing the first criterion for contractual instruments – to convey attributes (EC 2022a, p. 48):

"*The energy type mix shall be calculated based on delivered electricity, incorporating certificates sourced and retired (obtained, acquired or withdrawn) on behalf of the relevant company (for the supplier-specific electricity product) or on behalf of the supplier's customers (for the supplier-specific electricity mix).*"

However, it might be better to simply state, in the PV Regulation, that the most recent version of the general PEF rules should be applied.

6.2 Pros and cons of the method

The PEF approach fits in the context of attributional LCA, where the focus is on identifying how the electricity used is generated. It also corresponds to how the production of other goods is typically modelled in LCA.

However, the PEF approach does not reflect how the use of electricity affects the electricity production and its emissions. The use of data based on contractual instruments such as Guarantees of Origin means that the PEF results can grossly underestimate the importance of using or saving electricity. The use of national residual data entails the same problems, if the residual mix is much cleaner compared to other countries with interconnected electricity grids. In this sense, the PEF approach allows for greenwashing.

The PEF approach is difficult to apply for the typical LCA practitioner. A correct application needs interpretation of concepts that are unclear even to some energy experts: tracking, tracking system, contractual instruments, certificates, etc.

In addition, there is a lack of information on the tracking systems and residual mixes in countries that are not covered by the Association of Issuing Bodies (AIB). These includes all countries outside Europe and also a few European countries.

The competitiveness of European PV producers that do not buy tracked electricity suffer from this lack of data. They have to use data representing the dirtier residual mix, while producers in many countries outside Europe can use data representing their full average mix.

Finally, the PEF rules states that data on supplier-specific electricity products must be used for processes in a country with a 100% tracking system. This rule cannot be applied to many processes in the background system, and hardly ever to future processes.

6.3 Clarifying the text on PEF

Clarifying terminology on allocation

To avoid confusion between allocation based on physical quantities and what ISO 14044 calls allocation that reflects physical relationships, the head of Table 5 in the draft PV Regulation (EC 2022a, p. 47) should be revised. The heading "Physical relationship" should be replaced by, for example "Basis for allocation".

The second sentence of Subsection 4.4.2.4 in the general PEF Guidelines (EC 2021a, p. 39) should be revised to avoid an even greater confusion regarding what is subdivision, what is allocation based on underlying physical relationships and what is simply allocation based on physical properties:

"*In general, the subdivision of electricity supply used among multiple products is based on a physical unit (e.g. number of pieces or kg of product).*"

can be replaced by, for example

"*In general, the allocation of electricity supply to each of the products is based on a physical unit (e.g., number of pieces or kg of product).*"

Clarifying the market-based approach

If the rules for modelling electricity supply are not revised as suggested in previous section, the text describing the current approach in the general PEF rules and in the PV Regulation should be amended to help PEF practitioners understand the approach. A few clarifications are suggested here:

I) An amendment should be made in both documents (EC 2021a, p. 36; EC 2022a, p. 48) to avoid double-counting of supplier specific electricity products. The second step in the hierarchical order:

"*The supplier-specific total electricity mix shall be used if...*"

Should be revised to read, for example:

"*The supplier-specific residual electricity mix, i.e., the part of the total electricity mix of the supplier that is not sold as specific electricity products, shall be used if...*"

II) A reference to AIB (2022b) should be added in the PV Regulation to explain the concept of tracking system. This reference can be added as a note in the list of definitions (EC 2022a, p. 35) or in the text describing the minimum criteria for tracking systems (ibid. p. 49).

III) The criterion to be a unique claim, and the conditions to meet this claim, are concisely described in the draft PV Regulation (EC 2022a, pp. 48-49). The corresponding text in the general PEF rules (EC 2021a, pp. 37-38) includes some redundancy, particularly in the table. Here, the general rules can be revised to reduce redundancy. The draft PV Regulation can be used as a starting point for this revision.

IV) To reduce confusion, the following text in the general PEF rules (EC 2021a, p. 38):

"*2. Is the plant located in a country where consumption is partly untracked (> 95%)?*"

should be revised to read, for example:

"*2. Is the plant located in a country where consumption is untracked to a very large extent (> 95%)?*" or

"*2. Is the plant located in a country where the electricity is tracked to a very small extent (< 5%)?*"

Allowing for specific data

An amendment should be made to Subsection 4.4.2.5 in the general PEF guidelines (EC 2021a, p. 39) to avoid contradiction to the general rule to model electricity as precisely as possible. With the amendment underscored, the first sentence of this section could read, for example:

"*If a product is produced in different locations or sold in different countries, and calculations are made for the full production volume of the product or for a part of this flow where the country of production or country of use is unknown, the electricity mix shall reflect the ratios of production or ratios of sales between ~~EU~~ countries/regions.*"

The word EU should be deleted from this text, because the rule should be applied also when production and/or use of the product occurs in countries outside the EU.

Note that Subsection 4.4.2.5 deals not only with production but also with use of products in multiple countries. For clarity, the heading of this subsection should be amended to read (with amendment underscored):

"*4.4.2.5. For multiple locations producing or using one product*"

Subsection 4.4.2.6 (EC 2021a, p. 39) should simply be deleted, because a consistent methodology requires that electricity consumed in the use phase be modelled using the same rules as electricity consumed in other parts of the life cycle. This, of course, requires that Subsection 4.4.2.7 be renumbered.

6.4 Alternative calculation rules

Two alternative approaches

To make PEF results accurately indicate what actions and decisions reduce climate and environmental impacts, the rules for modelling electricity supply should be revised. Ideally the electricity supply should be modelled using marginal data, i.e., data that reflect how a small change in the electricity demand affects the electricity production.

Less accurate but still reasonable results would probably be obtained if electricity supply is modelled using average data for the electricity market where the electricity is used. Exemptions from this rule should then be made when:

- the electricity is produced at the site where it is used, and contractual instruments are not sold to a third party,
- the electricity is produced in a directly connected power plant, if this power plant was built after or at the same time as the production plant where the electricity is used, and contractual instruments are not sold to a third party,
- the electricity user built or had a power plant built elsewhere after or at the same time as the production plant where the electricity is used, and contractual instruments are not sold to a third party,
- the electricity user enters a long-term power purchase agreement that enables investment in new electricity-production capacity that would not otherwise have been viable, or
- the electricity is used only when the price is low enough to indicate that wind, hydro, solar, or nuclear power supplies the marginal electricity.

Robust feasibility in all three methods

A PEF study, like any LCA, can include processes and electricity use anywhere in the world. The PEF methodology would benefit greatly from a database with electricity data for all parts of the world. This would make

the methodology more feasible to apply. It would also make the methodology more robust by reducing both subjective choices of data and the risk of errors in the calculations. The database can be used as a reference both in the general PEF rules, in the PV Regulation, and in similar documents.

What data should be in the database depends on the approach chosen for modeling the electricity supply. The work involved in developing the database will also depend on the approach. If electricity production is modelled using marginal data developed through the Ecoinvent approach, the electricity data that already exist for 40 countries in the Ecoinvent database would be a good start. The Commission could buy this dataset from Ecoinvent and make the data freely available to PEF practitioners. Marginal data for other countries need to be developed from publicly available plans or projections on the future electricity production. Where such projections are not available, projections need to be developed as part of the task to build the dataset. A team of experts on international energy systems and LCA could be assigned to do this.

The essentially location-based approach recommended in this report would require an investigation of to what extent different countries and electricity-price areas form common markets. Data on the electricity supply in each country and electricity-price area would then have to be calculated based in this information. A team of experts on energy systems and LCA could be given the task to do this. This is likely to be a major assignment, but (and in part for this precise reason) it should not be left at the hands of individual PEF practitioners.

If the current, market-based approach remains, a group of experts should be given the task to produce and publish a list of countries with tracking systems that are considered valid in the PEF context. This list should ideally be published together with information on the level of tracking in the valid systems, and with data on the residual mix. If the expert group is to apply the criteria of transparency, independency, fraud-resistance, etc. given in the draft PV Regulation (EC 2022a, p. 49), it should include legal experts along with experts on energy systems and/or LCA. It should also include or have access to staff with knowledge in all necessary languages. This is also likely to be a major assignment and, for that reason, should not be left to individual PEF practitioners.

Regardless of what approach is chosen, the dataset on electricity production would have to be updated now and then to keep the data valid.

6.5 Interpreting the residual mix

If the market-based approach to model electricity in PEF is retained, the Swedish interpretation of national residual data to mean Scandinavian residual data (EMI 2013) should be changed. The use of national residual data is explicitly stipulated in the PEF rules. It is difficult to defend a contradiction to this rule, since LCA and PEF practitioners in other Scandinavian countries apply data that reflect their national residual or average electricity supply.

If the essentially location-based approach described in previous section is used, the choice between national or Scandinavian data disappears. The average is instead calculated over the market where the electricity is used.

7. Three paths forward

We see three options for future modelling of electricity supply in Product Environmental Footprints. Each of these needs further development to be fully operational and robust:

A. Market-based approach with contractual instruments and national residual consumption mix
   - Update PV Regulation with option for use of regional data
   - Clarify terminology
   - Establish rules and practice for checking validity of instruments
   - Assess the reliability of tracking systems beyond AIB
   - Calculate and publish data on residual mixes beyond AIB
   - Keep data fresh

B. Location-based approach with market production mix and exceptions for additionality
   - Agree on rules for showing additionality
   - Identify markets around the world
   - Calculate and publish average data
   - Keep data fresh

C. Long-term marginal data based on plans or projections for future national electricity production
   - Agree on method for identifying marginal data
   - Collect and select projections beyond the 40 countries in Ecoinvent
   - Decide on what technologies are constrained
   - Calculate and publish national marginal long-term mixes
   - Keep data fresh

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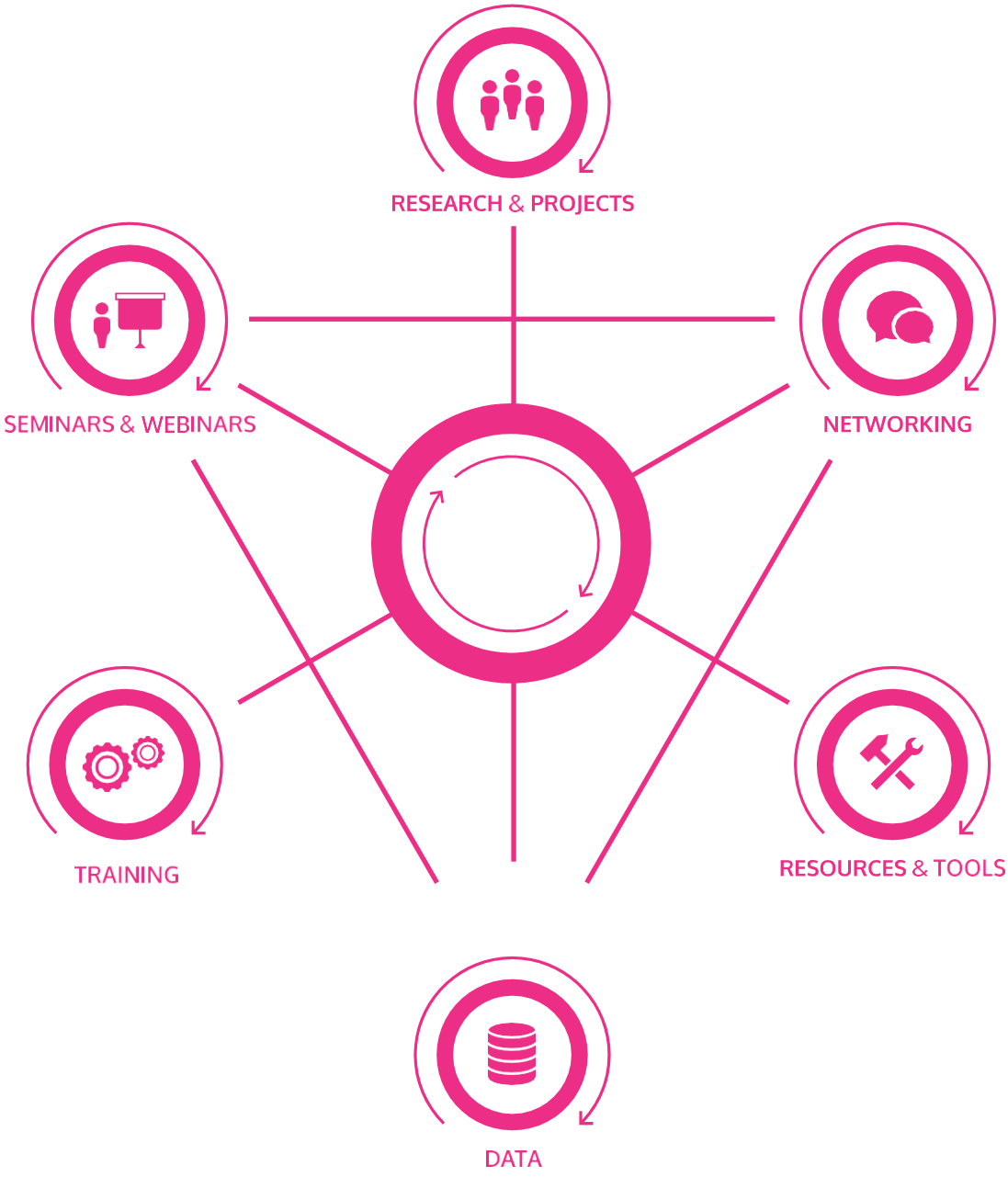

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