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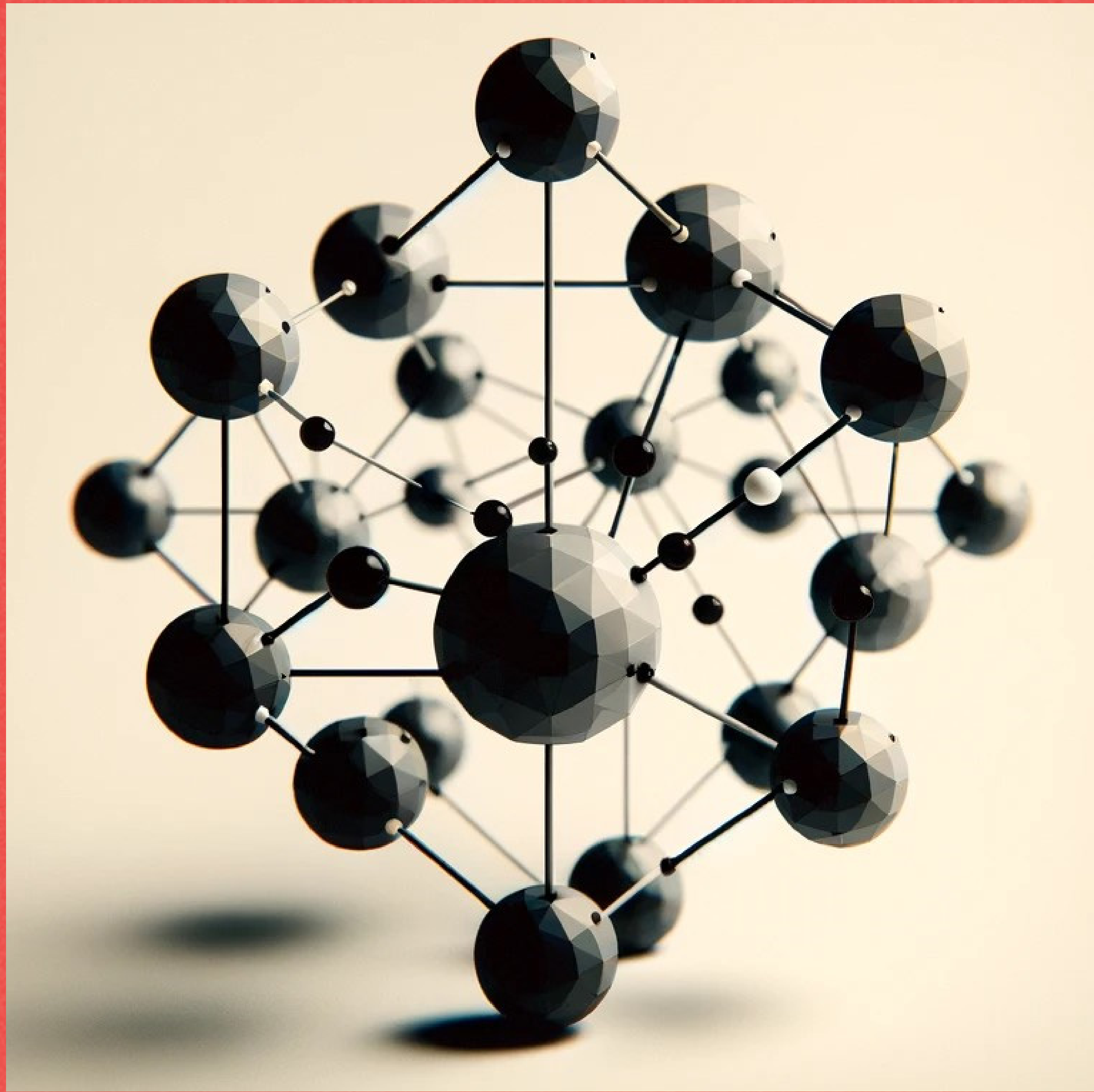
A Prototype for a Carbon Tracking System



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1. Project information and introduction

In a time where governments design and implement various policies to reduce fossil carbon flows, tracking these flows is becoming increasingly important. This report documents a project regarding this matter, carried out by Rebel Group and Kryha. The project was commissioned by Rijksdienst voor Ondernemend Nederland (RVO, Netherlands Enterprise Agency) on request of the Topsector Energie programma Digitalisering (Top Sector Energy Digitalization Program), in collaboration with Unilever. The aim was to deliver a prototype for advanced carbon accounting or a "Carbon Tracking System" (CTS). The end goal of a CTS is to equip organizations with the tools necessary to make informed decisions that promote, support and prove the use of sustainable carbon and to calculate the associated scope3-emissions of material use. This chapter provides

PROJECT OBJECTIVES

Project Objectives

The main research question of the project is: **What are the effects of a Carbon Tracking System, compared to the current way of working?** To answer this question a clickable prototype of a CTS was developed that can be used by governments and businesses to track carbon flows through a value chain. The designing of a prototype with active market players and the government, by determining requirements of a future way of working, reveals the benefits and costs of a CTS. These effects include various potential implementation elements such as decentralization and further digitization.

PROJECT SCOPE

The scope is deliberately set to concentrate on tracking carbon atom sources and not carbon emissions. This focused approach allows for an understanding of possible choices in the design of a CTS and their effects on the useability of the product as was concluded from previous studies on the design of a Carbon Tracking System[1] and see more on previous Carbon Tracking System projects on slide 5.
here. The focus of the prototype is to track carbon throughout the value chain and to allocate carbon to the output, not the allocation of sustainable carbon within the processes (see Figure 1). Rules for allocation of carbon within processes are determined by legislation or (when specific rules are not present in legislation) by certification schemes used by companies.

METHODOLOGY

To attain these objectives, the project followed a structured methodology consisting of five main phases:

1. **Contextualization:** in this phase, the current way of working and developments around carbon tracking and certification were researched
2. **Exploration:** in this phase, the project team established a list of requirements that state the precise needs and specifications of a CTS. This phase includes determining which elements may be required in future CTS developments, but beyond scope of the prototype.
3. **Prototype development:** following requirements definition, the prototype was developed.
4. **Stakeholder validation:** the design is assessed with stakeholders, verifying whether the system meets the set requirements.
5. **Comparative analysis:** the benefits and costs of the proposed CTS is compared the current way of working to measure the viability of a CTS.

OUTLINE OF THIS REPORT

This report describes the steps and outcomes of the project. The current context of carbon accounting and the need for a digital system with decentral elements is described in the following chapter. In chapter 3, the requirements and limitations of the CTS are defined. The main result of this project, the prototype for a CTS, is presented in chapter 4. Chapter 5 depicts the possible costs and benefits of that prototype if it were to be implemented. The findings of this project are described in chapter 6, followed by acknowledgements in chapter 7.
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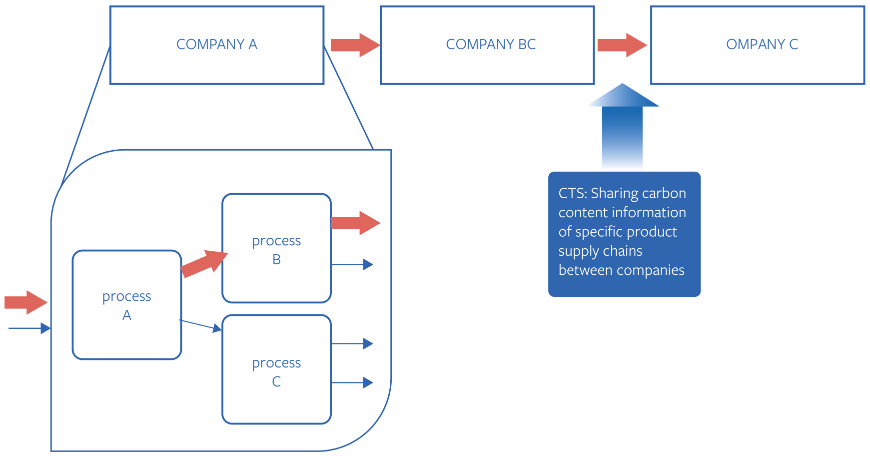


Figure 1. Focus decentral administration on passing information on in the value chain (rather than allocation in a process/step)

[1] Whitepaper "Design of a Carbon Tracking System" RVO 2021

2. Context of physical carbon accounting

This chapter describes the context of carbon accounting, ranging from the current way of working via certification to the development of a Carbon Tracking System (CTS). It states the possible benefits and downsides of a CTS and how decentral digital solutions might counter these downsides.

THERE IS A NEED FOR WAYS TO TRACK CARBON FLOW SOURCES IN VALUE CHAINS

Regulatory frameworks in the Netherlands and European Union (EU) underscore the significance of carbon accounting as a useful tool for environmental accountability and sustainability.
The EU Green Deal and the Dutch Climate Agreement and National Circular Economy Program represent clear roadmaps toward net-zero emissions by 2050 and circularity targets. These EU and Dutch legislation and programs require companies to track

1. The EU's Corporate Social Responsibility Directive (CSRD), scheduled to be fully implemented by 2024, necessitates companies to report on environmental and societal impacts[1].
2. **Sustainable Carbon Cycles[2],** Industrial Sustainable Carbon: by 2028, any ton of CO_2 captured, transported, used and stored by industries must be reported and accounted from its origin; by 2030, at least 20% of the carbon used in products must come from sustainable non-fossil sources;
3. Initiatives mandating the use of recycled materials, such as the **Single-Use Plastics Directive (SUPD)[3]** and the proposed revision of the **Packaging and Packaging Waste Regulation (PPWR)[4]**, are stimulating organizations to trace the origins of recycled content in their products.

These measures collectively encourage transparent carbon tracking, both for companies and governmental bodies in the EU and the Netherlands. Companies increasingly need to be able to prove claims on the sources of carbon in their products. Governments need instruments to track value chains in order to steer and validate new and existing policies.

THE CURRENT WAY OF WORKING IS VIA CERTIFICATION

At this moment, certification is the prevalent working method. To prove a claim on the origin of a material (e.g., residual materials or biomaterials), certificates from the origin (collecting/sorting plant for residual materials or biological sources) are needed. The lack of digitalization and automation in this process increases human error likelihood.

Organizations can check validity of certificates in databases, but there is currently limited view on material flows along a supply chain. The current way of working does give the government insight into certified sustainable companies and location but little insight in total yield, the (ratio between) certified/sustainable or uncertified/unsustainable material flows and the overview of a vertical supply chain

(PHYSICAL) CARBON ACCOUNTING IS UNDER DEVELOPMENT

Systems for carbon accounting are being researched, developed and already implemented in several sectors. The textbox below mentions two other known initiatives.
These examples show that carbon accounting systems are developed in parallel. Carbon accounting, implemented in such systems, enables tracing material through value chains. This has clear benefits:

- **Transparency** in value chains enables companies to verify their sustainability claims. A CTS could, for example, eliminate a lot of work for companies that are required by the CSRD to report their impact on people and the environment from 2024.
- Gaining **insight on material flows** by gathering (or bundling existing) data and providing an overview of the value chain. This enables both companies and governmental bodies to steer and reinforce policies. This could mean complying with mandatory minimum recycled or renewable content by companies, but also tracking the effects of policies by governmental policymakers.
- **Transfer information through the chain**. A CTS can not only gather (correct) data on carbon flows in value chains following certification rules, but also selectively transfer data from company to company, making sure confidentiality is not compromised.

Other developments Carbon Tracking Systems

Several companies are developing carbon accounting systems, enabling their clients to track materials and products in value chains. Two examples are:
Circularise offers a blockchain-powered traceability solution for comprehensive supply chain oversight. It enables actors to share sensitive data while promising no compromises to privacy. It promotes resource use improvement, provenance verification, carbon footprint assessment, and impact analysis using mass balance chain of custody.
GreenToken is a web-based SaaS solution by SAP that aims at tackling the challenge of proving sustainability and circularity in raw material supply chains. It uses blockchain, mass balance, and tokenization principles. The platform is validated through Proof-of-Concepts with industry leaders and targets the chemical industry
Both examples are systematically similar to a CTS, with the most important difference that the concept of CTS is developed with the government as an additional user in mind.

[1] In the Annex I of the European Sustainability Reporting Standards (ESRS) the reporting standards for resource use and circular economy are described, including reporting on total weight and percentages of biological and recycled material.
[2] See the site on Sustainable Carbon Cycles by the European Commission.
[3] See this publication on rules for recycled plastic content related to the SUPD.
[4] See the site on the revision of the PPWR

Implementing a CTS also brings possible drawbacks that should be addressed before it can be implemented on a greater scale:

- **Confidentiality** play a role when organization exchange information on products and material sources.
- **Complexity of the value chain.** When a company uses materials and products from a variety of suppliers, which in turn have multiple suppliers themselves, the complexity of the value chain increases exponentially. A CTS should be able to deal with this complexity.
- A CTS will be **data-heavy.** For a carbon accounting system such as a CTS to be of use, a lot information should be transferred on materials and products through the (exponentially complex) value chain.
- Working with a CTS will be **additional work for companies** to comply. The additional work could be compensated by audit costs that are not longer needed.

In this study we have:

1. **designed and built a prototype of a digital CTS that illustrates the benefits and minimizes the drawbacks and;**
2. **done a comparative analysis of the benefits and drawbacks.**

Together these elements allow us to answer our research question: **What are the effects of a Carbon Tracking System, compared to the current way of working?**

Previous experiences by Kryha related to carbon tracking

Since 2018, Kryha has been involved in many projects related to traceability of raw materials and green house gas emissions.

An example comparable to CTS is Re|Source, a collaborative traceability platform that aims to ensure that all battery metals, starting with cobalt, in EV end- products are sustainably sourced. Companies within the can account for every unit of battery metal in their end-product and prove their origin. After confirming battery metals origins, batches are traced and digitally verified. Inputs are matched with outputs, and vital documents are uploaded and stored at every touchpoint, making relevant information real-time available for key stakeholders, with respect to the confidential nature of specific data. This results in verified claims, informed decision making, and an industry wide collaboration to drive sustainability performance.

Next to this, Kryha has designed and built traceability products for the renewable fuels, plastics, and mining sector.

Previous Carbon Tracking System projects

Since 2020, Rebel has undertaken several projects for the Dutch government concerning the design and development of a Carbon Tracking System (CTS).

The first study, conducted for RVO and Topsector Energie in 2020, focused on design principles for a CTS to map CO2 chain effects (scope 3) in the industry. Rebel outlined design principles for a feasible system, emphasizing two preferred variants: one tracking carbon origin and another that tracks CO2 emissions. Recommendations included aligning system goals with circularity or emission reduction, considering the international component, and ensuring complementarity with the ETS. A pilot was advised, preferably for the plastic chain, focusing on simplicity, testing both variants, involving key players, and using fixed values to address data gaps or complexity issues.

The second project was commissioned also by RVO and Topsector Energie. Addressing the limitations of current industrial sector climate policies, the project emphasized the need for a CTS to tackle Scope 3 emissions. It was undertaken to enhance transparency and traceability in the industrial value chain via a CTS, and aimed to administer the effects of circular measures, such as substituting fossil raw materials with biomass, recyclate, and captured CO2. A pilot study, conducted in the PET bottle value chain, explored the two CTS variants from the preluding study. Variant B, mapping carbon flow origins, was preferred in the end. The study concluded that a CTS is not only feasible and desirable but also necessary. The participants endorsed its purpose, recommending careful determination of emission allocation methods and control mechanisms for a successful prototype implementation.

Commissioned by the Dutch Ministry of Infrastructure and Water Management (IenW), this third project by Rebel focused on rules for calculating emissions from carbon streams and origins. The study explores the feasibility of implementing a carbon accounting system based on the traceability of carbon molecules' origins. Studying variants of a CTS in the PET and asphalt chains revealed varying levels of traceability. Findings suggest that a carbon accounting system could complement existing methods, providing insights into emissions associated with carbon origins. A challenge was dealing with assumptions in Life Cycle Analyses (LCA). Recommendations included further validation in other chains, exploring the feasibility of tracing carbon origins, and enhancing transparency while respecting confidentiality constraints. Overall, the study underscores the potential of a carbon accounting system to promote the use of sustainable carbon sources and reduce CO2 emissions in industrial chains.

3. Requirements and limitations of the prototype design

The CTS is designed based on a complete set of requirements that ensure the necessary information overview and insights for companies and governmental organizations, while recognizing the confidentiality restrictions and operational reality of supply chains. The criteria form a middle ground between an envisioned optimal future work approach and a practical progression from current work methods. They have been collected based on desk research and discussions/interviews with the government and industry players.

The approach to developing requirements utilizes a **backtracking methodology** (see figure 2), structurally working in reverse from the envisioned outputs to logically derive the necessary inputs and information flow. This includes the following four steps:

1. The desired **system outputs** are identified, based on future desired reporting. User needs and stakeholder requirements are carefully considered to ensure that the system outputs align with decision-making objectives.
2. The **calculations required** to generate these outputs are determined, keeping in mind current and possible future calculation standards.
3. Specific **system inputs needed** for the calculations are identified.
4. The **information flow** is determined so that the inputs, calculations and outputs are integrated.

The resulting requirements from this methodology are as follows:

SYSTEM OUTPUTS

- Total quantity produced (ton/kg); total carbon content (% of total mass), (preferably) total quantity (ton/kg/ yield %) carbon lost (for emission tracking)
- Percentage distribution of carbon sources e.g. 50% bio-based, 25% recycled-based, 25% fossil-based and proof of sustainability.
- Industry and government access to data updates (new incoming/outgoing shipment reviews), insights (total production and carbon sourcing, material origin) via dashboard.

CALCULATION METHOD

- Calculation is (initially) done according to the mass-balance chain of custody. This allocation method is a common chain of custody model that allows tracking of net (non-)sustainable materials while they are mixed during processes and passed through supply chains. This chain of custody has higher credibility, accountability and lower greenwashing risk compared to the book and claim calculation method in which credits (and thus claims) can be traded, without any connection between certificates and physical products. This method is currently commonly used since, without a CTS, it is the easiest chain of custody. Other chain of custodies (segregation, identity preservation) can also be implemented in a CTS for products with specific needs, but these have not been demonstrated with the prototype (see limitations)[1].
- Within the mass-balance chain of custody, the prototype follows the proportional/ technical balance allocation, meaning that % carbon sources of inputs are allocated (based on their mass output proportion) to all outputs of the process. Other ways of allocation are free allocation (supplier can choose distribution of sources across outputs), polymers only, auto-consumption- or fuel-exempt (allocation allowance depends on certain output properties).
- Differentiation between carbon-intensive materials input and materials with <x% carbon content, of which sourcing information may be excluded.
- Differentiation between material inputs for product and material input used as energy source (and not embedded into product).
- Calculation of carbon lost during processing due to inefficiencies.

SYSTEM INPUTS

- Quantity of material inputs and outputs for each process
- % Carbon atoms per material input
- % Carbon source (bio/fossil/recycled) per material
- Process efficiencies to calculate carbon lost
- Applied certification (e.g. ISCC) that correspond to material inputs
- Production location (in some cases this information can be drawn from certificates)

INFORMATION FLOW

- Suppliers should allow certain information (% carbon source bio/fossil/recycled after processing) to flow to recipients (their customers). The benefit of a CTS is that information can be passed along the supply chain in a traceable and verifiable manner. More specifically, the system input data required can be a result of the CTS calculations if the product supplier has uploaded the material batch onto the CTS and given permission to share certain information with the recipient
- Multi-party verification (supplier/recipient)

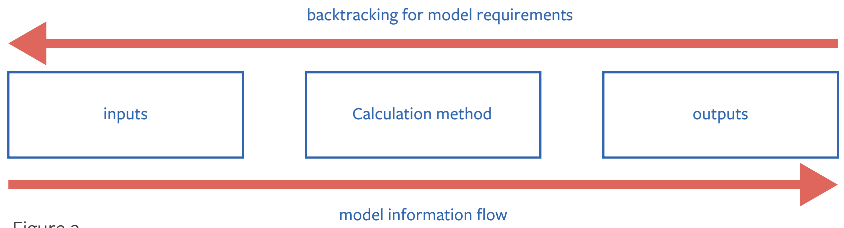


Figure 2

[1] Circularise (2022), Four chain of custody models explained

In determining the requirements, certain elements were excluded since they were found to be nice-to-haves that can be part of further development stages of a CTS, but considered out of scope for an initial prototype that should illustrate the foundational function and benefits of a CTS. These limitations include:
Other chain of custodies including:

- Other chain of custodies including:
  1. **Segregation,** in which certified materials are not mixed with uncertified materials. This allocation method allows for more product distinction and higher credibility and comes at a higher logistical effort and cost. A CTS would be able to administratively track the materials and provide an overview similar to the mass balance.
  2. **Identity preservation,** is similar to segregation, but does not allow for mixing of certified materials that have the same standard. This requires an even higher logistical and auditing effort and cost and allows companies to make stronger unique product claims.
  3. **Book and claim,** a commonly used method, in which credits (and thus claims) can be traded. This method requires the least auditing and logistical effort but makes no connection between physical products and certificates.
- Other allocation types within the mass balance chain of custody such as free allocation (supplier can choose distribution of sources across outputs), polymers only, auto-consumption- or fuel-exempt (allocation allowance depends on certain output properties).
- Other forms of data input such as Excel upload and API integration can be added to the CTS to integrate the system in existing internal administrations.
- Other certification documents such as REDcert and RSB based on government standards (t.b.d.) and specific product properties (e.g. FSC for wood materials). Only ISCC has been included in the prototype as this is generally considered as a standard that covers a wide range of sectors. However, there are many more certificates that can be registered in a CTS.
- More specifications on carbon sources e.g. differentiation between biomass source based on 1st/2nd/3rd/4th generation feedstocks. If specific sectors need to adhere to biomass standards, the CTS can be further developed to account for this.
- Additional material characteristics like biodegradability and recyclability.
- The requirements include the calculation of carbon lost and carbon used for energy sources during the processing, so that the companies can also report on resulting carbon emissions since these flows that are not passed on. The prototype does not include the calculations of these emissions (e.g. for CSRD reporting), but it is optional to include this as an additional step.
- The requirements do not include a notification when carbon crosses a EU border (e.g. for CBAM reporting), but it is also possible to include this in the further development of the CTS.
- Information flow CTS
- In the Appendix A, a step-by-step visualisation is given to explain what information is calculated and shared with supply chain partners and which information is not.

INFORMATION FLOW CTS

In the Appendix A a step by step visualisation is given to explain what information is calculated and shred with supply chain partners and which information is not.

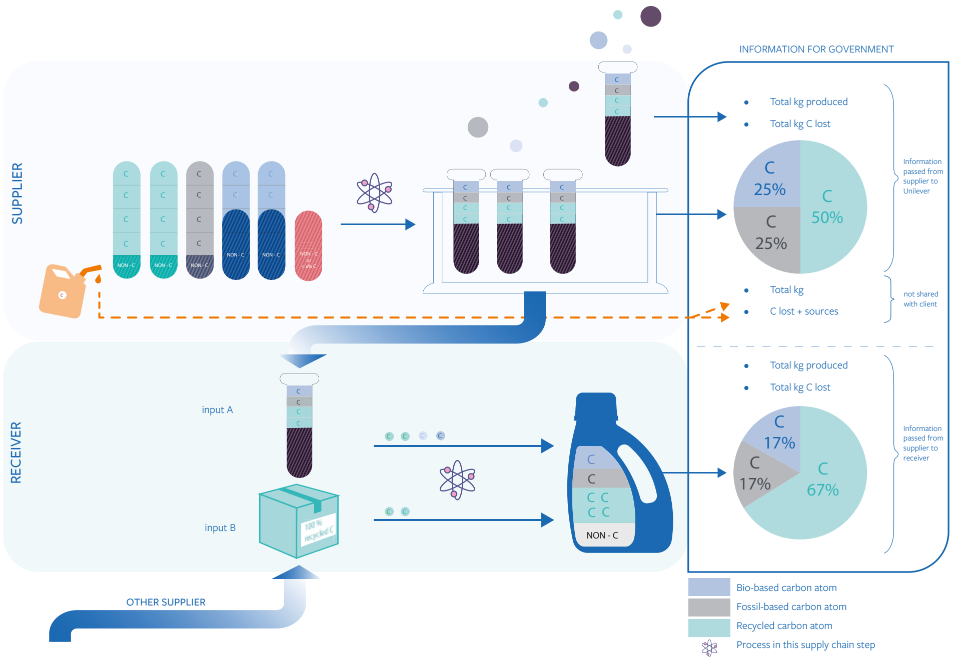


Figure 3. Preview of information flow in Appendix

4. Prototype and validation

The purpose of designing a prototype for this project was to validate the desirability of the solution and to validate more in-depth features of a future CTS. Before the design work commenced, several (online) workshops were held. These sessions involved representatives from the RVO, Top sector Energy (digitalization program), Unilever, Ministry of Economic Affairs, Ministry of Infrastructure and Water Management and Unilever. During these sessions, the data and tool requirements were gathered to get a better understanding of what features the solution had to encompass. Additionally, the boundary conditions were defined with the same group.

This process was iterated after three validation sessions (with governmental actors, Unilever and the Dutch Emission Agency (NEa). The resulting prototype, outcome of this iterative design process, was validated during feedback sessions with Unilever's suppliers.

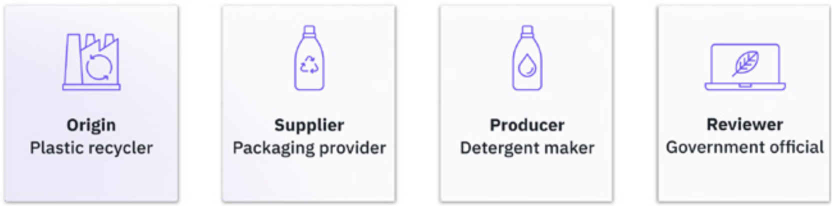


Figure 4. Status of validation

As a result, the prototype and its features are validated by most relevant parties. See figure 4

PROTOTYPE

The resulting prototype can be found following this link. When you click on the link, you will land on the dashboard for the supplier. From here, you can navigate to the other features using the navigation menu. To navigate, please follow the following instructions:
Step 1: To hide/show UI, press Command + \ (if you're using an Apple device) or Ctrl + \ (if you're using a Windows device)
Step 2: To turn on/off full screen, press "F"
Step 3: To know where to click in the prototype, just click anywhere and follow the blue highlighted boxes
Once you have walked through the flow of a single user, press "R" to navigate back to the Main menu.
In appendix B, relevant screenshots from the prototype are explained.

FINDINGS FROM VALIDATION SESSIONS

Producer validation

1. **Certifications:** Select a certification at the start of the outgoing flow in the system. Then, use the information in certifications to autocomplete parts of the flow like material type and allocation method.
2. **ID number:** As a unified identification number, use the material ID. Other identification numbers can be added in future implementations.
3. **Allocation:** Allow multiple allocation methods in the later versions of the system but use free allocation for prototype and the initial version of the product..Loss: There is a need for including carbon loss in the form of yield.
4. **Loss:** There is a need for including carbon loss in the form of yield.
5. **Multiple shipments:** Allow multiple shipments and materials in the same outgoing shipment. Use material ID to differentiate.

Government validation

1. **Legislation:** a CTS could work if enforced on producers in the Netherlands only, if these producers receive information from international suppliers upstream. However, ideally a CTS is applied EU-wide. The legislative implications should be researched further.
2. **Enforcement:** A regulatory body (e.g., the Dutch Emissions Authority, NEa, in the Netherlands) could be well placed to oversee and enforce the reporting for future regulations regarding physical carbon.
3. **Dedicated portal:** Instead of receiving a static report from the organizations, the NEa expressed that that it would be beneficial to have a dedicated CTS interface for the governmental body that should oversee/enforce the regulation.
4. **Additional data for report:** The following data should be included in the dynamic report that is shared by the organizations:
   - What percentage of the total volume is certified;
   - The sources of the material volume that contains carbon;
   - The percentage of the total volume that is certified AND comes from a renewable source.
5. **Acceptance threshold:** Need to create a threshold for acceptance criteria e.g. with regards to the volume, anything below 0,01% of the total volume is negligible.

All points above are implemented in the prototype, except for point 1 and 2 from the government validation because they do not directly relate to the prototype.

Supplier validation

1. **Mass balance as chain of custody** – The CoC is now adapted to the customer's wishes. As more tools become available to improve traceability, suppliers are willing to use a stricter chain of custody and can therefore make strong claims. Suppliers endorsed the current use of mass balance in the prototype.
2. **Open to different certification schemes** – The system should be able to use various certification schemes. Suppliers are currently mainly using ISCC as a certification scheme and therefore the prototype uses ISCC.
3. **Confidentiality** - The ratio of raw materials and energy required per delivered product is confidential. This has to do with the efficiency of the pricing of the party in question.
    1. Action: only make carbon loss from material and fuels used transparent to the government / don't share data with clients.
4. **Biodegradability** - Adding international standard for biodegradability (compliant with NEN/CEN) can be a useful addition
5. **Small players** ((niche players) often are not certified due to costs to set up systems. Next step is to investigate how/if a CTS can promote certification
6. **Guidance and standardization** - various systems are emerging (Circularise/ Greentoken, etc.). A possible advantage or unique selling point of CTS is that the volume of non-renewable flows are also registered. However, suppliers are waiting for guidance and/or specific rules from their national government or the EU:
    1. Requirements for certification
    2. Focus on tracking CO_2 emission or (starting with) carbon sources
    3. Obligations for using sustainable carbon or materials
7. **Provide incentives** - - Offer financial incentives or subsidies for companies that adopt sustainable carbon inputs, not only obligations. This is possible with direct subsidies and Contracts-for-Difference (CfDs) for sustainable carbon use in material production for biobased and recycled carbon. The application of Carbon CfDs can mitigate market uncertainty, fostering a stable investment environment.

Unfortunately, the supplier validation interviews took place after the prototype was delivered. Therefore, point 2 and 4, could not be implemented in the prototype. Furthermore, the following suggestions from suppliers are currently not included in the CTS protoype:

- Shipment system (contract number), also stated on certificate (which states volume)
- Unique supplier code
- Base chemicals code (material codes)
- A visualization of the mass balance

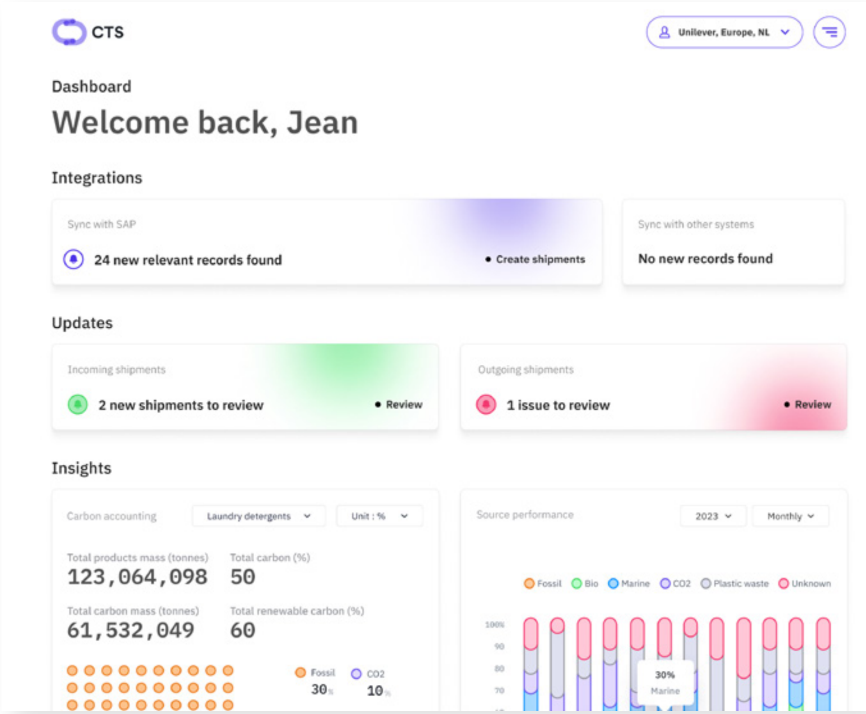


Figure 5. Screenshot from dashboard in prototype

5. Comparative analysis

This chapter presents a comparative analysis to assess the feasibility of the proposed Carbon Tracking System (CTS). Our analysis involves a comparison between the current method of carbon accounting, which relies heavily on certification, and the prospective scenario in which the CTS is implemented. The central question guiding this analysis is whether the benefits of the proposed CTS outweigh the associated drawbacks.
This comparison serves several essential purposes, primarily:

- **Decision support:** Provides a structured way to evaluate the financial and operational trade-offs between the existing and proposed system.
- **Resource allocation:** Helps in determining the required resources like time, money, and workforce for the implementation and operation of the system.
- **Impact assessment:** The bottom-line benefits of the project.

Given the early development stage of the CTS, the main purposes of the analysis is **decision support**. The analysis is based on in-house expertise, interviews and comparisons with the current way of working.

The approach follows the following steps:

1. **Description reference scenario**
2. **Proposed measures**
3. **Effects per measure**
4. **Conclusion**

The specific question the comparative analysis answers, in order to answer the greater question of this research, is whether **the increase in accessibility, reliability, and potentially confidentiality** outweighs the downsides of **the development, implementation and maintenance of a CTS?**

Limitations of this comparative analysis:

- It is assumed there are regulations in place that for example, reduce use of fossil-based carbon. However, is unknown how the government will exactly implement regulations. It is assumed that no significant changes in regulation occur.
- Adoption, acceptance and cost assumptions are not based on a market consultation.
- It is very difficult to estimate the cost of a **Carbon Tracking System** because:
  - It is not fully validated yet
  - It is not fully designed yet
  - It is unclear how many value chains (or products) will be using it
  - It is unclear if blockchain will be used.
  - It is unclear what the necessary level of system integration is.
  - It is unclear how many stakeholders should be onboarded

Definition of used terms

Confidentiality	the breaching risk of data/information (i.e. risk private information is disclosed to a third party without the owner's consent)
Reliability	consistency and stability of data over time and across different conditions (how controlled and trusted)
Accuracy	how close the data is to the actual or true value (how precise and consistent)

Example quantification of costs of a CTS

The initial investment to fully develop the prototype designed in this project including verification, validation, implementation testing for a Minimum Viable Product, for one value chain is estimated to be between EUR 0.5-1 million. Scaling up the system towards an initial production ready system is estimated to be between EUR 2-5 million. The operational costs for running the production ready infrastructure of the CTS will be about EUR 20.000 per year, per organization*. This is excluding the labour costs of people using the system, potential software licensing and the support & maintenance costs. The licensing and support & maintenance is dependent on the software provider.

Costs in perspective of CO2 reduction potential

A CTS does not directly result in CO2 emission reduction and the CO2 emissions of sustainable carbon source need to be calculated first, see also the text box on slide 13. Still, the potential reduction of CO2 emissions for fast-moving consumer goods is enormous. For manufacturers, Scope 3 emissions are much higher compared to Scope 1 and Scope 2 emissions (from factories and workplaces)[1]. For Unilever Scope 1 and Scope 2 make up just 2% of the estimated total footprint[2]. Of their Scope 3 emissions, about 70% can be traced to raw materials, ingredients and packaging.

In Europe, greenhouse gas emissions from packaging alone are projected to increase to 66 million tonnes of CO2 in 20303. This does not include scope[3] emissions from packaging of exported products. With current CO2 price of EUR 78 EUR/ton (Nov-23 d.d. 13/11/23), this is an equivalent of 5 billion. The potential is therefore enormous.

*This is the case if organizations wish to run their own system instance, with databases separated and a blockchain node per company. This can be considered the costliest option. Several variations are possible to lower the costs per organization.

[1] Scope 3 GHG Emissions from European FMCG Companies in 2021 – GlobalData
[2] Comment: Why it pays for companies to pick their battles in the transition to net zero | Reuters
[3] EUR-Lex - 52022SC0384 - EN - EUR-Lex (europa.eu)

In this section, we outline the current scenario, often referred to as the reference scenario. This represents the existing approach to carbon accounting and sets the foundation for comparing it to the proposed CTS.

REFERENCE SCENARIO	PROPOSED MEASURES
Traceability in reference scenario: • Material (source) information is available per organization, but not tracked across entire vertical supply chains. • Increased demand for information about material use from customers and therefore companies, but limited information is available. • Limited standardization of chain of custody and allocation (only posed through certification schemes) • Limited insights in source of carbon	**Proposed measure** for traceability Carbon source, carbon percentage and certification tracked from origin to offtake using a standardized digital system with automation of material and carbon source traceability (e.g. mass balance).
Verification in reference scenario: • Transactions/certificates have to be manually verified. System is prone to human error and inconsistency • Shortage on the labor market, also for accountants.	**Proposed measure** for verification: Transaction volumes are automatically verified and enforced based on pre-defined principles. One of these principles is that the CoC rules of the certification should be enforced.

Government reporting in reference scenario:
• Companies report manually (e.g. using forms)
• Increased need for insights for the government on scope 3 emissions of material usage:
  ◦ Currently announced regulation is in place (e.g. CSRD)
  ◦ Government considers additional instruments to reduce scope 3 emissions, of which one is more sustainable carbon sources
	Proposed measure for government reporting:
	Link tracking system with government reporting. Governments can get information from the same system used by companies in a controlled manner.

Ownership and data storage in reference scenario: • Central and commercially owned certification systems. No blockchain technology implemented.	**Proposed measure** for ownership and data storage: Blockchain implementation with decentral ownership/governance of the solution and distributed data storage.

The analysis covers the advantages and disadvantages of implementing the proposed system in a single large industry for the value chain of one (mass produced) laundry detergent with the assumption that government regulations of carbon sources are in place. The table below describes the advantages and disadvantages of the proposed measures.

SUBJECT AND MEASURE	ADVANTAGES	SECONDARY ADVANTAGES	DOWNSIDES
Traceability Carbon source, carbon percentage and certification tracked from origin to offtake using a standardized digital system	• Data breaching risk is reduced because access is granted based on roles and permissions. Data can't be easily copied and modified. • The reliability of data increases because data is verified at each transaction point and the system is standardized. • The accuracy is improved because system has enforced logic built in. E.g., the mass balance principles of a certification scheme. • Reduced internal administration costs of organizations due to uniform digital way of working across the supply chain. • A standardized system can be scaled-up across many supply chain partners and sectors.	• More information available leading to more insight in carbon sources, thus leading to improved steering mechanisms for stimulating the use of sustainable carbon sources • Higher chance of meeting reporting obligations / less delays (less risk losing license to operate)	• More development and implementation costs of this system compared to the current way of working • Problems (bugs, errors, integration failure, etc.) in the starting phase
Verification Transactions/certificates automatically verified, checked and secured	• The possibility of double-counting or invalid certification and reporting is reduced because system can have certain checks in place (e.g., automatic link with ISCC database, amount claimed cannot exceed amount certified etc.) • Operational costs of verification are expected to be lower since it saves time to check sources. Note: a CTS doesn't avoid the need for audits (only reduce).	• Lower risk of fraudulent behavior • More certainty for companies and government that claims are correct	• TTime and effort to implement a CTS • Several CTS-like systems might be introduced, leading to possible issues on the interfaces or integrations and double work.
Government reporting requirements Link tracking system with government reporting	• More insights for the government with limited additional costs for insights in value chains • Implement legislation in time	More insight of (potential) effect of government measures on reducing scope 3 emissions. This may lead to more measures to incentivize the use of sustainable carbon	• Time and effort put in this system while a different system is implemented sooner
Ownership and data storage Blockchain implementation	• Increased verifiability of claims by the companies due to better insight into transactions. This leads to increased trust by companies (see more information see here[1]).	More trust in the CTS system by participating companies	• Development costs are higher due to the relative immaturity and complexity of the technology. Maintenance costs are higher in the situation where organizations run their own system instances (i.e. fully decentralized).
General	• Reduced costs for auditors and accountants since data is gathered, checked and verified continuously.		• Risk of developing multiple CTS like systems, while one system is becoming the dominant, widely accepted system • Using a CTS might take more time from companies than periodic manual calculations

Table 1. Advantages and disadvantages of measures of a CTS compared to the reference scenario.

The following table describes whether the net effect per measure is positive or negative (or neutral). The net effects are based on the advantages and downsides on the previous page and form the basis for the general conclusions on the right side of this page.

	NET EFFECT PER MEASURE
Traceability	**Positive**: the costs of developing a CTS and the risk of another system turning out to be the industry wide adopted system, outweighs the potential benefits. On a long-term having a CTS can save time in collecting information. Using a CTS might take more time from companies than periodic manual calculations, but it should reduce the need costs of external auditors and accountants (see the graph below). It can avoid delays and get more information with limited extra resources (that are scarce at the moment). This should increase the chance of companies meeting reporting obligations / less delays and ultimately leading to more sustainable material use / reduction of scope 3 emissions for industry.
Verification	**Positive**: the scarcity of resources resultants in "do more with the same amount of people". A CTS can help avoiding human errors and inconsistency and create a better quality of data and reduced the need for extra resources.
Government reporting requirements	**Positive**: having more information will provide the government the opportunity to implement measures to reduce scope 3 emissions better and it's easier to prove the net positive effect on CO_2 reduction.
Ownership	**Neutral/ unknown** the additional trust companies may have in the data or the decentralized system in general is hard to quantify. Moreover, it is unknown if the higher costs of implementing a blockchain-based CTS will outweigh the potential of additional trust. This still has to be validated.

Table 2. Net effect per measure

CONCLUSIONS

Positive Impact of CTS:

- In the long term, implementing a carbon tracking system (CTS) is beneficial as it saves time, prevents delays, and enhances data collection with limited additional resources, helping companies to be compliant and meet emission reduction targets. The potential benefits outweigh the development costs and the risk of another system becoming industry-wide.
- The use of a CTS is seen positively, particularly in resource-constrained scenarios, as it allows for achieving more with the same workforce. It reduces human errors and data inconsistencies, leading to higher data quality and reduced reliance on extra resources.
- Access to more information via a CTS is advantageous for government efforts to reduce scope 3 emissions. It facilitates the implementation of effective measures and provides clearer evidence of a net positive effect on CO_2 reduction. Previous studies commissioned by RVO concluded that tracing carbon atoms and deducing scope 3 emissions based on carbon lost is easier to implement and less data-intensive than tracing CO_2 emissions. These studies also found that this method can be used for scope 3 emissions of carbon-intensive products but should be clearly separated from scope 2 emissions and transportation emissions.

Neutral/Unknown Impact of CTS:

- The impact of decentral ownership (decentral storage of data) on trust in the CTS system is uncertain and difficult to quantify. Moreover, the high costs associated with implementing a blockchain-based CTS may not justify the potential trust benefits, leaving the overall effect as neutral or unknown.
- The overall CTS costs are unknown until the industry further determines the specifications of the system, and which CO_2 reduction targets can be met using this system. In the next stage of development this should be further specified, but the quantified benefits are likely to outweigh the costs

Relationship between a CTS, sustainable carbon & Scope 3 emission reduction
A CTS does not directly lead to CO_2 emission reduction. However, it is a tool to increase insight in carbon sources and can help to accelerate the use of sustainable carbon. More information on Scope 1, 2 and 3 emissions and the Greenhouse Gas Protocol for Product Life Cycle Accounting and Reporting Standards can be found here[1]. An example of the relation between sustainable carbon and CO_2 emission reduction of a high and a low carbon content product can be found here[2]. For some products, most Scope 3 emissions are found upstream, for others the larger part is emitted during end-of-life treatment.

[1] GHG protocol for Product Life Cycle Accounting and Reporting Standards
[2] Koolstofboekhouding rekenregels (overheid.nl)

6. Suggested roadmap

To bring the prototype towards implementation to important next steps should be taken: further validation & technical research.

Validation

Before a Carbon Tracking System can be realised, further validation is required. This section explains the main topics for validation and some of the key questions to be answered. It's important to conduct the validation before starting implementation. This will save a tremendous amount of costs down the line. Please note that this is a non-exhaustive list. Every step on the roadmap will unveil new insights and new topics to be validated.

The first considerations should determine the general desirability for a CTS system further upstream in the value chain and in different industries and validate specific functionalities it should have. The list hereunder describes the to be validated elements:

- The willingness to share data in a larger group of suppliers. Not only within the supplier domain of Unilever, but also in different industries.
- Under what circumstances the stakeholders are willing to share data. E.g. If certain commercial value can be extracted from the system or only if regulation forces them to adopt a CTS-like system.
- What the preferred default chain of custody is/are and what the industry thinks of the option to "downgrade" a chain of custody model. For example, from fully segregated to mass balance when substances are blended. It should be investigated how this practically works with the complexity of various supply chains in mind (e.g. keeping mind blending/mixing, the use of different certifications in a supply chain, the use of different systems, etc.).
- The necessity for a dedicated product User Interface for the stakeholders. In doing so, also investigate what parts of the system are redundant considering the required carbon data and the current system landscape of the organisations. I.e. What data can be retrieved from integrations and what type of systems are currently used for managing (part of) the required data?
- What type of ID numbers are most commonly used to identify shipments along the supply chain. In doing so, try to find a common denominator among stakeholders and across industries if possible.

Next, it's important to validate the necessity of blockchain or distributed ledger technology for this system. The following validation topics and questions will ultimately determine whether the use of blockchain technology is necessary:

- The required level decentralisation for data storage.
  - Are the stakeholders comfortable with allowing an external software provider to store their carbon-related data in a shared database or cloud system, even if other supply chain stakeholders, possibly including competitors, also have their data stored there?
  - When it comes to keeping data confidential, would the stakeholders be comfortable with an external software provider having the ability to access and edit the carbon-related data on the platform?
- The required level of decentralisation for platform management (governance)
  - Would they be ok with a private/public organisation managing the software centrally or should the platform have a decentralised governance structure?
- The required level of public verifiability by external organisations or individuals.
  - Is it important to the stakeholders that claims can be (publicly) verified via a digital solution by external parties and/or individuals?

OPERATIONALIZATION OF VALIDATION PHASE

Purpose: (in)validating the overall desirability of CTS and determining the need for blockchain technology in the CTS.

Initial focus value chain: Robijn Klein & Krachtig

Duration: 3 months*

Necessary participants: VO, Top sector Energy (digitalization program), Unilever, Ministry of Economic Affairs, Ministry of Infrastructure and Water Management, Unilever, three (+) tier 1 suppliers of Unilever and three (+) tier 2 suppliers of Unilever.

Method: Ideally conduct this validation via semi-structured interviews, in a 1:1 setting. This will result in the least biased results, with the highest quality of output. Online 1:1 interviews are also possible.

Additional notes: During this phase, the governmental bodies should find an answer to the question: How do we as a country (or continent) want to steer on the carbon data? I.e. what do they want the regulation regarding physical carbon management to look like? This will provide input on the vision to be developed in the technical research phase.

Experience of Kryha has shown that development and implementation is most efficient if the Dutch government will allow the private sectore to take the initiative on implementing one or multiple CTS' instead of taking the initiative themselves. This means that the government will only provide the regulation, with associated boundary conditions. It is then up to the market to answer with appropriate tools and systems. This is inherently tied to the question if blockchain technology is needed or not. I.e. If the government decides to take ownership of the solution, it does not make sense to use blockchain technology in the CTS.

Technical research

After the conceptual validation, a (technical) research phase should take place. This is the final phase before implementation of the CTS can start. At this point, it's unclear what route to take to realize the CTS system. Simply speaking, there are two options:

1. Source the software from a Software-as-a-Service (SaaS) provider ("buy")
2. Build the software together with a software development company ("make").

However, there are many factors that influence what option suits best.

First, considering the outcomes of the validations regarding the required level of decentralization, it's important to create a vision on how the platform should be governed. This should contain the following:

- A description of what (kind of) entity owns the solution;
- The change process for the system. I.e. who proposes, accepts and checks changes to the system once it is operational;
- Who is responsible for implementation (of changes), maintenance and support;
- How financing for system development, implementation, maintenance and governance is ideally organized and managed.

The outcome of the above should provide guidance for a decision on the entity (type)
The outcome of the above should provide guidance for a decision on the entity (type) responsible for the implementation and governance. This could be a for profit, non-profit, not-for-profit or public organization. It should also provide guidance in deciding to either source the software from a Software-as-a-Service (SaaS) provider or to build the software with a software development company.

Second, if the above does not yet exclude either one of the implementation options (make or buy), it is recommended to conduct a market analysis on potential SaaS providers for option 1. If it turns out that there is no SaaS provider on the market with a fully ready to be implemented product, which is likely but not certain, the only option is to build the software. The nuance to this statement is that there will be SaaS vendors that already developed part of the solution. Of course, this would still mean that the remainder of the functionalities still have to be built. In the market research, try to identify what vendors operate in the field of traceability/tracking systems, what functionalities they have built in their system and investigate how this overlaps with the functional requirements from CTS..

Lastly, to decide to "make" or "buy" it is of course important to consider the costs for development, implementation, maintenance and support. Depending on the outcomes of the validation, the spread of the costs will vary greatly. Some factors that will influence the costs are:

- How feature complete the current concept is (validation will point this out);
- The (non-)necessity for a separate product interface;
- The level of customization required per stakeholder;
- The level of system integration required per stakeholder;
- The level of support needed per stakeholder;
- The level of decentralization of the system and the infrastructure associated with that.

After a decision has been made, it should be up to the software vendor to decide what specific technology stack should be used for the implementation. For both options, it will be invaluable to that organization to provide a list of (non-)functional requirements to the vendor. This will help them to make a comprehensive product backlog in the case the software needs to be built or update their product backlog in the case the software is sourced from a SaaS provider.

Operationalization of technical research phase

Purpose: Determining whether to build ("make") or source ("buy") the software.

Initial focus value chain: Robijn Klein & Krachtig

Duration: 3-6 months*

Necessary participants: Same participants as the previous phase.

Method: (small) group sessions and 1:1 interactions with possible technology providers.

Additional notes: An outcome of this phase could be that ownership of the solution is no longer the responsibility of the current stakeholder group, but the responsibility of one or more technology providers. If the technology provider doesn't offer it directly himself, it is advised to request a forum (e.g. working group, committee, etc.) in which the collaboration between the technology provider(s) the government entities is secured. This is necessary to keep alignment between (future) regulations and the systems that are/will be built to meet the requirements of these regulations.

7. Findings

In this section the major findings of this study are summarized to answer the research question: **What are the effects of a Carbon Tracking System, compared to the current way of working?**

The current way of working with certificates has limited transparency and credibility

The lack of digital automation in the currently used system of certification increases human error likelihood and double counting risk – where a certificate is claimed by more than one entity. Organizations can check validity of certificates in databases, but there is currently no overview of certified material flows along a supply chain. The current way of working does not give the government insight of (un)sustainable material flows or allow it to prevent double-counting.

Current tracking system developments are promising, but implementation remains a challenge

Similar to this study, other tracking systems are being developed and tested through pilot programs. Key commonalities include the exploration of decentralized information sharing, assessing the added value of blockchain (or decentralized data storage) and a specific focus on scope 3 emissions and value chains. The existing systems prove the benefits of more digitization and automation of data transfer including more transparency for accurate reporting and valuable insights through data analysis that can be used for more sustainable strategies.

Implementing a CTS into a supply chain is challenging because of confidentiality concerns when (too much) information is transferred between organizations. Moreover, if a CTS requires a lot of information input, it becomes more difficult for organizations to integrate this into their existing systems.

A simplified approach to carbon tracking can overcome confidentiality and data complexity concerns

The main element of the CTS designed in this study that sets it apart from other systems is its distinct focus on the source of carbon rather than just CO_2 emissions. Supply chain partners have expressed (in previous studies) that this information is easier to obtain and to verify from an entire, international supply chain. This is because it is based on production input and output information that is already known and important decisions regarding carbon source are made in the beginning of the value chain whereas CO_2 of non-circular product value chains is mostly emitted end-of-life in waste processing which is harder to track for products sold worldwide.

Moreover, by tracking the carbon embedded in materials separately from the carbon in fuels and other additives, confidential processing information does not have to be passed on. Suppliers expressed no concerns regarding sharing carbon content (mass percentage of C in material) or the source of carbon. However, it was expressed that yield is confidential especially regarding fuel use/efficiency of the process. This information could be tracked separately and only reported to government, not to other partners.

The disadvantage of merely looking at carbon sources is that in order to know CO_2 emissions the conversion to CO_2 must be calculated and not all CO_2 emissions can be derived from carbon sources alone.

The CTS information output should be relevant for the government

The design of this system includes elements which ensure relevance for governments to understand the impact of governmental steering instruments and other measures. These elements include consideration of both yield and non-renewable material flows, emphasis on the share of renewable content rather than solely proof of renewability, and an interface designed for information sharing with governmental entities.

The value of the CTS designed in this study depends on future government policy

The main components of a CTS is the information flow between supply chain partners. Therefore, the benefit of CTS for an organization is limited if it cannot acquire information from suppliers. The government's role is crucial in overcoming this problem and accelerating material tracking and sustainability. The effects of the CTS are therefore dependent on clear guidance on tracking methods by government including:

- Rules for chain of custody (and allocation in mass balance/book and claim)
- Steering on CO_2, carbon source, minimum share of sustainable material use (e.g. single use plastic directive)
- Minimum data sharing requirements
- Use of blockchain

It can be useful for the government to further consult with the market players currently developing carbon tracking systems to determine the specifications.

Blockchain and the role of the government

Experience has shown that an efficient way to roll out a CTS is if the government provides the regulation, with associated boundary conditions for a CTS, which allows the private sector to take the initiative on implementing one or multiple CTS. This is inherently tied to the question of whether blockchain technology is needed or not. I.e. if the government or any other organization decides to take full ownership of the solution, it does not make sense to use blockchain technology in the CTS, as decentralized ownership is one key element of blockchain.

Given appropriate government efforts, the CTS advantages can outweigh the disadvantages

Implementing a Carbon Tracking System (CTS) has numerous positive impacts, including saving time (of external auditors and accountants) and enhancing data collection enabling more achievements with the same workforce. Additionally, it supports government efforts to reduce scope 3 emissions by providing crucial information and evidence for effective measures. These potential benefits outweigh the development costs.

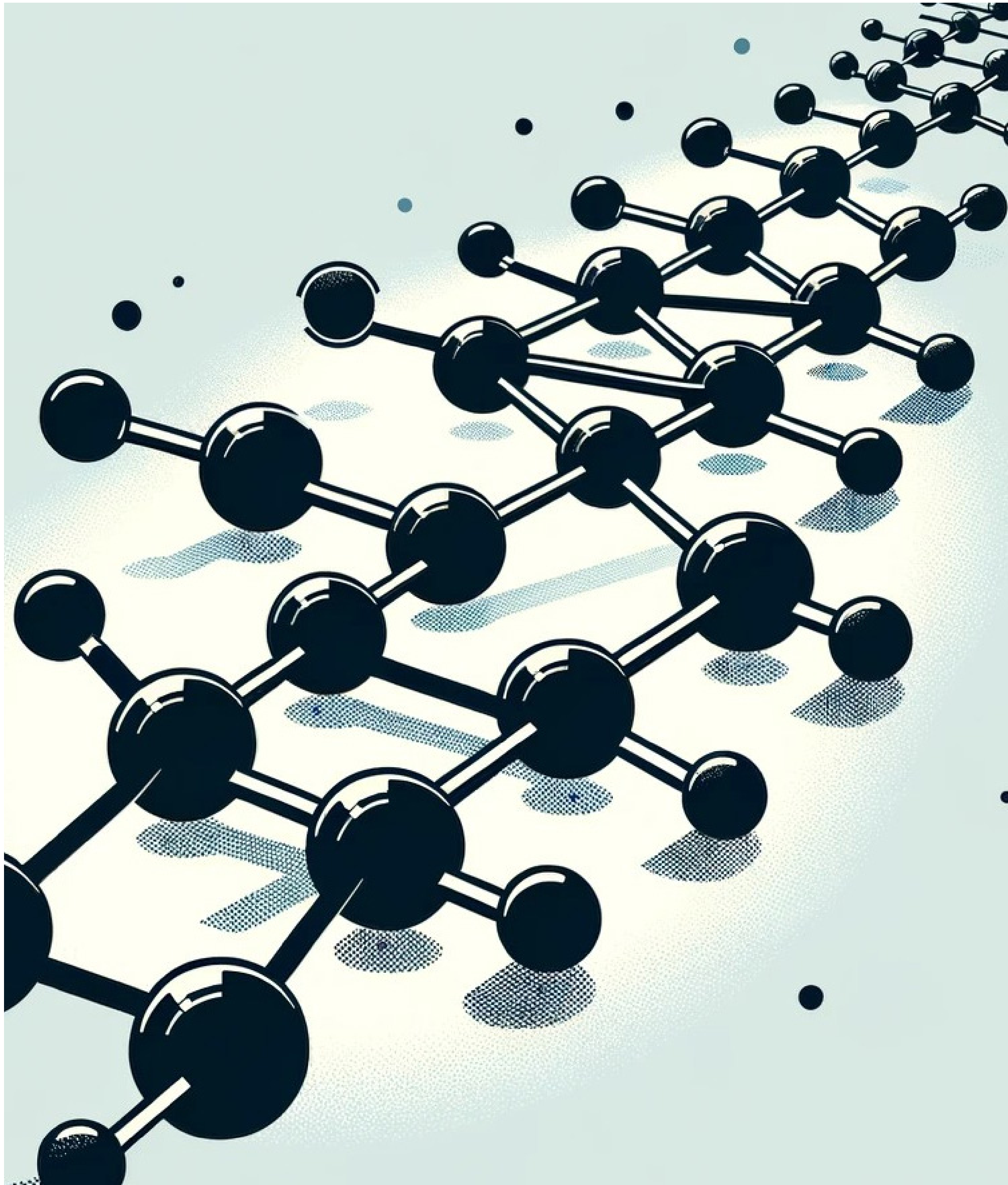
The impact of blockchain is uncertain and difficult to quantify. Moreover, the high costs associated with implementing a blockchain-based CTS may not justify the potential higher trust in the system.

Recommendations

The overall CTS costs are unknown until further specifications of the system are determined, and which sustainable carbon targets can be met using this system. In the next stage of development this should be further specified.

Our recommendation is to:

- Enacting guidance on traceability, chain of custody and allocation into law and regulations
- (in)validating the overall desirability of CTS and determining the need for blockchain technology in the CTS.
- Evaluating whether software should be developed by the government. And if so, determining whether to build ("make") or source ("buy") the software or



Acknowledgements

Rebel and Kryha extend their heartfelt appreciation to the individuals and organizations whose contributions have been instrumental in the success of this project. Special thank to the steering committee:

Edith Engelen-Smeets	RVO, Netherlands Enterprise Agency
Harold Veldkamp	Top Sector Energy Digitalization Program
Elisa Vandermeer	Ministry of Economics and Climate
Roos Havinga	Ministry of Infrastructure and Water Management
Thor Tummers	Unilever
Mark Intven	Royal Association of the Dutch Chemical Industry (VNCI)

We also want to express our gratitude to the Dutch Emissions Authority (Nea), Shell and Neste for participating in interviews for the prototype.

kryha

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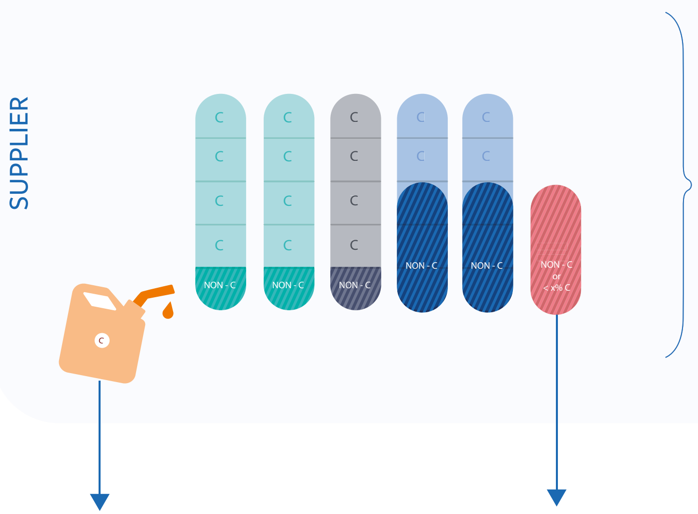
Appendix A - Information flow CTS: step 1



- Determine different inputs
- Determine input quantities
- Determine C (carbon) content and non-C content
- Determine source of carbon (bio/fossil/recycled

Inputs such as energy sources used for the process and not embedded into the product are excluded

Inputs with <x% C are excluded from reporting

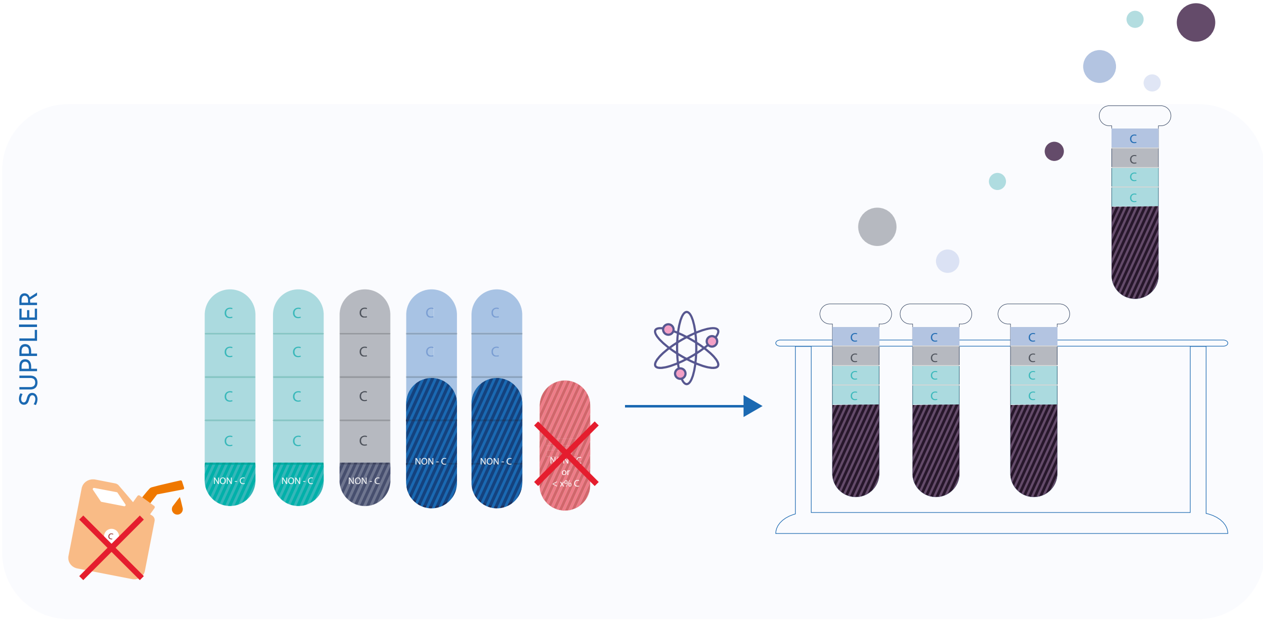
Bio-based carbon atom

Fossil-based carbon atom

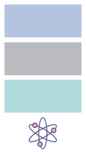
Recycled carbon atom

Process in this supply chain step

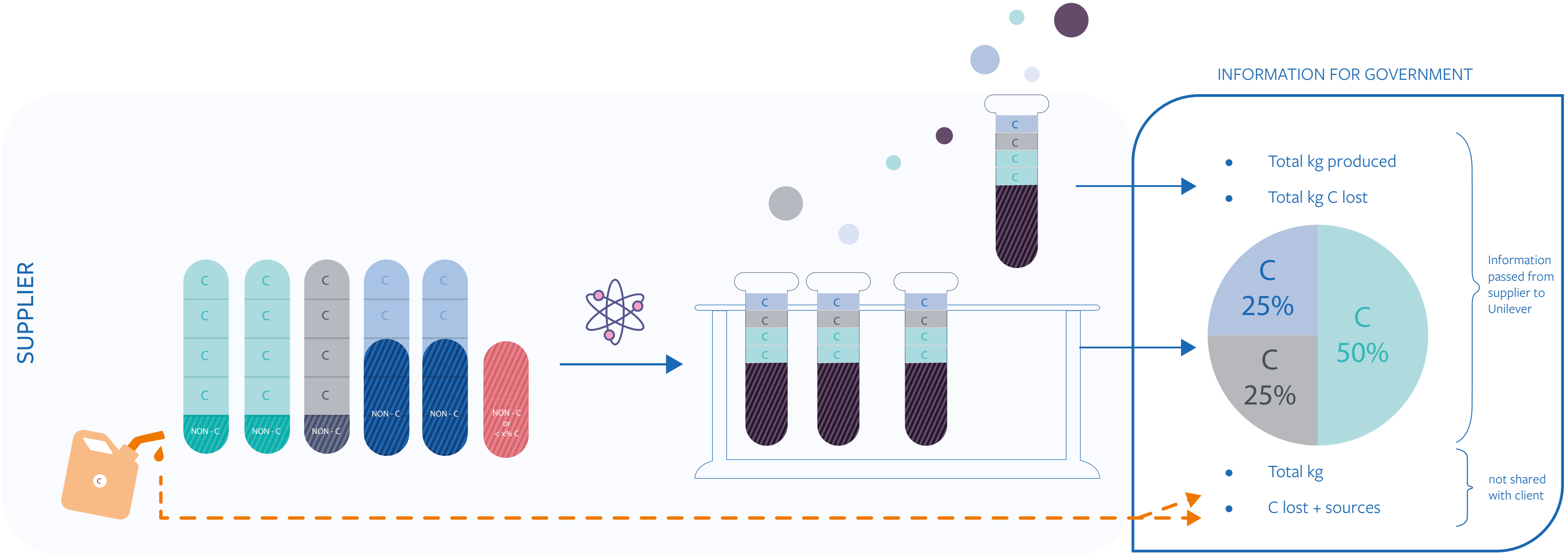
Appendix A - Information flow CTS: step 2



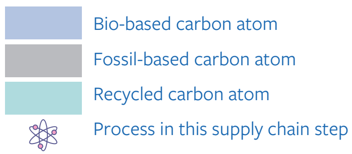
- Using mass balance chain of custody, determine carbon content of product after production process is done.
- The mass balance calculation excludes non-C mass, input with <x% C-mass, and energy sources used for the process and not embedded into the product



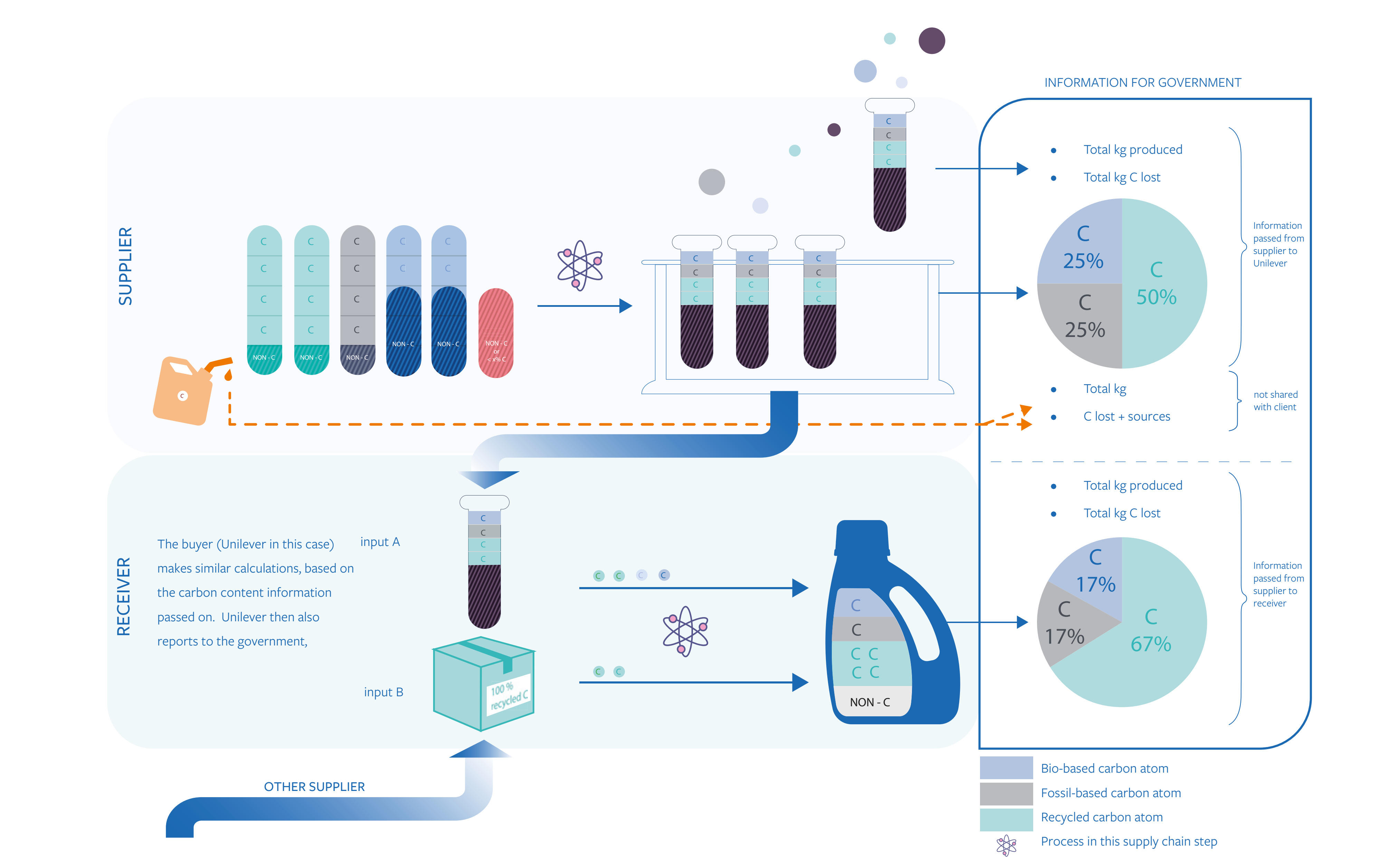
Appendix A - Information flow CTS: step 3



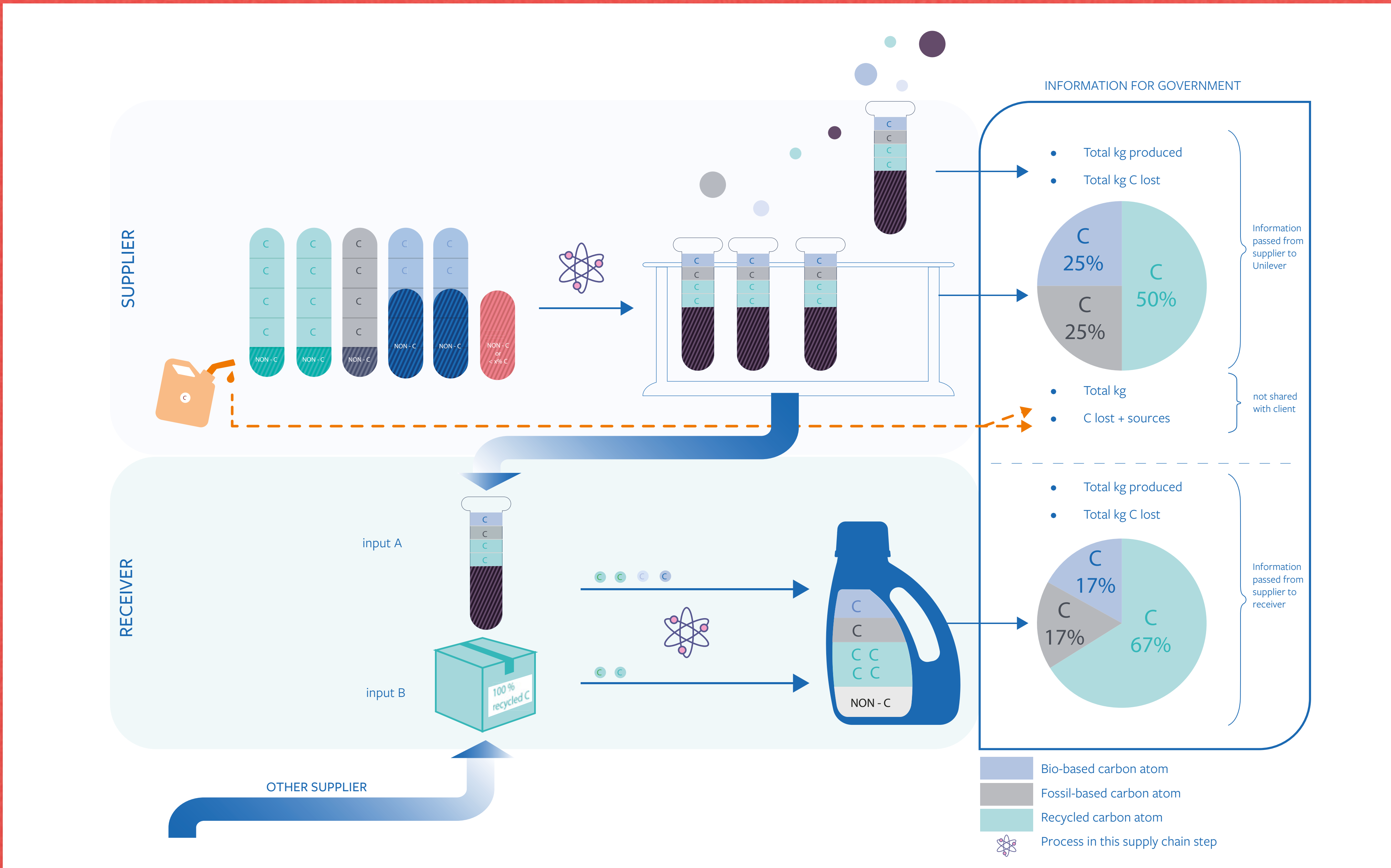
- Determine how much of product is lost during production process (due to inefficiencies)
- Information on how much product is lost and how much of the energy for processing (not embedded into the product) can be reported to the government as this leads to direct (or indirect if lost product is later incinerated) carbon emissions.
- The mass balance calculation is used to report the distribution of carbon content (% bio, % fossil, % recycled). This information is not only passed to government but also to the product buyer so that they know the carbon content of their input.



Appendix A - Information flow CTS: step 4



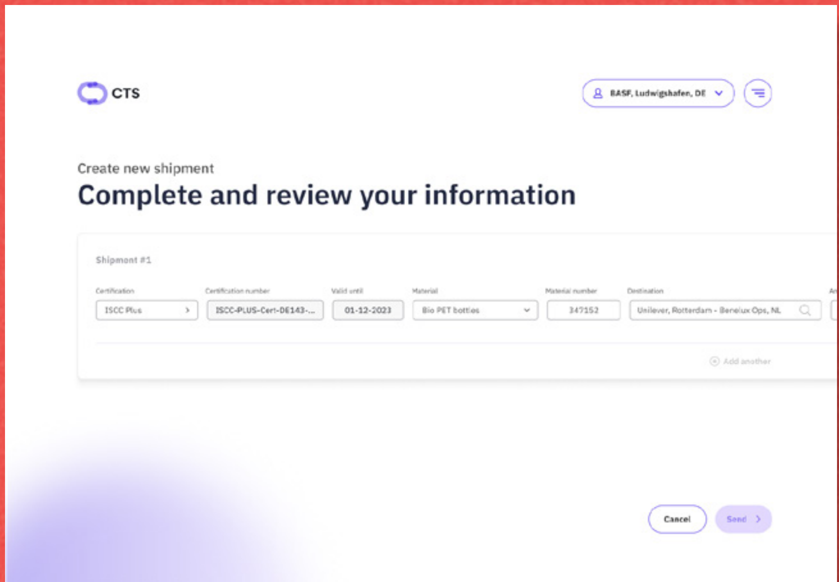
Appendix A - Information flow CTS: step 5



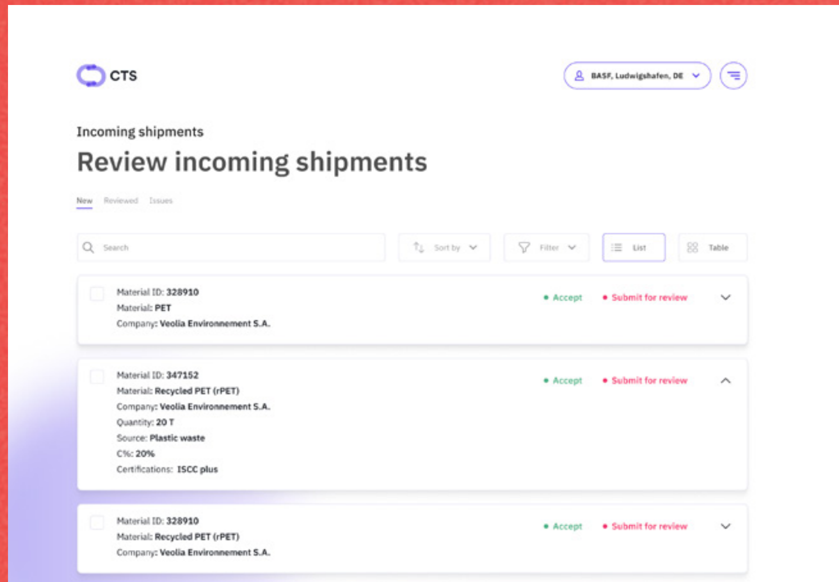
Appendix B

This appendix gives a rough impression of the digital prototype. The full digital version can be found by following this link.

Example 1:
OriginThe first example shows how the organisation at the origin of the supply chain makes an initial shipment entry. By filling in a row in the form, the user creates an outgoing shipment. Upon submitting the form, the shipment and its associated data is digitally sent and allocated to the destinating organisation.



Example 2:
SupplierThis example shows how incoming shipments can be reviewed by the supplier. The supplier checks contractual information and has the possibility to review carbon content related data as well as the certification of that shipment.

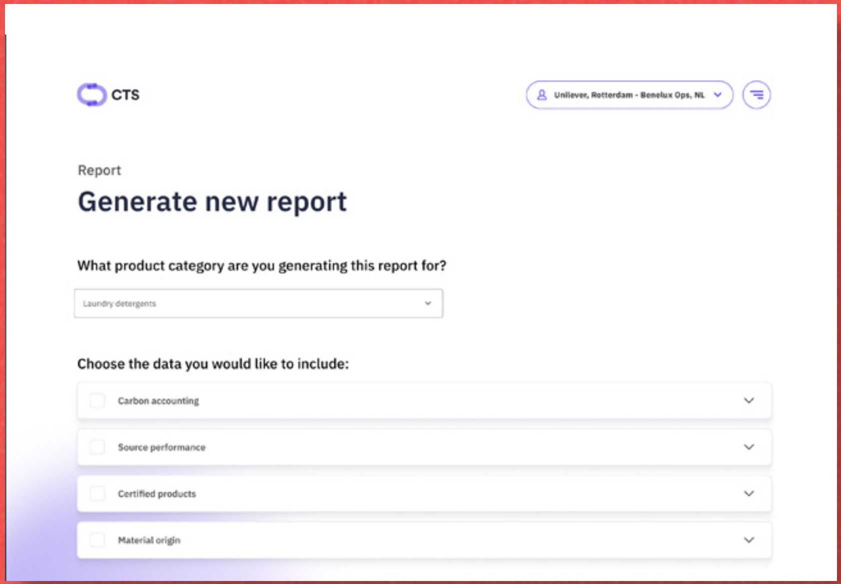


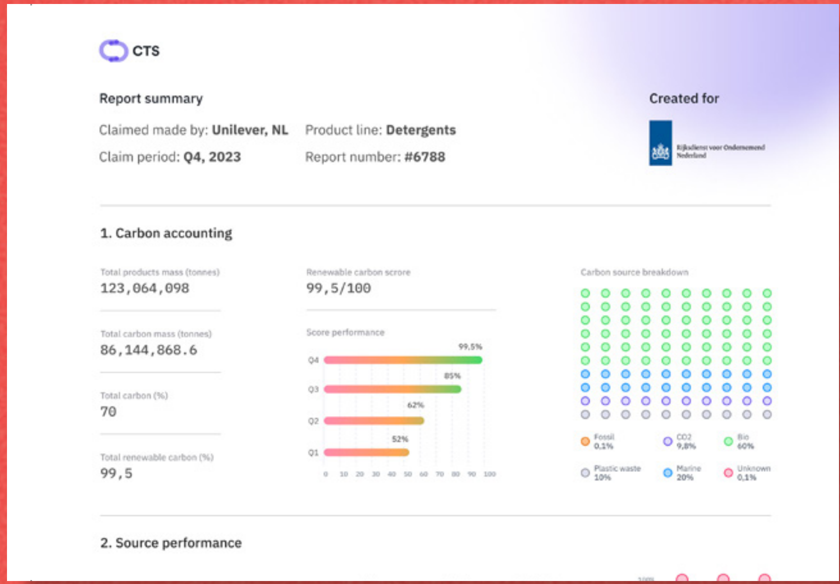
Appendix B

This appendix gives a rough impression of the digital prototype. The full digital version can be found by following [this link.]

Example 3:
UnileverIn this example, the user creates a report that is sent to the government agency that should review the carbon related data. In this case, the user of Unilever has the possility to toggle on/off the data that it wishes to send

Example 4:
GovernmentThe last example shows how a government representative is receiving the report with the carbon related data that – in this case - Unilever sent them.





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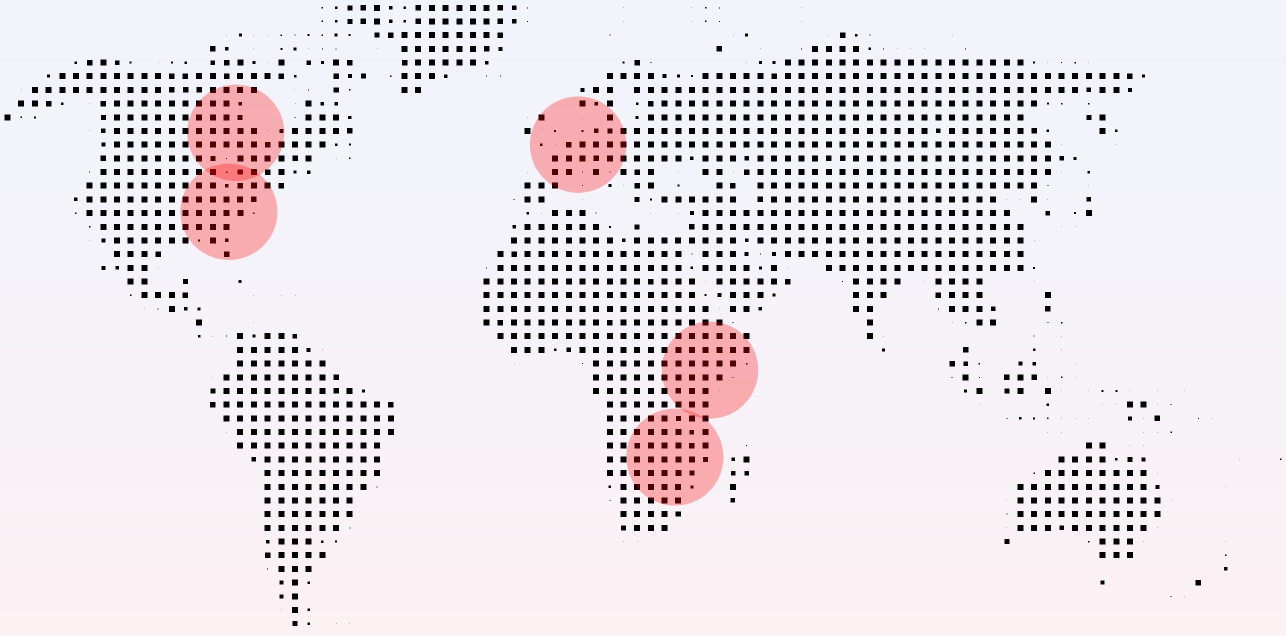

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