Work Package 1 – Shared modelling framework and learnings

D1.2 – Description of scientific methods

Task 1.1- Framework for background life cycle inventory of bio-based sectors

Method for modelling prospective LCI background databases

Lead Contractor: Norwegian Science and Technology University (NTNU)
Author(s): Marcos D.B. Watanabe, Francesco Cherubini

This document is a part of the ALIGNED project (grant no. 101059430) deliverable D1.2. It contains the methodological background and a guide to consistently implement the prospective life cycle inventory databases in both attributional and consequential approaches.

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DELIVERABLE CONTRIBUTORS			
	Name	**Organisation**	**Job title**
Deliverable leader	Francesco Cherubini	NTNU	Professor
Contributing Author(s)	Marcos D.B. Watanabe	NTNU	Researcher
Reviewer(s)	Massimo Pizzol	AAU	Professor
	Agneta Ghose	AAU	Assistant Professor
	Kíra Lancz	AAU	Research Assistant
	L.Hamelin	INSAT	Senior scientist
	Ugo Javourez	INSAT	Post-doctoral researcher
	Maxim Tschulkow	ANTW	Post-doctoral researcher
Final review and quality approval			

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Executive summary

This task consists of coordinating a consistent implementation of prospective life cycle inventory databases in ALIGNED. It first set the basis for modifying current background database both for attributional and consequential LCAs through elaboration of tutorials and codes that can be used by the partners and LCA stakeholders in general. It will then facilitate its application to the case studies in the bio-based sector by providing specific guidelines for modeling and generating future databases, considering different levels of complexities and needs, which can vary according to the skills of practitioners when implementing prospective LCAs (Tiered approach). The output databases rely on the use of ecoinvent and premise, which will generate future databases compatible with both SimaPro and Brightway2 software.

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1. The need for prospective background databases

The bio-based sector is indirectly reliant upon many background activities such as the energy sector for power generation, chemicals, materials, transportation, and others which can highly affect the results of life cycle assessment (LCA) studies. The technological profile, efficiencies, and emissions from such background sectors are currently and usually modelled using existing inventory databases, such as ecoinvent (Wernet et al., 2016). In this context, most LCAs employ a static background database approach, meaning that future technological improvements from background activities cannot be considered.

The prospective life cycle assessment (pLCA) is useful to assess the environmental performance of current and emerging technologies in the future (Sacchi et al., 2022). It introduces the expected changes in technologies and the environment at given point in time and addresses the limitations of conventional LCA by allowing for the gradual incorporation of technological improvements into future life cycle inventories. This approach can be useful to assess bio-based products since pLCA investigates the environmental performance of an existing product in the near future, which comprises technologies that may not have reached the market or have merely been introduced into minor niche markets (Arvidsson et al., 2018).

Although the literature about prospective life cycle assessment is broad (Bisinella et al., 2021; Sacchi et al., 2022; Thomassen et al., 2020; Thonemann et al., 2020), one of the main challenges of performing pLCA involves modelling consistent future background systems, thus avoiding a temporal mismatch with future foreground systems. For example, if a bio-based product is expected to be introduced into the market 5 years from now, the environmental assessment made in the present should consider the future changes in the structure of supply chains, gains in process efficiencies, and so on. Usually, scenarios to generate future background inventories are inconsistent, technology maturity is not accounted for, and reproducibility of these scenarios can be difficult due to large amounts of data required and assumptions made during scenario generation (Arvidsson et al., 2018).

According to previous works (Beltran et al., 2018; van der Giesen et al., 2020; Van Vuuren et al., 2014), such challenge can be overcome if existing life cycle inventory databases are transformed towards future contexts, informed by the Integrated Assessment Models (IAMs) that provide scenarios in line with the Shared Socioeconomic Pathways (SSPs). In this sense, background inventory databases are both linked to IAM's projections made for global supply chains and to technological and socio-economic narratives obtained from the different SSPs. This should be consistent temporal and geographical scopes, reproducible, and clear in terms of assumptions made during scenario generation (van der Giesen et al., 2020).

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2. Premise (Prospective Environmental Impact assessment)

Performing a pLCA depends on a prospective life cycle inventory database which adjusts entire clusters of industrial activities other than the sector of interest in the LCA. In this sense, a tool which integrates the expected transformation in the major (energy-intensive) sectors of the economy is needed. An open-source Python-based model named 'premise' (Sacchi et al., 2022) can be utilized to generate prospective versions of background inventories for bio-based industries. This model aligns the life cycle inventories of key processes in ecoinvent with the outputs generated by Integrated Assessment Models (IAMs) and different Shared Socio-Economic Pathways (SSPs). The full description can be found at https://premise.readthedocs.io/en/latest/introduction.html, however, we prepared a quick overview of this framework and a guidance on how to implement such programming routines.

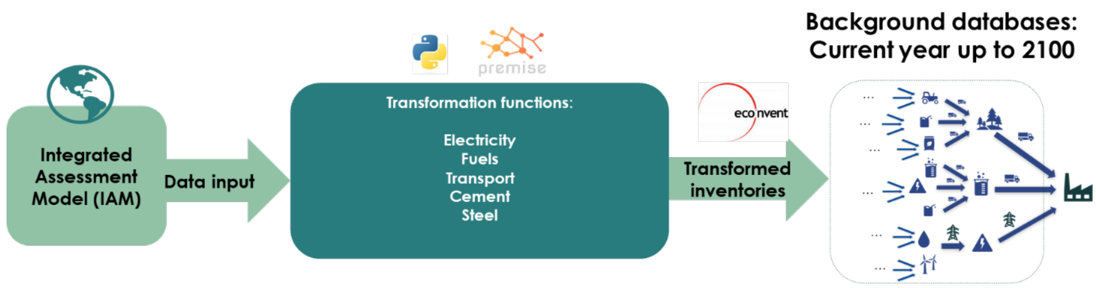

Figure 1 Visual representation of the prospective life cycle assessment carried out by premise (Sacchi et al., 2022)

2.1 IAMs and SSPs available

Integrated Assessment Models (IAMs) are technology-rich computer models that provide a comprehensive coverage of the global socio-ecological system: they cover environmental mechanisms, in particular the climate system and natural vegetation; the biophysical basis of society, including industries, households, and infrastructure; the economic, political, and behavioral superstructure that governs human decisions; and major coupling mechanisms between these elements (Pauliuk et al., 2017).

The outputs derived from IAMs serve as inputs for the transformation functions used in *premise* when generating prospective life cycle inventory databases. The projections made by IAMs are used to modify existing background LCI databases and include technological enhancements in electricity production mixes, power plant efficiencies, average fleet characteristics, energy mixes used for transportation, and advanced technologies for fuel and material production. Based on the scenario projection from the IAM, new background inventories can be developed to reflect the projected technological conditions for specific years, from present to 2100. Diverse future scenarios outlined by IAMs, influenced by the Shared Socio-Economic Pathways (SSPs), can guide these projections.

Currently, *premise* software is connected to the outputs of two main IAMs: REMIND and IMAGE. REMIND (Regional Model of Investments and Development, developed by the Potsdam Institute

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for Climate Impact Research) is a global multi-regional model incorporating the economy, the climate system, and a detailed representation of the energy sector. It embeds economic and energy investment models in each model region for the world (12 regions), fully accounting inter-regional trade in goods, energy carriers and emissions allowance. REMIND is often used for the analysis of technology options and policy proposals for climate change mitigation as well as related energy-economic transformation pathways (Luderer et al., 2015). IMAGE (Integrated Assessment Model to Assess the Global Environment, developed by the Netherlands Environmental Assessment Agency) simulates the environmental consequences of human activities worldwide by representing interactions between society, the biosphere and climate system. Originally, the model was built to represent the impacts on climate change, but the focus has shifted to other environmental and sustainable development issues over time. IMAGE simulates most of the socio-economic parameters for 26 regions of the world and its framework is structured around the causal chain of two main systems: the human or socio-economic system and the earth (Van Vuuren et al., 2021).

Also important in premise, the Shared Socioeconomic Pathways (SSPs) are alternative futures of societal development, which describes the future evolution of key aspects of society that would together imply a range of challenges for mitigating and adapting to climate change. The SSP narratives consist of variations of considerations regarding the future changes in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources (O'Neill et al., 2017). There are five shared socio-economic pathways: 'Sustainability: Taking the Green Road' (SSP1), 'Middle of the Road' (SSP2), 'Regional Rivalry: A Rocky Road' (SSP3), 'Inequality: A Road Divided' (SSP4), and 'Fossil-fueled development: Taking the Highway' (SSP5). The current version of *premise* covers three SSP options for REMIND (SSP1, SSP2, and SSP5) and one for IMAGE (SSP2).

Therefore, future background databases can be generated by selecting different Policy Scenarios that cover a range of emission reductions based on the stringency of climate policy implementation globally. As depicted in Figure 2, there are 18 possible scenarios to be modeled, 15 scenarios in REMIND and 3 scenarios in IMAGE. The different options are here ranked by order of stringency: no policy implementation (Base), National Policies Implemented (NPi), Nationally Determined Contributions (NDC), and the achievement of different CO_2 emission peak scenarios according to Paris Agreement Objectives.

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Integrated Assessment Model (IAM)	World Regions	Shared socioeconomic pathways (SSPs)	Stringency of Policy Scenarios
REMIND Macro-economy, energy and climate systems. Emphasis on technological changes, policy and energy system dynamics **Developer: PIK (Germany)**	**(12)** CAZ CHA **EUR** IND JPN LAM MEA **NEU** OAS REF SSA USA	**SSP2** **'Middle-of-the-road':** reasonable population growth, lower energy use, slow progress in achieving SDGs	**Base:** No policy. Representative concentration pathway (RCP) equivalent to RCP6.5, or 6.5 W/m2. Global mean surface temperature (GMST) increase: 3.5°C by 2100 **NPI**: National Policies implemented. RCP equivalent: None. GMST increase: 3.3 °C **NDC**: Nationally-determined contributions. RCP equiv.: None. GMST increase: 2.5 °C **PkBudg1150**: CO2 emissions peak at 1150 Gt. RCP2.6. GMST 1.6-1.8 °C (Paris Agr.) **PkBudg500**: CO2 emissions peak at 500 Gt. RCP1.9 GMST 1.2-1.4 °C (Paris. Agr.)
		SSP1 **'Taking the green road':** Optimistic trends for human development and economy, driven by sustainable practices (renewables)	**Base:** No policy. RCP equivalent: None. GMST increase: 2.3-2.8 °C by 2100 **NPI**: National Policies implemented. RCP equivalent: None. GMST increase: 2.2 °C **NDC**: Nationally-determined contributions. RCP equiv.: None. GMST increase: 1.9 °C **PkBudg1150**: CO2 emissions peak at 1150 Gt. RCP2.6. GMST 1.7 °C (Paris Agr.) **PkBudg500**: CO2 emissions peak at 500 Gt. RCP1.9 GMST 1.3 °C (Paris. Agr.)
		SSP5 **'Fossil-fueled development':** Optimistic trends for human development and economy, but high challenges to mitigation, world driven by fossil fuels	**Base:** No policy. RCP equivalent: None. GMST increase: 4.5 °C by 2100 **NPI**: National Policies implemented. RCP equivalent: None. GMST increase: 4 °C **NDC**: Nationally-determined contributions. RCP equiv.: None. GMST increase: 3°C **PkBudg1150**: CO2 emissions peak at 1150 Gt. RCP2.6. GMST increase: 1.7°C (Paris Agr.) **PkBudg500**: CO2 emissions peak at 500 Gt. RCP1.9 GMST increase: 1°C (Paris. Agr.)
IMAGE Society, biosphere and the climate system. Addresses climate change and other environmental issues and sustainability challenges **Developer: PBL (Netherlands)**	**(26)** CAN, USA, MEX, CAM, BRA, RSAM, NAF, EAF, WAF, SAF, **WEU**, **CEU**, TUR, UKR STAN, RUS, ME, INDIA, KOR, CHN, SEAS, INDO, JAP, OCE, RSAS, RSAF	**SSP2** **'Middle-of-the-road':** reasonable population growth, lower energy use, slow progress in achieving SDGs	**Base:** No Policy, representative concentration pathway (RCP) equivalent to RCP6.5, or 6.5 W/m2 translating into a GMST increase 3.5 °C **RCP26:** compliant with the soft targets of the Paris Agreement, reaching 2.6 W/m2 by 2100, GMST increase: 1.6-1.8 °C **RCP19:** compliant with the hard targets of the Paris Agreement, reaching 1.9 W/m2 by 2100, GMST increase: 1.2-1.4 °C

Figure 2 Compilation of available scenarios in the prospective life cycle inventory database creation (premise)

2.2 Transformation functions

The backbone of premise is ecoinvent, whose LCA database is re-shaped by using transformation functions. Essentially, this step applies improvements in the current industrial technologies (by increasing future process efficiencies, for instance), introduces future and new technologies (by inserting new foreground inventories which are extracted when running premise), and adjust the structure of the supply market mixes according to the outputs from IAMs and SSPs. Also, depending on climate Policy Scenario stringency, technology changes will be applied along with transformation functions. For instance, the stricter the environment policy is, the higher the use of new/greener technologies such as CCS, hydrogen, etc. These changes are introduced in the main energy-intensive and emitting sectors of the economy: Power generation, Cement production, Steel production, Transport, and Fuels. Since the global supply chains are highly dependent on these main sectors, all other downstream activities are indirectly affected by them. For instance, although the production of chlorine and sodium hydroxide are not directly transformed by premise, indirect changes in the performance of these production processes will be noticed because this industry is strongly dependent on power generation. Since electricity is expected to be generated by cleaner sources in the future, such chemical products have a better performances due to the indirect changes made by premise. In the current version of premise, there are main transformation functions directly changing ecoinvent activities:

a) Power Generation: it considers future gains in efficiency of power plants, as well as introduces cleaner technologies such as carbon capture and storage (CCS), increased adoption of photovoltaic panels, wind turbines, geothermal energy, and other cleaner sources.

b) Cement production: for the current activities in ecoinvent, it adjusts kiln technology and clinker-to-cement ratio efficiencies. For future technologies, it can consider the adoption of CCS.

c) Steel production: it assumes improved efficiency in the input of fuels for pig iron and steel production datasets for current activities in ecoinvent.

d) Transport: it provides changes in the future fleet of light and heavy transport vehicles (passenger cars, medium and heavy trucks, and buses). Also, it applies increasingly efficiency in fuel use and adoption of cleaner fuels.

e) Fuels: used by transport and power generation, it gradually introduces increasing shares of cleaner technologies such as hydrogen, biofuels, synthetic fuels (based on hydrolysis or direct air capture), and batteries.

When using premise, it is possible to choose which set of transformation functions will be applied to ecoinvent. For the attributional premise databases, all the transformations described are available. For the consequential, premise is limited to the changes in power generation and fuels.

3. Recommendations for database creation in ALIGNED

When running *premise*, some decisions need to be made regarding IAMs, SSPs, climate policy scenarios and year. The tested version for this tutorial (*premise 2.0.1*) allows many possible combinations between these parameters: 2 IAMs, 3 SSPs for REMIND, 1 SSP for IMAGE, 5 climate policy scenarios and selection of years between 2005 to 2100. This would generate a substantial number of databases, which might not be necessary for the objectives of some stakeholders in ALIGNED.

Considering the different skills among LCA practitioners, we suggest three different levels (or Tiers) based on the skill and time availability when using premise software:

3.1 Tier 1. Pre-determined scenario and single database generation

In Tier 1, the coding for premise software already considers a predetermined selection of one database scenario representing the average conditions, based on historical socioeconomic development and successful implementation of the existing National Determined Contributions (NDCs). The modification of ecoinvent database considers the following assumptions:

a) **Integrated Assessment Model**: REMIND**.** This IAM has a very in-depth description of technology development scenarios across energy-intensive sectors of the economy. Currently, it provides more flexibility when being integrated to other SSPs and climate policy narratives when compared to IMAGE.
b) **Shared Socioeconomic Pathways**: SSP2, Middle of the Road. Compared to others, SSP2 represents a balanced narrative of the future, with extrapolation from historical developments. Moderate development trends, moderate challenges to mitigation and adaptation, but with significant heterogeneities across and within countries. We assume that bio-based sectors are part of a world following a path in which social, economic, and technological trends do not shift markedly from historical patterns.
c) **Policy Scenario**: NDC (National Determined Contributions). This scenario represents the collective emissions reduction commitments submitted by countries as part of the Paris Agreement. These commitments, known as Nationally Determined Contributions, outline the efforts that each country is willing to undertake to limit global warming. The NDC scenario assumes that countries will implement and achieve the targets outlined in their submitted commitments. The SSP2-NDC scenario would represent a trajectory by which global mean surface temperature (GMST) increases by 2.5 °C by 2100.
d) **Year:** 2050. Most policies described at European level aimed at achieving climate neutrality by 2050. This is the basis of the 'Fit for 55' package, for instance, which comprises many different sectoral targets reduction of net greenhouse gas (GHG) emissions in the future. Although bio-based product implementation can happen much earlier, adjustments in the year of background database implementation can be made following the Tier 2 approach.
e) **Transformation functions:** ndb.update(). With this selection, all transformation functions available in the software will be applied. For the attributional analysis, this could be the best option since efforts made to achieve a sustainable future should address multiple sectors of the economy. For the consequential analysis, only ndb.update("electricity") and update("fuels") can be updated (2.0.1 version).

As described in the tutorial, this pre-determined code will generate the **REMIND-SSP2-NDC-2050 database** as main output. This modified ecoinvent database can be further connected to foreground inventories by both SimaPro and Brightway users.

Table 1 Summary of Tier 1 approach

	Tier 1
Speed of implementation	The fastest option. Users don't have to worry about linking their foreground inventories to innumerous background databases.
Output database	REMIND_SSP2_NDC_2050
Coding skills	Although some coding is needed, any Windows user can implement it reading the tutorials [Tutorial Tier 1 attributional.docx] and [Tutorial Tier 1 consequential.docx)].
Trade-offs	It only generates a single database option, so the variability from different IAMs, SSPs, Policy

	Scenarios, Years and Transformation Functions are not covered in the analysis.
Tested by NTNU?	Yes, by NTNU and ALIGNED consortium. For premise version 2.0.1, the main bugs were solved by the developers.

3.2 Tier 2. Flexible scenario and multiple background databases

In Tier 2, users make their own choices regarding IAM, SSP, Policy Scenario and Year. Moreover, the user can generate as many databases as they need, thus reflecting their interest on creating sensitivity scenarios to different years, narratives for the future and IAMs. A modified tutorial with instructions for implementing such minor modifications will be available. Some reflections to guide user's decision making can be found below.

a) **IAM.** The choice between REMIND and IMAGE can follow at least two criteria. The first is more practical, related to flexibility of multiple scenario creation in the current version of the software. So far, REMIND allows more flexibility since it offers more options of SSP narratives and policy scenarios. The second is related to methodological choices. IAMs are built under different assumptions and framework, so there is no 'right or wrong' choice. IMAGE focuses on analyzing energy systems, technology adoption and economic development in a regionalized context with strong emphasis on technological change. IMAGE also captures the global and regional dynamics but with focus on addressing a wide range of environmental and sustainability issues beyond climate change, including biodiversity loss, air quality, water resource, etc. To avoid trade-offs related to IAM choice, users can use both models to compare environmental impacts under similar SSP and policy narratives whenever it is possible.

b) **Shared Socioeconomic Pathways.** The narrative for the future world can vary substantially across scenarios, so considering either more optimistic or pessimistic SSPs will depend on how user perceive the future societal development pathways. SSP1 ("Taking the Green Road), for example, can be more suitable if bio-based sectors are assumed to be inserted into a world shift toward a more sustainable path and increasing use of renewable energy among most regions in the world. In such scenario, there are relatively low challenges to mitigation. There are improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation. SSP5 ("Fossil-fueled development—Taking the highway"), on the other hand, describes a world driven by the economic success of industrialized and emerging economies. However, the strong reliance on fossil fuels and the lack of global environmental concern results in potentially high challenges to mitigation.

c) **Policy scenario:** stringency of climate policy adoption is also uncertain, and the actual implementation of them can vary among countries and regions. Based on efforts made by some countries in Europe, for example, NDC might align closely with their commitments. If countries remain dependent on fossil fuels (for energy, transport, and heat generation) without further plans to change their trajectory of production and consumption, for instance, Base scenario would describe the future societal trajectory without any environmental policy

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implemented. However, the different regions of the world might implement more ambitious or less ambitious measures based on domestic circumstances, political context, technological advancements, and international collaboration. If the best policy circumstances are achieved worldwide and warming is kept below the 1.5 to 2 °C limits by 2100, the scenarios of carbon budget constraint (in REMIND, represented by PkBudg 500 and PkBudg1100, respectively) should be considered.

d) Year: The software allows choosing any year between 2005 and 2100. Therefore, the first observation is that background databases should reflect future scenarios, i.e., consider scenarios after 2024. The selection of years can be based also on at least two main criteria. The first one is to consider specific bio-based sector targets, such as emission reduction goals by 2030, 2050 and so on. In this case, future background inventory databases should reflect relevant years according to sectoral policy targets. The second one is the to consider the year that the product will be introduced into the market. For example, if someone expect that the bio-based product will be released in 2025, the background database should be generated reflecting the supply chain conditions of that year. Furthermore, users could generate more scenarios picking any year between 2025-2050 also to assess how their bio-based products would perform under sectoral policy. We advise not using years beyond 2050 due to large uncertainty involved in projections made for IAMs, SSPs and Policy Scenarios.

e) Transformation functions: When using premise, it is possible to choose which set of transformation functions will be applied to ecoinvent. For the attributional databases, it is possible to apply either all, or just a customized selection of options (power generation, cement, steel, transport, and fuels). For the consequential approach, the current version of premise is limited to changes on power generation and fuels. Selecting a specific transformation function, i.e., power generation, means that progress towards sustainability will only be made in a single sector of the economy.

In Tier 2 approach, multiple background databases can be generated. The creation of innumerous databases will imply more time spent when liking foreground and background databases. A Python code is made available to accelerate this linking of foreground LCI to background databases; but such codes apply only to Brightway2 users. The tutorial for generating multiple databases under Tier 2 approach was also made available, which requires only a few adaptations to the codes from Tier 1.

Table 2 Summary of Tier 2 approach

	Tier 2
Speed of implementation	It will depend on how many databases will be generated by the user.
Output databases	Flexible, multiple databases
Coding skills	Very similar to Tier 1, with the need of editing some lines in the code. Any Windows user can implement it: Tutorial Tier 2_attributional.docx and Tutorial Tier 2_consequential.docx
Trade-offs	If too many are generated, linking foreground to background databases can be very time-consuming. However, a tutorial to accelerate database linking can foreground and background databases is provided in

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	the links above. This tutorial can only be applied for Brightway2 users.
Tested by NTNU?	Yes. For premise version 2.0.1, the main bugs were solved by the developers.

3.3 Tier 3

Tier 3 applies the same features of Tier 2. In addition, it opens the possibility of developing user-defined scenarios and increasing geographical resolution.

3.3.1 User-defined scenarios

As explained by the developers, user-defined scenarios enable users to integrate custom scenarios, in addition to (or as an alternative to) existing IAM scenario. The current version of the software also allows the creation of user-defined scenarios. This feature is particularly useful when users wish to incorporate projections for a sector, product, or technology that may not be adequately addressed by standard IAM scenarios (see more info at: https://premise.readthedocs.io/).

For example, we consider the production of a bio-based polymer ('BB polymer', in this example). Let's assume that BB polymer's foreground inventory depends on electricity purchased from the grid, wood chips, as well as using a specific chemical (e.g., 'chemical A') which is transported by trucks, as depicted by Figure 2. This example shows that, after carrying out the LCIA, 50% of greenhouse emissions of a bio-based polymer production (namely 'BB polymer', as an example) can be reliant on a specific chemical (e.g., 'chemical A'). Although electricity, biomass and transport systems are well represented in projections made in premise, there is a possibility of creating specific trajectories for 'chemical A'. In this example, 'chemical A' becomes relevant due to its large environmental impacts (GHG, in this example)

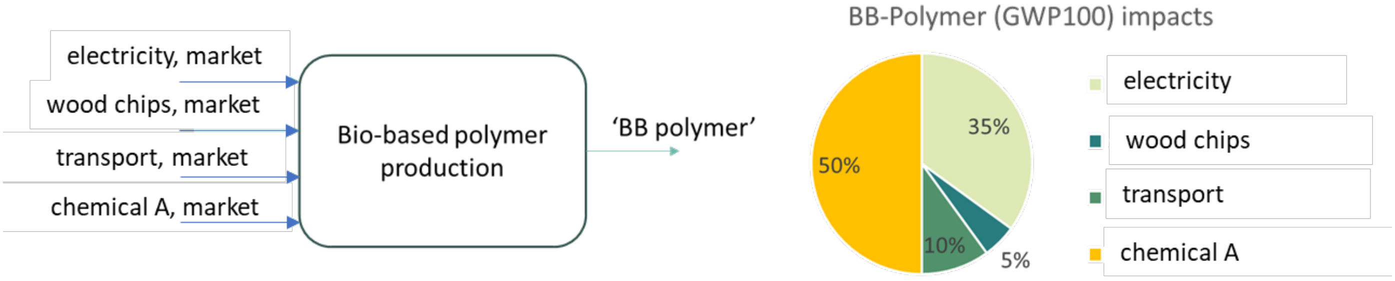

Figure 3 Illustration of the hypothetical case of bio-based 'BB polymer' production and GWP100 impacts

However, implementing Tier 3 within the scope of ALIGNED can be challenging and time consuming. This approach is data intensive and requires more developed programming skills. The application of Tier 3 would depend on preliminary results from case-studies to identify which background activities would require a better description of technologies and market structure.

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Here we highlight some data required to perform Tier 3 analysis.

a) **New foreground inventories:** a mix of the production technologies and the market structure to better describe 'chemical A' would be required. Considering that this chemical could be produced via different technological routes in the future, a roadmap with the most promising technologies projected production volumes of 'chemical A' would be needed. In this sense, a through research would be required to create new foreground inventories describing various ways of producing chemical A in the future. Besides, this approach also requires the forecasted industrial efficiency that will be observed in the forthcoming years, such as for example, increase in product yields and reduction in the consumption of inputs, such as electricity.
b) **Data alignment with IAM**: As IAMs are built to represent different regions of the world, data at this level of disaggregation are required, such as production volumes, for instance. Moreover, projected data should be aligned to IAM trajectories, and SSP narratives. Finding/estimating this type of data can be very time consuming.

Because Tier 3 involves a customized approach with specific data collection and assumptions, we did not develop any tutorials. For more information, more information can be found at **https://github.com/premise-community-scenarios**.

Table 3 Summary of Tier 3.1 approach

	Tier 3.1
Speed of implementation	The slowest of all Tiers.
Output databases	The most complete option, it can build upon Tier 2 generating multiple and flexible databases, with customized scenarios.
Coding skills	Harder to implement, it has more complexity for users without any programming skills.
Trade-offs	It can be risky given the project deadlines. Very time consuming and data intensive. Depend on data from market reports and deeper knowledge about how technologies and market structures will evolve globally across the forthcoming years.
Tested by NTNU?	Partially. Some tests were made with examples available online, however, new scenarios built from scratch were not tested yet.

3.3.2 Increasing geographical resolution

Because IAMs cover world macro-regions, sometimes data can be aggregated and do not reflect properly the projections made for specific sectors or products. In the same illustration of 'BB polymer' production, we could assume that such production is occurring in Norway. In this case, although premise applies transformation in power generation systems, the profile of European electricity mix from IAMs would not reflect the carbon intensity of the Norwegian electricity mix,

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which has a much larger share of renewable sources when compared to the European average. In this case, it is possible to create additional databases to represent future Norwegian electricity mixes, whenever data is available.

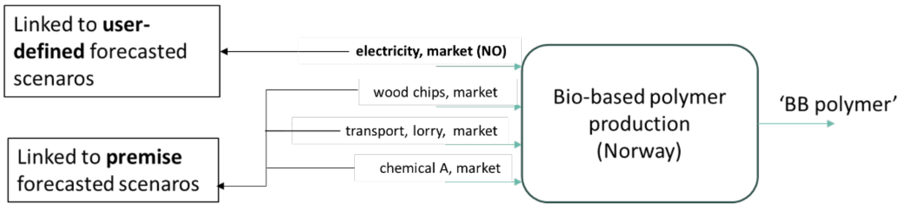

Figure 4 Illustration of the hypothetical case of bio-based 'BB polymer' production and different linkages to background databases

The approach depicted in Figure 3 was previously applied to both biofuel and e-fuel production for long-haul transportation under prospective life cycle assessment approach (Ballal et al., 2023; Watanabe et al., 2022). The approach consists of creating new/separate background inventories according to user-defined forecast data. This approach is possible whenever projections are available. In the case of the Norwegian electricity mix, market shares were adjusted and linked back to existing inventories from premise databases (i.e., hydropower, wind power, solar power, etc). In the example of Figure 2, the other input activities from the technosphere (such as biomass, transport, and chemical A) would be linked to premise-generated databases. This approach might lead to small inconsistencies, but it can be justifiable when a regional mix is remarkably different when compared to the markets projected by IAM macro-regions. Tier 3.2 also does not have a tutorial available since it deals with specific situations, depending on a set of assumptions and data availability.

Table 4 Summary of Tier 3.2 approach

	Tier 3.2
Speed of implementation	It can be faster than Tier 3.1
Output databases	It can build upon Tier 2 (flexible and multiple databases) and adds additional user-defined background inventories.
Coding skills	Same as Tier 2.
Trade-offs	Implementation will depend on data availability and projections with higher geographical resolution. This approach might lead to small inconsistencies with IAMs, but it can be justifiable when a regional activity is remarkably different from IAM macro-regions.
Tested by NTNU?	Yes.

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4. Final remarks

Ensuring a consistent implementation of prospective life cycle inventory databases within ALIGNED is paramount. This methodological framework provided the groundwork by applying state-of-the-art software to compile background databases for both attributional and consequential LCAs. Through comprehensive tutorials and codes tailored for ALIGNED partners and LCA stakeholders, they will be able to carry out their own prospective LCAs. With guidelines accommodating varying levels of complexity and practitioner skills, we enable different types of users to implement their prospective analysis, ensuring compatibility and accessibility through different LCA software.

This tutorial was designed to be easily implemented by LCA practitioners without any previous experience with coding. It provided each step to ensure prospective database creation using premise. Tier 3, although it can provide a much more complete and case-specific database creation framework, has the disadvantage of being time-consuming, especially Tier 3.1. Database creation through Tiers 1 and 2 is strongly recommended since it can be quickly implemented with similar steps for coding. However, the user will decide how many databases to generate based on their specific needs and research questions.

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