Contributions to contribution analysis: structuring and extension of approaches to understanding contributions to impacts in Life Cycle Assessment

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Chapter 6

An analysis of the effects of changes in the *Premise* database on the environmental impacts of key products

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Abstract

Purpose: *Premise* has been quickly adopted as the state-of-the-art for performing prospective LCAs (pLCA). *Premise* databases are generated by combining the ecoinvent database and data from climate change (CC) scenarios implemented in Integrated Assessment Models (IAMs). Both the extent of changes and the focus on CC raise a question on how they affect LCA results. We evaluate 9 representative products in three scenarios to assess how impacts change and what contributes to those changes.

Methods: Our analysis of *Premise* consists of several steps. We begin by generating three *Premise* databases, one for 2020, and two for 2050 assuming different future changes one that represents a continuation of current trajectories and policies (Base) and one that represents assuming ambitious decarbonization strategies (RCP 2.6). We analyze *Premise* based on 9 representative products: Electricity, Heat, Road Transport, Steel, Aluminium, Copper, Concrete, Organic Chemical and Inorganic Chemical. We calculate results for each of the 9 products for 16 impact categories, although we focus on CC. We then assess impact change between different scenarios for every product. We do a contribution analysis where we analyze the contribution of 15 overarching product groups to each product.

Results & Discussion: For CC, we find that impact changes for most products are related to impact reductions in electricity production and increased use of biomass and Carbon Capture and Storage. We find that Electricity, Heat, Road Transport, Steel and Concrete are primary contributors to their own respective impacts. Other products are instead mainly affected by these groups. Furthermore, the contribution from the Ore & Minerals, Energy resources, Chemicals and Transport product groups is much higher when we include Indirect contributions (contributions 'connected through' another group, e.g. production of fuel for Transport), these product groups connect to impacts elsewhere in the system. In other impact categories we find much more varied results, though the uncertainty around these results is high, specifically 'land use' shows large changes in impact.

Conclusions: Our approach can highlight products or product groups of interest in large databases like *Premise*, which can aid in modeling and finding errors. We suggest *Premise* to be used primarily for assessments of climate change impacts and practitioners clearly communicate versions and settings to make their work reproduceable. Despite us taking a critical stance toward some aspects of *Premise*, we still recommend using it for pLCA.

6.1 Introduction

Life cycle assessment (LCA) is a method to assess the impacts of a product over its life cycle. LCA became more useful and relevant for policy when the scientific community started to explicitly assess possible impacts of new technologies in the future (Azapagic, 1999; Hirschberg et al., 2009; Hummen & Kästner, 2014; Villares et al., 2017). While modeling changes to future foreground systems (the core part of a supply chain for a reference flow, usually modeled by the practitioner) is important, it is important for consistency to also model changes to background systems (all other processes used, usually taken from large scale Life Cycle Inventory (LCI) databases such as ecoinvent (Wernet et al., 2016)) as well (Arvidsson et al., 2018, 2024; Bergerson et al., 2020; Cucurachi et al., 2018; Miller & Keoleian, 2015; Steubing et al., 2023; Thonemann et al., 2020). For example, Mendoza Beltran et al. (2018) showed the influence of changes in the climate change effects of electricity generation in future scenarios for electric vehicles compared to internal combustion engine vehicles. Sacchi et al. (2022) continued the work of Mendoza Beltran et al. (2018) and embarked on changing the ecoinvent LCI database based on future scenarios informed by Integrated Assessment Models (IAMs) and created the open-source library *Premise* to create such LCI databases and fill this gap. Since its introduction, *Premise* was quickly adopted as a major tool used to generate prospective LCI (pLCI) databases.

Premise enables LCA practitioners to adapt the background ecoinvent database to different future scenarios, facilitating the assessment of product impacts under changing technological and socioeconomic conditions. It translates scenario assumptions, such as shifts in electricity generation technologies or energy mixes, into corresponding modifications of LCIs by updating existing data or introducing new inventories where needed. *Premise* is most commonly linked to scenarios from IAMs such as IMAGE (Stehfest et al., 2014) or REMIND (Baumstark et al., 2021), though its scope is expanding to include other IAMs and scenario sources.

Initially limited to five sectors (electricity, steel, concrete, fuel, and road transport) (Sacchi et al., 2022), *Premise* now modifies around ten sectors (Sacchi, 2025b) and adds over a thousand new technology-specific inventories, resulting in well over ten thousand additional processes when regionalized. These databases intended as consistent, scenario-based projections derived from IAM outputs that combine Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2014) with Representative Concentration Pathways (RCPs) (Van Vuuren et al., 2011). Together, these scenarios reflect both how challenging it is to mitigate and adapt-to climate change (the SSP scenarios), and how much climate change occurs (the RCP scenarios) far into the future. Each IAM provides distinct trajectories toward the same SSP–RCP combinations, reflecting differences in assumptions about economic growth, population, energy systems, and material demand. *Premise* translates these IAM-specific outputs, using its own detailed technology assumptions, into prospective versions of ecoinvent (Wernet et al., 2016), enabling transparent and comparable LCA studies across a range of plausible future scenarios.

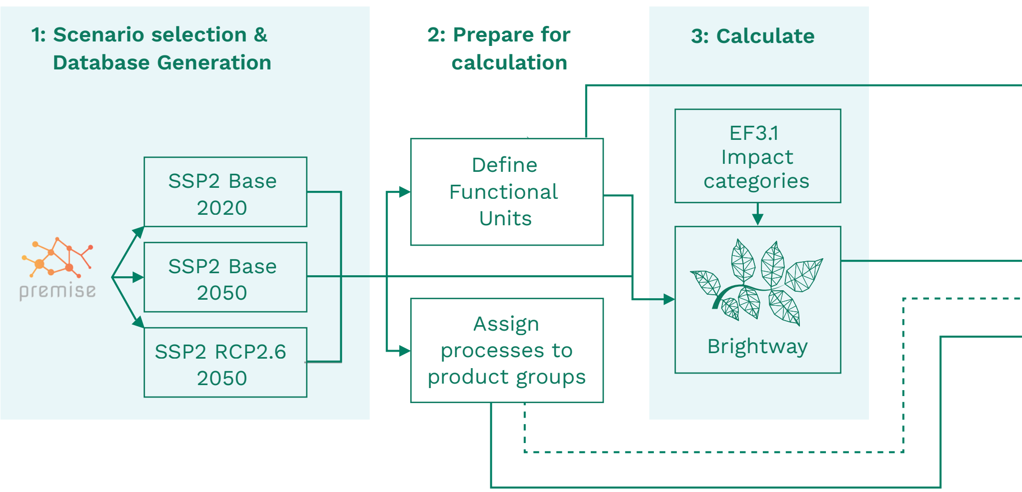
The IAM input data used in *Premise* revolves around climate change. This is thus the main focus of changes for pLCI databases generated with *Premise*. While LCA is arguably the best-positioned method to assess trade-offs with other impact categories within these scenarios, a requirement for an accurate assessment of these other impact categories is that they are properly modeled with the changes *Premise* makes. Sacchi et al. (2022) warn specifically that "toxicity related indicators [..] should be regarded as highly uncertain". Furthermore, *Premise* makes additional LCI changes that are not explicitly modeled in IAMs such as specific battery type market shares in electric vehicles or ore grade changes in mining. This increases completeness of 'future changes' at the cost of consistency with the underlying scenario data. *Premise* may not accurately model changes in elementary flows. *Premise* was further criticized on its IAM input data based on SSP based scenarios which embed optimistic technological assumptions, can neglect finance or biophysical limits and can have opaque ethical choices, this produces scenarios that could be technically implausible, ethically biased and thus misleading as inputs for pLCA (de Bortoli et al., 2025).

Both the focus of *Premise* source data on climate change and additional changes *Premise* makes to LCI data raise a question on how these changes affect LCA results from these pLCI databases. While it is documented clearly what changes are made on the inventory level by *Premise* (Sacchi, 2025b), because of the networked relationships between processes, it remains unclear what effects these changes have throughout *Premise* databases on the LCIA level, and how this can affect LCA results for both climate change and other impact categories.

In this study, our goal is to systematically analyze the effects of changes between several pLCI databases generated with *Premise* on LCIA results for practitioners. We assess the effects on impact results for important industrial products from these databases in various impact categories and which product groups (e.g., electricity, steel, transport) contribute to these changes. Through our analysis, we aim to give practitioners better insight into what kinds of changes they may expect when using *Premise* databases and how those may affect their own results.

6.2 Method

We first explain more about the workings of *Premise* where relevant to this study in section 6.2.1. We begin by generating three *Premise* databases (section 6.2.2). We choose nine products as functional units (FUs) to assess impact changes between the databases (section 6.2.3) and calculate LCA results for 16 impact categories (section 6.2.4). Next, we assess changes in results between the databases (section 6.2.5) and finally we assess what contributes to those changes (section 6.2.6). We show an overview of our approach in Figure 1. We provide more detail in SI 1.1.



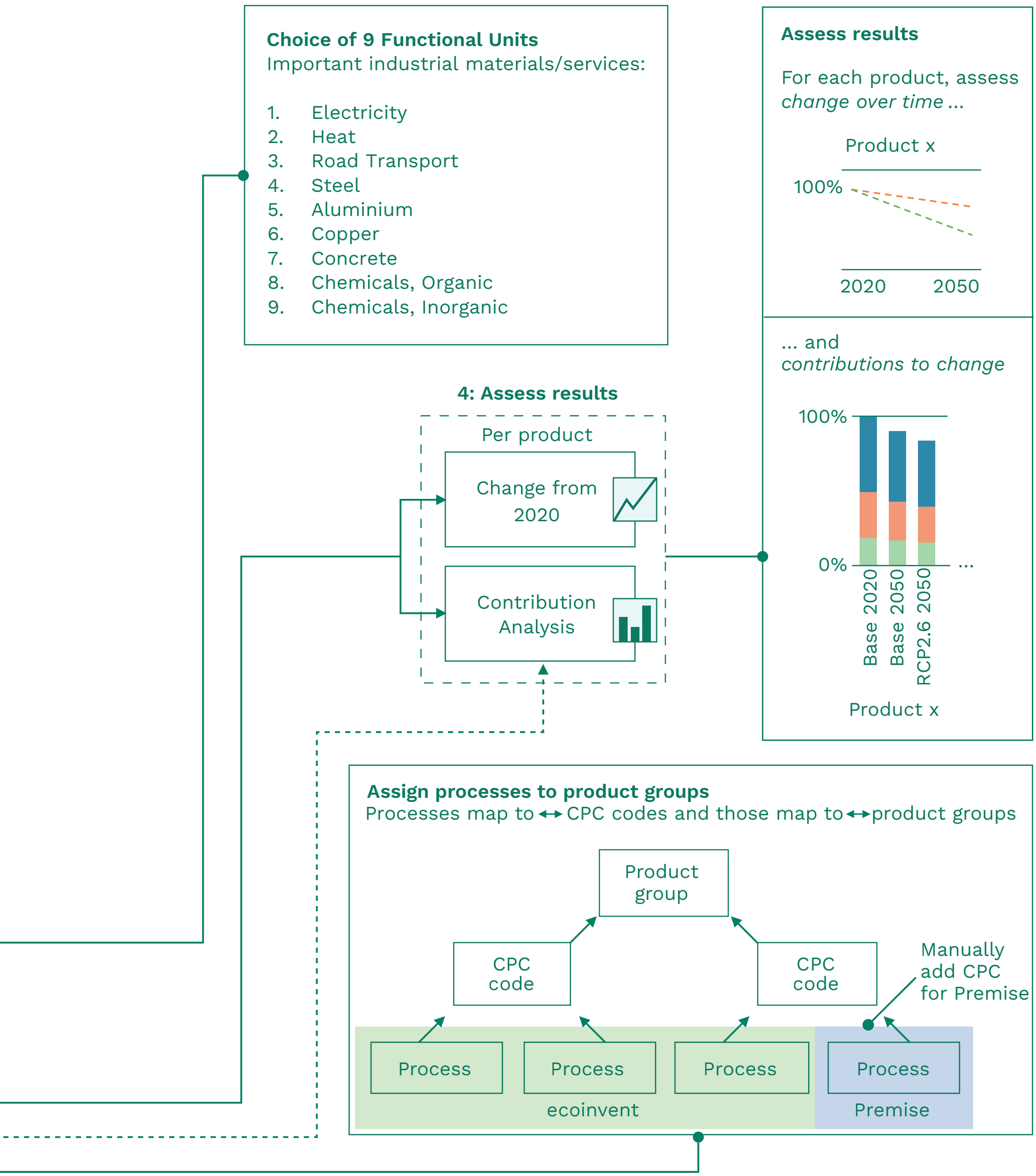


Figure 6.1 - Overview of our approach. We 1: choose scenarios and generate three scenario databases (section 6.2.2), 2: we define which processes serve as FU and their amount (section 6.2.3) and 3: choose impact categories (section 6.2.4), then we calculate LCA impact results and analyze 4: for each product group the change between scenarios (section 6.2.5) and what product groups contributes to those changes (section 6.2.6).

6.2.1 Workings of *Premise*

We shortly describe here some aspects relevant to how *Premise* works for this specific study, for more general information we recommend reading Sacchi et al. (2022) and the documentation (Sacchi, 2025b).

We make a distinction between the following (Steubing et al., 2023):

- *Premise* as a software library: If no other distinction is given we are discussing the software,
- *Premise* scenarios: The data from IAM-SSP-RCP combinations plus data from other sources for additional changes made by *Premise,*
- *Premise* databases: The resulting pLCI databases LCA practitioners can use generated by *Premise* from a *Premise* scenario and ecoinvent.

Premise takes input data from different IAMs such as shifts in electricity generation technologies or energy mixes from IAM-SSP–RCP scenario combinations. *Premise* then translates this into changes on the inventory level based on those scenarios. These changes are made either to existing processes, or to newly added processes. IAMs provide general information, which needs to be made specific to be used in LCA, for example, an IAM may prescribe a certain market share of 'electricity from solar' in a given scenario and year, but which specific technologies to generate that solar electricity is not provided. *Premise* developers need to make assumptions, either based on their own expertise or literature to map these high-level changes to inventory-level data. Furthermore, *Premise* makes other changes as well, which are not directly linked to the scenario data, like adding new battery chemistries, or ore grade decline data to alter mining processes. All *Premise* scenario data is eventually mapped to inventory data that practitioners can use in a *Premise* database. *Premise* generates reports on the changes that have been made to an underlying ecoinvent database with a *Premise* scenario to generate a *Premise* database and the documentation (Sacchi, 2025b) provides more information about additional changes.

6.2.2 Scenario selection & Database generation

We assess two *Premise* scenarios, the IMAGE SSP2 Base scenario and the IMAGE SSP2 RCP2.6 scenario, we assess these scenarios for 2020 and 2050. The IMAGE SSP2 Base scenario assumes global society follows current emission trajectories without major changes (thus base), which results in RCP6, suggesting >3 oC warming in 2100, the IMAGE SSP2 RCP2.6 scenario assumes a scenario where warming in 2100 is limited to below 2 oC (Van Vuuren et al., 2011). The year 2020 is a common point from which the two scenarios diverge, thus we create three *Premise* databases: The 2020 SSP2 Base database, the 2050 SSP2 Base database, and the 2050 SSP2 RCP2.6 database. As the goal of this study is to assess the effects of scenario changes from *Premise*, the ecoinvent database itself is not used in this study directly. Furthermore, not all FUs we assess exist in ecoinvent (FUs are presented in the next section).

We make use of the IMAGE (Stehfest et al., 2014) implementation in *Premise*. We use Brightway v2.4.6 (Mutel, 2017) and *Premise* v2.2.9 -the most recent version of *Premise* at the time of writing- and ecoinvent v3.10.1 cut-off (Wernet et al., 2016) for our analysis, the most recent compatible ecoinvent version compatible with this version of *Premise*.

6.2.3 Choice of Functional Units

With well over 30000 processes in each scenario database it becomes impossible to comprehensively show the impact change and contributions to those changes for all processes. Instead we choose a small subset of nine products which are (directly or indirectly) important to industry to assess the changes *Premise* makes. Where possible, we use high-level processes like markets. Doing this allows *Premise* to make changes to production mixes and production processes in different regions where relevant for the scenarios we use.

We define a set of FUs focused on industrial goods, utilities and services. The focus is on industry as ecoinvent and additional inventories in *Premise* represent these relatively well. Furthermore, this set of FUs is responsible for considerable climate change impacts, is produced in large volumes or has major expected increases in demand. We attempt to strike a balance between showing wide coverage of important industrial products while limiting the total amount to allow more in-depth assessment of results.

We make use of the following nine FUs presented in Table 6.1.

#	FU	Name	Database identifier	Relevance
1	1 kWh	**Electricity**	Market group for electricity, high voltage, World	Direct contribution to global climate change impacts *Sources:* • *Climate Watch, 2024* • *Gütschow & Pflüger, 2023* • *Harpprecht et al., 2024, 2025* • *UNEP, 2023* • *UNFCCC, 2022*
2	1 MJ	**Heat**	Market for heat, from steam, in chemical industry, World	
3	1 tkm	**Road transport**	Transport, freight, lorry, unspecified, long haul, World	
4	1 kg	**Steel**	Market for steel, low-alloyed, hot rolled, GLO	
5	1 kg	**Aluminium**	Aluminium ingot, primary, to aluminium, cast alloy market, GLO	Major metal with large dependence on electricity for production *Sources:* • *Harpprecht et al., 2024, 2025* • *UNEP, 2023* • *Watari et al., 2022*
6	1 kg	**Copper**	Market for copper, cathode, GLO	
7	1 m^3	**Concrete**	Market group for concrete, normal strength, GLO	Major construction material with large contribution to global climate change through cement *Sources:* • *Climate Watch, 2024* • *Gütschow & Pflüger, 2023* • *UNEP, 2023* • *UNFCCC, 2022*
8	1 kg	**Chemicals, Organic**	Market for chemical, organic, GLO	Major contribution to environmental impacts through dependence on energy and fossil feedstocks *Sources:* • *Climate Watch, 2024* • *Gabrielli et al., 2023* • *Gütschow & Pflüger, 2023* • *UNFCCC, 2022*
9	1 kg	**Chemicals, Inorganic**	Market for chemical, inorganic, GLO	

Table 6.1 - Functional Units used in this study. The columns show from left to right: the FUs numbering, the functional unit amount, the name we use in this study is marked in bold, the name in Premise databases is given and relevant sources as to why they are important are given.

One category of product that may seem to be obviously missing is agricultural products. Despite the substantial environmental footprint of the agricultural sector, we omit these as there is not one single or a few obvious products that could well represent this sector in our assessment. However, we still assess the contribution of the Forestry and Agriculture sector to the products above, as explained in section 2.6 below.

The above process names listed in brackets are the names and regions in the scenario databases. Any time we refer to one of these FUs in the further text, its name will be written in **bold**. Some of these processes are part of sectors directly changed with *Premise* (**Electricity, Heat, Road Transport, Steel, Concrete**), though the others will also be affected by changes in other sectors.

6.2.4 Choice of Impact Categories

Despite the primary focus of IAMs on climate change resulting in that same focus on climate change related changes by *Premise*, we will be using the EF 3.1 (EC, 2022) impact categories, to demonstrate the effects of changes in *Premise* in a broad range of impact categories. That said, we will mainly highlight climate change results to assess how this focus affects impacts to climate change. We also assess the impact changes to 15 other impact categories to demonstrate how this focus on climate change affects other impact categories. Full results for all impact categories are available in SI 1.2. For Climate change, we account for biogenic carbon flows (e.g., CO_2 uptake has a -numerically-negative impact, and burning biogenic CO_2 will have a positive impact) as prescribed by *Premise*[1].

6.2.5 Assessing impact changes

To assess the differences between scenarios, we calculate the impact score of each FU in each database and compare the relative change in score for each FU compared to the 2020 SSP2 base database, calculated as 'new' divided by 'old': ***2050 Scenario / 2020 Base***. Sacchi et al. (2022) already compared the total impact change between databases

[1] *https://github.com/polca/premise_gwp*

for some combinations of their original 5 sectors in their original introduction of *Premise* (2022), but assessing in this manner allows us to see the change in impacts of individual FU as opposed to a general idea of impact change throughout a *Premise* database.

6.2.6 Assessing contributions

To gain deeper insight into the effects changes of *Premise* have, we next assess the contributions from large product groups to each product.

Product groups
With well over 30000 processes in each scenario database, it becomes infeasible to assess the contribution of single processes, instead, we assess the contribution of fourteen product groups and one *Other* group for any remaining processes.

1 *Forestry & Agriculture**
2 *Ores & Minerals**
3 *Energy resources**
4 *Electricity**
5 *Heat & Steam**
6 *Steel & Iron**
7 *Aluminium*
8 *Copper*
9 *Other Metals**
10 *Basic Chemicals**
11 *Cement & Clinker**
12 *Construction*
13 *Transport**
14 *Waste*
15 *Other*

We map each of the processes to a product group in two steps as shown in Figure 1: First, processes in our scenario database are mapped to Central Product Classification (CPC) V2.1 (UN, 2015) codes, for ecoinvent, all processes are already assigned a code, for processes added by *Premise*, we add CPC classifications. As the CPC scheme does not completely match our groups of interest, we further aggregate CPC codes into the fifteen product groups shown above. We explain this mapping procedure in more detail in SI 1.1.

Any time we refer to one of these groups -and to avoid confusion with FUs- in the further text, product groups will be written in italic. The groups marked with * are (partially or completely) altered by the *Premise* scenarios. We refer to the *Premise* documentation (Sacchi, 2025b) for an overview of exact changes. As an example for Other Metals; this would be production of battery metals, e.g., Lithium and Cobalt. Additionally, *Premise* implements CCS, but it does so in different ways depending on the sector where it is implemented, effectively meaning CCS cannot be assessed as a single product group in our approach.

In addition to the product groups that *Premise* directly changes, we also assess some other relevant groups; we add the metals product groups (*Aluminium*, *Copper* and *Nickel*) as these are often of interest in prospective LCA (Harpprecht et al., 2024). We add Construction as it is deeply integrated into LCI databases, despite often not being in the foreground (Frischknecht et al., 2007). Finally, we add Waste as it is relevant from a life cycle perspective.

Contributions from product groups
We assess the Direct contributions (direct contributions are the contributions caused by the elementary flows (EFs) from a process where those flows occur Srocka & Montiel, 2021; van der Meide et al., 2025) of the product groups, e.g., the climate change contribution of Energy resources to Electricity could be the effects of mining coal, gas, and other fossil fuels for electricity production.

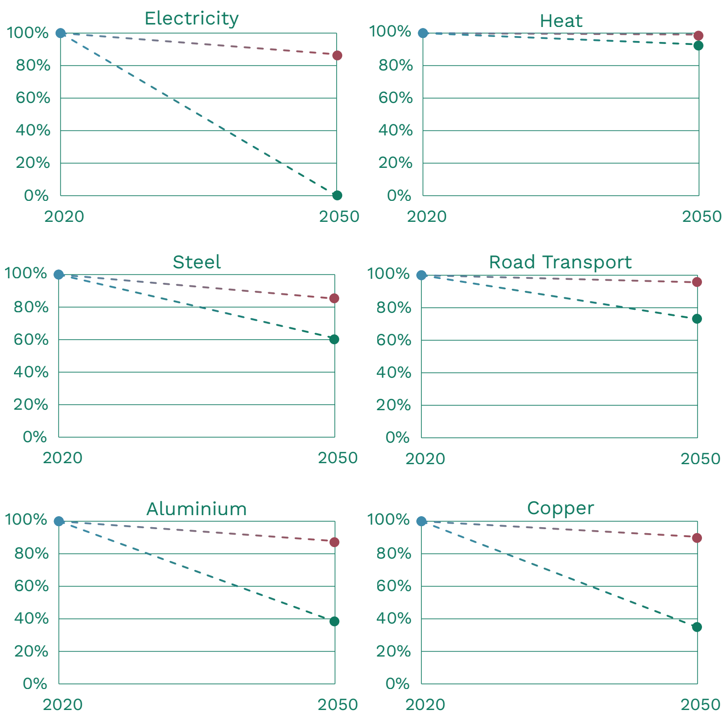
We do process group contributions (van der Meide et al., 2025) based on the 15 product groups we defined above.

Additionally, in SI 1.2, we also assess the combination of Direct+Indirect contributions. Indirect contributions are from all EF of processes contributing to the intermediate flows (products) (van der Meide et al., 2025). An example of this could with the contribution from the *electricity* group to **Steel**. Here, all impacts to produce the electricity for steel production would be included in the electricity group, the CH^4 released during the mining of coal (in the energy resources group) for the production of electricity (in the *electricity* group) would be included as contribution from electricity to **Steel**. This is explained in more detail in (van der Meide et al., 2025). With the combined Direct+Indirect approach, we assess how contributions propagate through different sectors, providing a ‘connector’ role (Reinhard et al., 2016) for some sectors. We adopt the Hypothetical Extraction Method from Input Output Analysis (van der Meide, 2025a) for this combined perspective and explain this approach in more detail in SI 1.1. By using both a Direct and Direct+Indirect approach, we can take multiple complementary perspectives on the contribution of each product group to the FUs.

6.3 Results

6.3.1 Impact changes in different scenarios

For Climate Change, we show impact changes for each product in Figure 6.2 and provide results for all impact categories in SI 1.2. We go deeper into the causes of our observations in the section after this with our contribution analysis. Overall, we see the expected result that the 2050 Base database has lower climate impacts compared to the 2020 Base database, and that the RCP2.6 2050 database has lower climate impacts compared to both scenarios. We also see that the 2050 Base database does not have major changes (max 15% reduction) in climate change impact compared to the 2020 Base database. One notable product is **Heat**, where impacts change very little between the different *Premise* scenarios compared to the other products, despite this being a sector that is changed by Premise. However, it should be noted that this result excludes a possible larger difference with ecoinvent, which was not assessed.



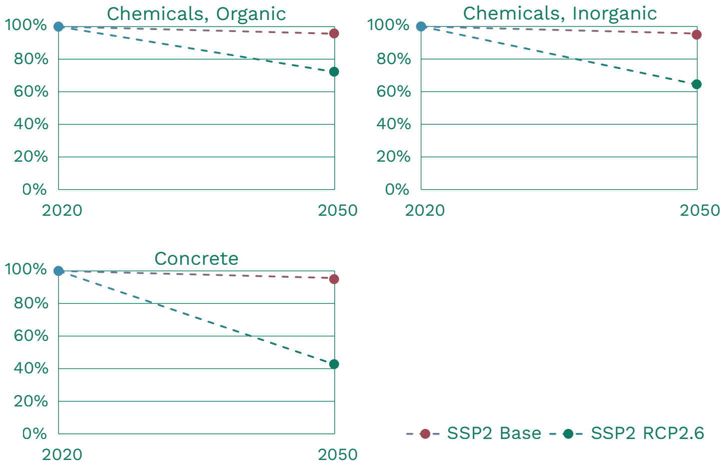


Figure 6.2 - Overview of the relative change of the Base 2050 (orange) and RCP2.6 2050 (green) scenarios from the Base 2020 scenario in Climate Change impacts for each of the 9 products. Note that the dotted line does not represent data points between 2020 and 2050 but is a visual aid to show the direction of change.

6.3.2 Direct contributions

In Figure 3 below, we show the Direct contributions from each of the product groups to each product in each of the 3 scenarios for Climate Change. Contribution results for all impact categories are presented in SI 1.2. Each stacked bar shows the contributions from a product group in a specific scenario, normalized to the SSP2-Base 2020 database; the black diamonds show the total change compared to the SSP2-Base 2020 database, similar to Figure 2 above. We find that total impact results are decreased through carbon uptake causing negative contributions from agriculture, though this result is skewed through our cradle-to-market approach, that biogenic carbon is generally emitted later, unless it is compensated for with CCS. For example, the Climate Change result for **Electricity** would still be low in the RCP 2.6 2050 database without the biogenic carbon contribution (~15% of 2020), though notably less with it included (~1% of 2020).

Also shown in Figure 3 is that the product groups *Electricity, Heat & Steam*, *Transport, Steel & Iron, Cement & Clinker* and *Chemicals* are primary direct contributors to their own respective FUs (**Electricity, Heat, Road Transport, Steel, Concrete** and both chemical products:

Chemical, organic and **Chemical, inorganic**). This means that these products are strongly affected by their own Direct contributions. Of these, only *Electricity, Steel & Iron* and *Cement & Clinker* show major changes. One other major product group contributing to all products is *Energy Resources*. The other products (A**luminium** and **Copper**) are also mainly affected by the previously mentioned product groups, primarily *Electricity* and *Heat & Steam*, though to a lesser extent than the product groups above.

Changes in impact for the FU **Electricity** are mainly affected by reductions in direct contributions from itself and *Forestry & Agriculture*. Changes in impact for **Road transport** are mainly from *Electricity* and *Forestry & Agriculture*, with little change in direct contributions from itself. Changes in impact for the metals (**Steel**, **Aluminium** and **Copper**) are mainly affected by reduced contributions from *Electricity* and *Energy resources*. This confirms that the product group *Electricity* is a major contributor in reducing climate change impacts. Finally, we see that changes in impact for **Concrete** are mainly affected by *Cement & Clinker*.

When we look more in-depth at the change in contribution from the product group *Electricity*, in Figure 3 we find that **Road transport, Concrete** and **Chemical**, **Organic** have a much higher relative impact from *Electricity* in the RCP 2.6 2050 database compared to Base 2020, this means these products make more use of electricity in the given scenario.

6.3.3 Direct and Indirect contributions

We also include a perspective of both Direct+Indirect contributions from each sector to each sector in SI 1.2. Contrasting to the Direct-only perspective for all databases for Climate Change above, we find that *Energy Resources* becomes more relevant in contribution for all FUs and scenarios, especially for **Chemical**, O**rganic** (45% - 57% of total impact). Transport also has a higher contribution for most FUs (from 10% to 17% avg.). Ore & Minerals becomes has a higher contribution for metals (**Steel, Aluminium**) but especially **Copper** (from 1% to max. 38%). Ore & Minerals also becomes more relevant for **Concrete** (from <1% to max. 9%) and **Chemical**, **inorganic** (from 2% to max. 22%). Chemicals also has a higher contribution for the metals, especially **Aluminium** (from <1% to max. 19%). This indicates that the product groups *Ore & Minerals*,

Climate Change Direct contribution from product groups to products in different scenarios

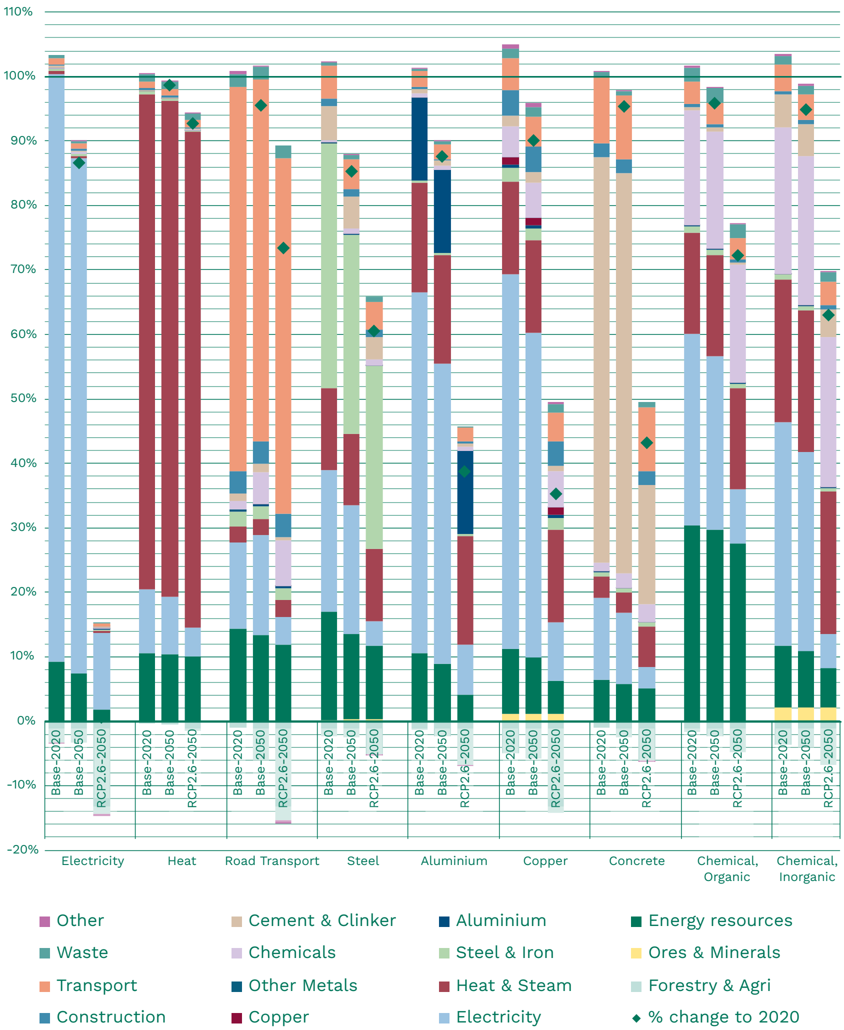


Figure 6.3 - Direct contributions for Climate Change of product groups to products. Each column represents Direct contributions from product groups to that specific product/scenario combination using SSP2-Base 2020, SSP2-Base 2050, and SSP2-RCP2.6 2050 databases. Each result is normalized to the Base-2020 database result of that product group, with a green diamond showing the percentage of the 2020 impact (e.g. a diamond at 80% implies the impact is 20% reduced). Due to (numerically) negative contributions, bars can total over 100%, as negative contributions offset all contributions >100%, the total will be 100%. For the exact values for this graph, see SI 1.2

Energy resources, *Chemicals* and *Transport* have strong connector roles, despite not always having high direct contributions themselves in each of the databases. Finally, specifically between the Base 2020 and RCP2.6 2050 databases, we also see that *Electricity* decreases in importance as a product group (37% avg. decrease), more so than we see with just Direct contributions (30% avg. decrease), due to the additional use of biomass (in the *Forestry & Agriculture* group) and CCS (of which a part happens directly in the *Electricity* group).

6.3.4 Impacts in other impact categories

We show an overview of our most relevant findings for all impact categories in Figure 6.4. This figure shows for each impact category the change in impact compared to the 2020 Base database for both 2050 databases. In SI 1.2 we show the Direct and Direct+Indirect contributions for each product group for each impact category.

In general, the trend we see is that impacts decrease the most in the RCP2.6 2050 database, in line with the storylines for both scenarios. We find that **Electricity** is generally a product with larger changes (Base 2050: 19% avg, RCP 2.6 2050: 70% avg.) than average (Base 2050: 10% avg, RCP 2.6 2050: 26% avg.), additionally, **Road Transport** and **Aluminium** are often found to have high changes (max. 47% and 151% increase compared to Base 2020 respectively). Of these, changes in impacts from Aluminium impacts are primarily driven by changes in the *Electricity* product group, as shown in SI 1.2.

With regard to impact categories, the following show the least change overall: 'Ecotoxicity, Fresh water' (Base 2050: 5% avg, RCP 2.6 2050: 19% avg.), 'Human Toxicity, Carcinogenic' (Base 2050: 3% avg, RCP 2.6 2050: 11% avg.), 'Ozone depletion' (Base 2050: 8% avg, RCP 2.6 2050: 13% avg.) and 'Water use' (Base 2050: 9% avg, RCP 2.6 2050: 12% avg.). Contrastingly, specifically in between the Base 2020 and the RCP 2.6 2050 database, 'Climate Change' and 'Eutrophication, freshwater' show major decreases overall (with -47%, -42% avg. respectively). Furthermore, 'Ionising Radiation: Human Health' shows the largest difference between the two 2050 databases, with major decreases in the Base database (with -56% max.) and major increases in the RCP2.6 database (with 151% max.). 'Land Use' is variable with major increases or decreases depending on the product with no obvious pattern. We

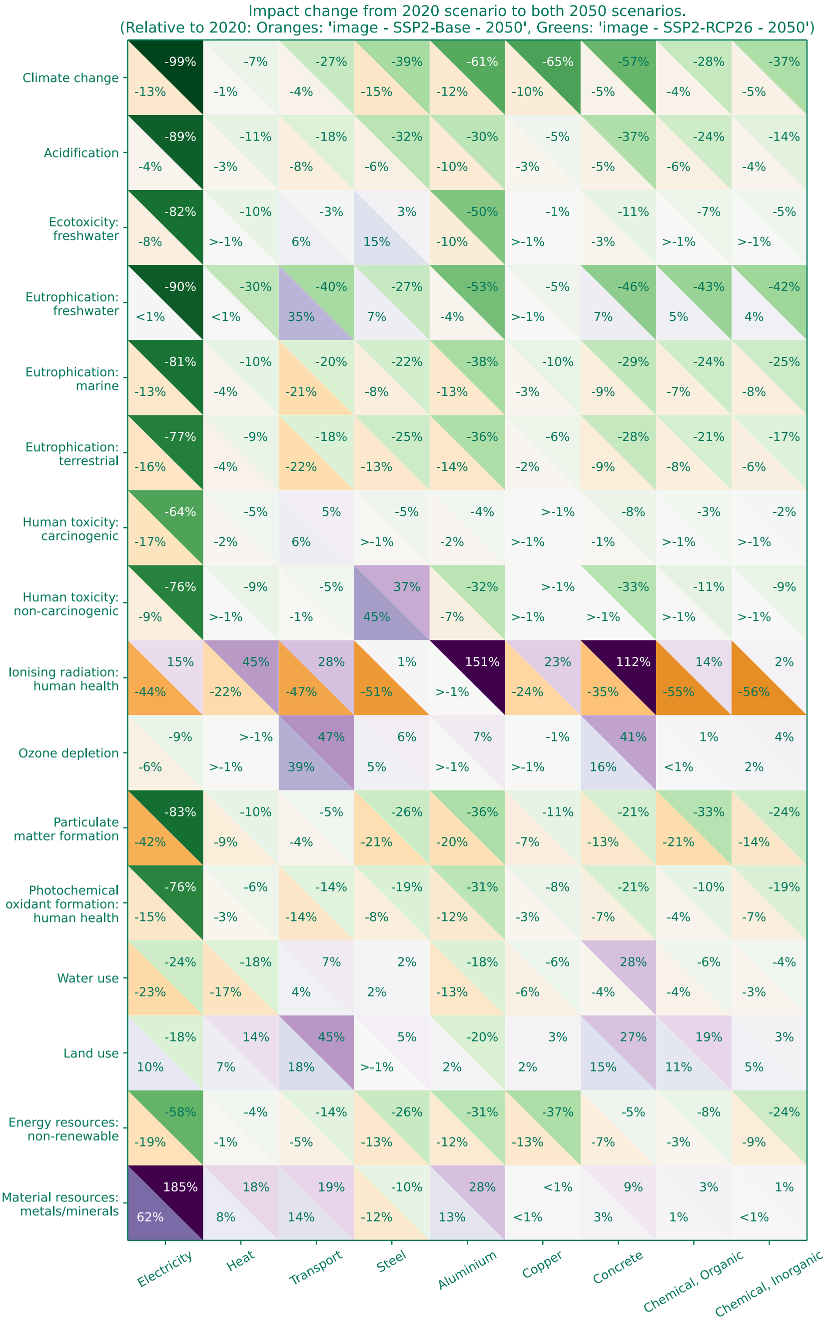


Figure 6.4 - Combined heatmap showing relative change in impact from 2020 scenario to both 2050 scenarios. Lower-left triangles in Orange for SSP2 Base 2050. Upper-right triangles in Green for SSP2 RCP2.6 2050. Columns show FUs, rows show impact categories. Note that purple triangles mean impact is increased compared to 2020.

also see a substantial increase in 'Material resources, Metals & Minerals' impact for **Electricity** (Base 2050: 62%, RCP 2.6 2050: 185%), this comes from increased material intensity from use of batteries and solar generation, conversely, we find decreases for **Steel** (Base 2050: -10%, RCP 2.6 2050: -12%), which comes from increased steel recycling.

6.4 Discussion

6.4.1 Key findings

We find that the product group *Electricity* is singularly the most important contributor to decrease future climate change impacts. *Forestry & Agriculture* is also a major contributor to decrease climate change impacts. Only the use of biogenic carbon when combined with CCS can be a source of CO^2 removal for the *Forestry & Agriculture* sector. We have also found that product groups like *Ore & Minerals*, *Energy resources*, *Chemicals* and *Transport* have strong connector roles (meaning they have relatively low direct contributions but link to processes with high impacts (Reinhard et al., 2016)) and can help reduce climate change impacts if used differently or less (e.g. switching ore types, or switching to electrified transport). Furthermore, we find that *Heat & Steam* is another important contributor to climate change impacts, with almost no change between databases in the FUs studied. While the *Heat* product group is currently changed by *Premise*, it is confirmed to be re-evaluated a future version of *Premise* (Sacchi, 2025a).

CCS is an important driving factor for decarbonization in *Premise* scenarios -specifically in the IMAGE IAM model (Stehfest et al., 2014)- but the implementation of CCS on the inventory level in *Premise* makes it challenging to assess the effects of CCS properly. Depending on whether CCS is modelled directly within a production process (e.g., clinker production) or indirectly via a separate CCS process (e.g., direct air capture), the flow of captured CO_2 may not be modeled as an elementary flow. While both implementations can technically be correct depending on the context, the use of different approaches makes it challenging to assess the effects of CCS at the scale of our assessment and impossible to create a single 'CCS' product group to assess contributions from.

We have shown that while climate change impacts can be expected to go down over time, depending on the specific scenario, we also see trade-offs between impact categories. These findings are in-line with recent work from Harpprecht et al (2025, Fig. 9) and Müller et al. (2024, Fig. 8) who studied steel and cement respectively. However, they do find that these trade-offs occur with different impact categories. While we cannot make direct quantitative comparisons, this still indicates that small modeling changes could contribute to high uncertainties in other impact category results than climate change.

As we shortly discuss in our results and more completely in SI 1.2, 'Land use' is an impact category with large changes in impact scores and large contributions from some product groups. We also see exceptional -but less large- land use impact changes in other recent work from Harpprecht et al. (2025) and Müller et al. (2024) who both use *Premise* as well. We discuss potential data problems in *Premise* based on our findings further in SI 1.2.11.

While *Premise* implements many different changes in different sectors, many are focused on improved technologies related to the energy transition or reduced climate change impacts. More negative potential changes have received less attention so far. For example ore grade has been established as an important variable for the environmental impact of many metals, (Aramendia et al., 2023; Harpprecht et al., 2021, 2024; van der Meide et al., 2022), inventories in *Premise* in product groups like Copper and many metals in the Other Metals product groups are often not changed to account for this. Not considering ore grade decline and other potential negative developments could mean impacts for metals production and other processes could turn out to be higher than found with current *Premise* databases. Such future developments should ideally also be included in pLCI databases for completeness, though attention should also be paid to keeping such work consistent with existing scenario story lines.

Our assessment shows that while *Premise* is a useful tool for the Prospective LCA community, there could be many specific details and nuances that practitioners need to be aware of, depending on the application. How representative the changes *Premise* makes are for other impact categories besides climate change, and how accurate these are, remains a question that is hard to answer. Though efforts are being made to make future scenarios more accurate for other impact categories as well, for example, changes to Ozone depletion (Van Den Oever et al., 2024). While some practitioners are aware of the additional uncertainty in interpreting LCA results for other impact categories besides climate change, this awareness may not be present in some parts of the *Premise* user community. Considering the advice Sacchi et al. (2022) give that “toxicity related indicators” should be considered to have high uncertainty and our findings for ‘Land use’, we advise practitioners to be very cautious with interpretation of any impact categories besides climate change.

6.4.2 Limitations

We identify two limitations to our work, both specifically relate to our choice of FUs.

First, we only assess the nine FU from over 30000 processes in *Premise* databases. While it is not reasonable nor feasible to assess each of those processes, we made a choice to limit our assessment to only nine processes. This is a result of balancing a ‘broad and shallow’ approach versus a ‘narrow and deep’ approach. Where the former assesses many processes superficially and the latter assesses a small set of processes in more detail. An example of a more ‘broad and shallow’ approach could be the work of Reinhard et al. (2019) on the ecoinvent database or the original presentation of results from *Premise* databases by Sacchi et al. (2022). We instead chose a ‘narrow and deep’ approach to gain deeper insight into the causes of changes, which may be missed with a more shallow approach.

Secondly, our specific choice of processes could also be considered a limitation. We chose these processes specifically for several reasons: They have global coverage (either the ‘GLO’ or ‘World’ regions) with many processes from each region feeding into those processes. They are often-used products by other processes, either directly or indirectly and contribute to global climate change impacts substantially. In our assessment, the product groups our FUs belong to contribute over two thirds of the climate change impact on average. Additionally, we chose a mix of products that are changed by *Premise* so we could thus assess the sectoral changes that affected these processes, but also processes that have no direct changes, so we could see to what level they were still affected by changes. As each practitioner could have different interests in processes, we encourage practitioners to critically inspect processes relevant to them in *Premise* databases themselves by for instance making use of our code supplied in van der Meide (2025b) to investigate processes they find of interest.

6.5 Conclusions

In this study, it was our goal to systematically analyze the effects of changes between several pLCI databases generated with *Premise* on results for practitioners, with the aim to give practitioners better insight into what kinds of changes they may expect in *Premise* databases and how those may affect their own results. We have shown with our approach that the effects of changes made by *Premise* have a wide reach within a database in terms of impact changes. We find that while climate change impacts for all products that we investigated decrease over time, they may cause substantial trade-offs in other impact categories, yet the quantification of these trade-offs is highly uncertain.

Our approach can help practitioners find potential errors -or otherwise product groups/processes of interest- in an LCI database, it could be useful for practitioners to adopt similar checks into product groups or processes to gain a deeper understanding of their results or find potential problems with inventory modeling or data. We also show that including an 'Indirect' perspective is important to highlight product groups connecting impacts from other product groups, an insight that a "Direct-only" perspective cannot provide, in line with findings by Reinhard et al. (2019). Though the approach of Reinhard et al. only allows the investigation of single processes, ours can assess groups of processes.

For practitioners, we recommend *Premise* be used primarily for assessing Climate Change impact and that practitioners emphasize the additional data uncertainty for other impact categories compared to e.g. the use of ecoinvent. Practitioners should explicitly mention which version of *Premise* databases and other software they use as continual development of the tool is likely to make their work irreproducible otherwise. While continuous improvement has advantages, it is also important for practitioners to realize this can lead to changes in results and to be explicit about what software versions they use to maintain replicability. Another option is to slow down the update cycle of *Premise*, e.g., aligning it with yearly updates from ecoinvent, this would give more time for quality assurance and fewer different versions used by practitioners, making studies using *Premise* more consistent with each other and more comparable. We discuss this in more detail in SI 1.2.11. We strongly recommend practitioners to review other recent work aimed at helping practitioners make correct use of *Premise* like that from de Bortoli et al. (2025) and Paris et al. (2026).

While we have taken a critical stance toward some aspects of *Premise* as a tool and the data it uses, we still recommend using it for prospective LCA and we encourage its developers to continue improving the tool. However, we suggest newly added LCI data to be peer-reviewed by experts in relevant fields to reduce inaccurate sources and mistranslation, we discuss this in more detail in SI 1.2.11.

6.6 Data Availability Statement

All data used in this manuscript is available in the Supplementary Information and code repository.

6.7 Funding declaration

The authors declare no external funding was used for the creation of this manuscript.

6.8 Competing Interest statement

Nils Thonemann serves as Guest Editor for this ‘Collection’ to which this paper was submitted but was not involved in the editorial handling of this manuscript.

6.9 Author Contributions

The authors contributions according to the CRediT taxonomy are:

	M. van der Meide	M. Hu	B. Steubing	N. Thonemann	A. Tukker
Conceptualization	●		●	●	
Data curation	●				
Investigation	●				
Methodology	●		●	●	
Software	●				
Supervision		●	●		●
Visualization	●				
Writing - *Original draft*	●	●	●	●	●
Writing - *Review & editing*	●	●	●	●	●

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