THE LIFE CYCLE ANALYSIS PROCESS OF CATIFA CARTA

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1. Reason Why

This document aims to transparently and reproducibly describe the innovative path undertaken to test a hypothesis that fully reflects Arper's commitment to becoming a model of responsible leadership, embodied in Catifa Carta — a one-of-a-kind product. Specifically, the calculation and validation processes of the environmental impacts of this product will be described below. Catifa Carta is a chair with a shell crafted from PaperShell, a material composed of kraft paper layers, bonded with a resin made entirely from biogenic sources. The paper is sourced from paper mills certified by the Forest Stewardship Council (FSC)[1] that use waste from sawn timber production from Swedish and Finnish forests. At the end of its life cycle, Arper commits to retrieving Catifa Carta from the market for pyrolysis — a combustion process that occurs in an almost complete absence of oxygen, thus preventing CO_2 emissions. Through this process, the PaperShell shell is transformed into biochar, a carbon-rich material capable of sequestering CO_2 in a stable form. Once applied to the soil, biochar not only retains the carbon it contains, but also enhances soil fertility and fosters biodiversity. Thanks to this virtuous cycle, the shell of Catifa Carta lays the foundation for a "carbon negative" product — one that captures more CO_2 than it emits during its production.
With this document, Arper intends to offer a benchmark for other companies, demonstrating how innovation and sustainability can translate into concrete, measurable actions in the interest of preserving Natural Capital and, ultimately, life on Earth (UN SDG 15).

2. Project Background and Objectives

The development of Catifa Carta is grounded in two fundamental concepts: the theory of change, originally proposed by Peter Drucker in 1954, and the importance of product end-of-life.
The theory of change is a planning and evaluation methodology that promotes social change by working backward: starting from the definition of long-term goals, a logical chain of resources, actions, and causal relationships is built to achieve those objectives.

[1] https://it.fsc.org/it-it

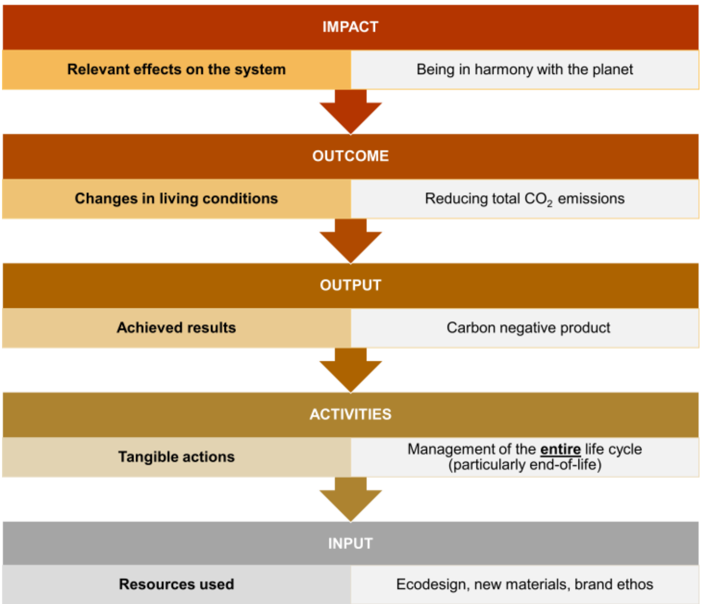

Fig. 1: The theory of change applied to Arper's Catifa Carta

In this context, the PaperShell material turned out to be crucial in developing a product that contributes to reducing CO_2 emissions and supports our original ambition: living in harmony with the planet.

It was also recognized that a product's end-of-life, often overlooked in operational planning, is a crucial phase in assessing environmental impact. Our experience and this study have allowed us to understand that a product's impact mainly depends on two phases: design — which, according to current literature, accounts for approximately 80% of a product's environmental impact — and end-of-life, as revealed by the LCA analysis.

Therefore, during the design phase of Catifa Carta, great attention was paid to selecting innovative materials that would allow for appropriate end-of-life management, accompanied by a strategy and operational model aimed at reducing the product's overall environmental footprint.

3. Project Launch and Involved Partners

The Catifa Carta project originated from extensive preparatory work begun in 2021 by three main partners, each playing a specific role:

PaperShell: A Swedish company responsible for developing the eponymous material—an innovative composite made from kraft paper sheets, pressed and bonded with a resin 100% derived from biogenic sources. Thanks to its intrinsic properties, PaperShell not only reduces the environmental impact of industrial production but also serves as an excellent example of biomimicry, mirroring the natural process by which trees retain CO_2 over time.

Arper: It transforms PaperShell into Catifa Carta, a finished product that combines aesthetics, functionality, and sustainability, effectively meeting market demands.

Arper has also implemented a take-back program for used chairs, which are sent to Sweden to its partner Stena Recycling, which operates a pyrolysis plant that also produces biochar. The biochar produced is not used directly by Arper, but is instead intended as a soil amendment for agricultural use.

Stena Recycling: A Swedish company providing industrial-scale waste collection, innovative reuse, and advanced recycling services. Responsible for managing Catifa Carta's end-of-life phase, it uses pyrolysis to treat the product. Through this process, the PaperShell shell is converted into biochar, a material that can be used as a soil amendment to support biodiversity. This process closes the product's life cycle in a virtuous way and actively contributes to promoting a regenerative economy—an economic model that goes beyond sustainability by aiming to reduce environmental impact while restoring and regenerating damaged ecosystems.

4. Pyrolysis and Its Impact on Catifa Carta

4.1 Introduction

Photosynthesis allows plants to absorb carbon dioxide from the atmosphere. This process not only fosters plant growth and biomass production but also contributes to the carbon cycle system of exchanges between different terrestrial compartments.

The carbon cycle spans four main domains, referred to as "Districts": the biosphere (living organisms and freshwater), the geosphere (sediments and fossil fuels), the hydrosphere (seas and oceans), and the atmosphere (the Earth's gaseous envelope). These Districts are all considered carbon sinks—reservoirs that naturally absorb and release CO_2 in a balanced way. The carbon that takes part in these natural exchanges is called biogenic carbon. This differs from fossil-based carbon, which does not participate in the natural cycle and accumulates in the atmosphere, contributing to global warming and climate change.

Within this framework, Catifa Carta contributes by leveraging the natural exchanges occurring in the plant world to offset fossil CO_2 emissions caused by human activities.

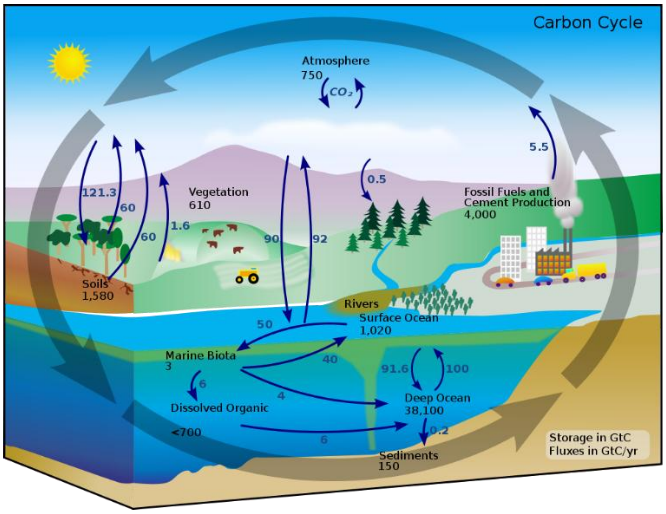

Fig. 2: The natural carbon cycle and its reservoirs. The numbers refer to exchange capacity in gigatonnes per year. (Source: NASA)

4.2 The Pyrolysis Process

Through a low-temperature incineration process (ranging from 400°C to 800°C) carried out in near-total absence of oxygen—known as pyrolysis—the Catifa Carta shell is broken down into three main elements: pyrolysis oil (also known as wood juice or bio-oil), syngas (synthesis gas), and biochar.

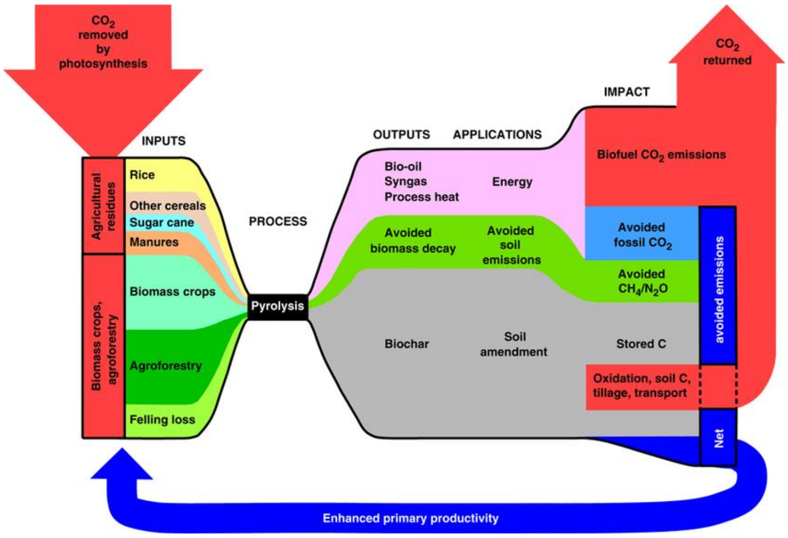

Fig. 3: Summary of the outputs and benefits of the pyrolysis process. (Source: Woolf et al., 2009)

Figure 3 summarizes the inputs, outputs, applications, and climate impacts of a standard pyrolysis process. Within each category, the relative proportions are approximated by the height of the colored fields.

CO_2 is removed from the atmosphere through photosynthesis, which generates biomass. A fraction of the total biomass produced annually—such as agricultural residues, biomass crops, and agroforestry products—is incinerated through pyrolysis to produce bio-oil, syngas, and

process heat, along with a solid product: biochar. Biochar is a stable (recalcitrant) form of carbon, suitable for use as a soil amendment. While bio-oil and syngas are typically burned to generate energy—re-emitting CO_2 into the atmosphere—biochar stores carbon for significantly longer periods than natural biomass decomposition. According to literature, this storage duration can exceed 100 years[2].
Finally, the pyrolysis process prevents the emission of other byproduct gases, such as methane and nitrous oxide, which would otherwise be generated by natural biomass decay.

5. Calculation of Biogenic CO_2 and Carbon Storage: LCA Scenarios and Results

Product Category Rules (PCR) define the methods for conducting a Life Cycle Assessment (LCA) to prepare an Environmental Product Declaration (EPD). They ensure a standardized analytical framework, enabling relatively objective comparison across various environmental declarations. The PCR, defined by regulatory bodies, adopt a neutral approach to biogenic CO_2—meaning the portion of carbon dioxide released during the decomposition or combustion of biological materials (plants, trees, or other living organisms), known as the natural carbon exchange cycle.
This **neutral approach** assumes that carbon absorbed during the product's life is fully released back into the atmosphere at its end-of-life. As a result, neither carbon sequestration nor biogenic CO_2 emissions are considered, resulting in a net carbon balance of zero.
To date, no known furniture product has demonstrated the capacity to retain CO_2 within its structure for over 100 years—the time frame used in the GWP 100a method released by the Intergovernmental Panel on Climate Change (IPCC) and recognized globally. Catifa Carta is the first furniture product that claims to achieve this.

To support this statement, two distinct LCA approaches were developed to evaluate the added value of the proposed process:

Approach 1

Standard LCA. It complies with ISO 14040–14044 standards and the PCR "2009:02 v3.0 'Seats', CPC Code 3811" issued by the Swedish EPD programme operator EPD International AB (Environdec), and allows for comparison with the LCA of the original Catifa 53 model, from which Catifa Carta originates.
This study **does not account for biogenic CO_2** and **adopts the cut-off approach** for

[2] Refer to the full results of the EUROCHAR project (https://cordis.europa.eu/project/id/265179/results/it) and Giagnoni et al. (2020), (https://hdl.handle.net/2158/1212562)

end-of-life allocation: it includes raw materials and production processes for virgin resources, but does not consider the benefits of materials being recycled, as these are considered inputs for the next life cycle, thereby avoiding double counting. In the Catifa Carta project, the standard LCA study has been third-party verified and turned into an Environmental Product Declaration (EPD) at the end of April 2025. Based on this framework, Catifa Carta's main environmental advantage compared to Catifa 53 is the **replacement of the shell material** (biogenic origin vs. fossil-based plastic), a benefit achieved without compromising the technical performance required for contract applications. Additionally, PaperShell performs better than wood in terms of carbon storage, due to its higher density.

Approach 2

LCA with Pyrolysis. This assessment is conducted in accordance with ISO 14040–14044 standards, though it does not strictly follow the Swedish PCR guidelines. The aim of this analysis is to evaluate the environmental impacts of the chair's life cycle with a specific focus on its innovative features—namely, the fully bio-based nature of the shell material and the potential to produce biochar through a pyrolysis process. This approach therefore explicitly addresses the issue of biogenic carbon sequestration, a topic that is undoubtedly controversial within the LCA methodology, yet highly relevant when assessing the environmental impact of the product in question.

The differences in the approaches used can significantly affect the LCA results of a biogenic-based product, and there is no unanimous consensus on how to assess emissions, biogenic carbon sequestration, and the allocation of recycling processes.

Therefore, various approaches related to biogenic CO_2 and the pyrolysis process for biochar production have been analysed. This study transparently considers both the neutral and non-neutral approaches. As previously described, the neutral approach does not account for either the sequestration or emissions of biogenic CO_2, assuming that the absorbed carbon is fully released at the end of life, resulting in a net-zero carbon balance. In contrast, the non-neutral approach takes into account both sequestration and emissions of biogenic CO_2 at different stages of the life cycle.

To test the different hypotheses, **4 scenarios** have been defined. These differ based on the approach adopted for biogenic carbon accounting (neutral or non-neutral) and on whether the benefits associated with the pyrolysis process for biochar production are included or excluded:

1. *Scenario 1 ("baseline" scenario): Biogenic CO2 with neutral approach and pyrolysis excluded from the system boundaries*

   Biogenic CO_2 emissions and removals are not accounted for. Pyrolysis is considered equivalent to a recycling process, with its outputs and the related energy consumption assessed in the subsequent life cycle. This scenario is consistent with major EPD systems and the ISO 14064 and ISO 14067 standards.

2. *Scenario 2: Biogenic CO2 with non-neutral approach and pyrolysis excluded from system boundaries*
   Biogenic CO_2 emissions and removals also include the sequestration resulting from biochar production, despite the final use of the biochar (e.g., agricultural application, energy production, etc.) being unknown. Pyrolysis is treated as a recycling process, with its outputs and the associated energy consumption assessed in the subsequent life cycle. This scenario is not aligned with major EPD systems and the ISO 14064 and ISO 14067 standards for biogenic CO_2 assessment.

3. *Scenario 3: Biogenic CO2 with neutral approach and pyrolysis included in the system boundaries*
   Biogenic CO_2 emissions and removals are not accounted for. Inputs and outputs related to pyrolysis are assessed. With regard solely to the approach adopted for biogenic CO_2, this scenario is consistent with major EPD systems and the ISO 14064 and ISO 14067 standards.

4. *Scenario 4: Biogenic CO2 with a non-neutral approach and pyrolysis included in the system boundaries*
   Biogenic CO_2 emissions and removals also include the sequestration resulting from biochar production. The CO_2 sequestration by biochar is accounted for, despite the final use of the biochar (e.g., agricultural application, energy production, etc.) being unknown. Inputs and outputs related to pyrolysis are included. This scenario is not aligned with major EPD systems and the ISO 14064 and ISO 14067 standards for biogenic CO_2 assessment.

Scenario 1, which adopts a neutral approach to carbon and excludes the pyrolysis process from the system boundaries, has been chosen as the baseline scenario, as it aligns with the majority of EPD systems and with ISO standards 14064 and 14067 for the accounting of biogenic CO_2.
The system boundaries for this study are defined as “cradle to grave” and include the following phases:

- *Upstream* phases and processes: raw material production, component and packaging material manufacturing, assembly;
- *Core* phases and processes: transportation of raw materials and components, storage;
- *Downstream* phases and processes: distribution, use phase, end of life of packaging and product.

For the calculations, both primary data provided by Arper and PaperShell and secondary data from the Ecoinvent database version 3.8 were used. Eurostat data was used to model the end-of-life phase.

To enable a comprehensive analysis of the product, two impact assessment methods were applied:

- *IPCC 2021: measures the Global Warming Potential (GWP) over a 100-year timeframe, considering emissions either separately or cumulatively.*
- *Environmental Footprint (EF): calculates the environmental footprint of products or services based on 16 impact categories and is the reference method of the European Union.*

For the scenarios that exclude pyrolysis from the system boundaries (Scenarios 1 and 2), and for the scenario that includes it but uses a neutral approach to biogenic CO_2 (Scenario 3), the life cycle involving pyrolysis of the shell shows a higher impact compared to the one that follows the average European disposal scenario. This is primarily due to the transport required for the take-back of chairs to be disposed of.

Conversely, the non-neutral approach scenario that accounts for the benefits of the pyrolysis process (Scenario 4) demonstrates that when the biogenic CO_2 sequestration from biochar is included within the system boundaries, the life cycle involving shell pyrolysis results in a lower global warming potential than the scenario assuming average European disposal of the entire chair.

Table 1 shows the detailed results for one of the Catifa Carta versions included in the Arper offering, where the red boxes highlight the 29.2% improvement achieved by Scenario 4 compared to the baseline (Scenario 1).

		Unit	Total	Upstream	Core C	Downstream	LC Packaging
Scenario 1: Neutro Cut off	Pirolisi	kg CO_2-eq	19,1	12,3	1,3	3,4	2,1
	RER	kg CO_2-eq	17,5	12,3	1,3	1,8	2,1
Scenario 2: Non Neutro Cut off	Pirolisi	kg CO_2-eq	15,8	9,7	1,3	3,4	1,4
	RER	kg CO_2-eq	14,2	9,7	1,3	1,9	1,4
Scenario 3: Neutro Biochar incluso	Pirolisi	kg CO_2-eq	19,1	12,3	1,3	3,4	2,1
	RER	kg CO_2-eq	17,5	12,3	1,3	1,8	2,1
Scenario 4: Non Neutro Biochar incluso	Pirolisi	kg CO_2-eq	12,4	9,7	1,3	0,0	1,4
	RER	kg CO_2-eq	14,2	9,7	1,3	1,9	1,4

Table 1: LCIA Results for Catifa Carta, 4-Leg Painted Version, Characterisation, IPCC 2021 100-year Method

To validate the results produced by Scenario 4 and ensure maximum transparency, Arper has chosen to operate on two distinct levels:

1. *Third-party verification of the model and calculation method only*: The certification body CSQA conducted a critical review on 06/12/24, confirming that the modelling and calculations are correct. This is a significant aspect, as it reduces the potential margin of error in the study to the assumptions alone, effectively shifting the discussion to a conceptual level focused on methodological choices.
2. *Assessment of the soundness of the calculation assumptions*: The most complex and debated part concerns the accounting of biogenic CO_2, the cut-off approach, and the benefits provided by biochar. To ensure the robustness of the proposed arguments, an open consultation process has been launched, involving a pool of industry experts to gather their input and incorporate it into the study.

6. Open Consultation: Development and Results

As previously mentioned, the current PCRs for seating do not account for carbon stored in a stable form in the soil, as is the case with biochar. To highlight the regenerative potential of this age-old technique, Arper developed LCA scenarios that include the accounting of biogenic CO_2 and the carbon stock contained in biochar, subsequently submitting them for verification and validation by a third-party body (CSQA).
However, given that this is an innovative and still largely unexplored area, Arper deemed it essential to share the initial calculation assumptions with experts in the field. This approach serves multiple purposes: to ensure greater transparency, foster dialogue with the scientific community, and communicate the company's efforts in a consistent and responsible manner. For this reason, on 18 January 2025, an open consultation was launched. The key aspects of this initiative are outlined below.

6.1. Drafting the Open Consultation Document: Assumptions and Questions

To ensure a thorough evaluation of the proposed hypotheses, all major assumptions were listed during the drafting phase of the consultation. The questions posed to the expert audience were as follows:

a) Scenario 2: Biogenic CO_2 with a non-neutral approach and pyrolysis excluded from system boundaries. This scenario is not aligned with the main EPD systems nor with ISO standards 14064 and 14067 for the assessment of biogenic CO_2.
Do you still consider Scenario 2 to be a valid option?

b) Scenario 4: Biogenic CO_2 with a non-neutral approach and pyrolysis included within the system boundaries. In this scenario, the inputs and outputs of pyrolysis are considered and, in addition to the emissions and sequestration of biogenic CO_2, the sequestration

resulting from the production of biochar is also accounted for. The CO_2 sequestration through biochar is included in the calculation, despite the uncertainty regarding the final use of the material (for example, in agriculture or for energy production). This scenario too is not in line with the main EPD systems nor with ISO standards 14064 and 14067 for the assessment of biogenic CO_2.
Do you think it makes sense to update Scenario 2 to Scenario 4?

c) The system boundaries include the production of raw materials, the production of components and packaging materials, assembly, transport of raw materials and components, storage, distribution, use phase, and end of life of packaging and product. The end of life of the product involves disposal of the shells in Sweden through pyrolysis. Specifically, the upstream processes include raw materials, their transport, the production of chair components, the assembly of the frame with the shell, and the packaging of both. The core processes include transport to the storage warehouse and the consumption of electricity and water for preservation. Final assembly of the product and/or its production are not included, as Arper does not produce or assemble its products in-house: these are partially assembled (shell and frame) directly by suppliers and then sent to an external storage warehouse. The downstream processes include distribution of the packaged product, the use phase, and end of life of both packaging and product. It has been assumed that the company's capital goods (e.g., machinery and buildings) do not have a significant impact in the life cycle assessment and are therefore not considered in the product system analysis. However, where already included, infrastructure has not been excluded, in accordance with the processes derived from the Ecoinvent database. Moreover, no cut-off criteria have been applied to exclude materials from the calculation.
Is there anything we are overlooking within the system boundaries?

d) The approach used to conduct this LCA study is attributional. The attributional model of a product's life cycle assesses the actual, average, or estimated supply chain. The existing or estimated system is considered within a static technological context.
Should the chosen approach be attributional?

e) In the baseline scenario, a cut-off approach is adopted and the pyrolysis process is excluded from the system boundaries, as it is considered a recycling process. In the other scenarios analysed, an alternative approach is evaluated which includes, solely for pyrolysis, the energy consumption required for the process to produce biochar, including the CO_2 sequestration resulting from biochar production. Avoided products are not considered.

Do you think the allocation rules are appropriate?

f) The neutral approach assumes that all CO_2 absorbed during the process is released into the atmosphere at the end-of-life stage. As a result, neither sequestration nor emissions of CO_2 related to bio-based materials are assessed, assuming a net carbon sequestration of zero. In contrast, the non-neutral approach evaluates the sequestration and emissions of biogenic CO_2 as they occur in the various stages of the analysed life cycle.
Based on your *knowledge and the available scientific literature, do you believe that biochar produced through a pyrolysis process can store CO_2 for more than 100 years, thus allowing for the accounting of biogenic CO_2?*

g) The PaperShell shell is produced by the company of the same name in Sweden. PaperShell AB provided a file containing the LCA analysis of the PaperShell material and a descriptive report, which enabled us to understand the material's impacts and to verify that the assumptions and approaches adopted in the provided LCA were aligned with those chosen for the present LCA analysis. Regarding the end of life of the shell, based on indications from the manufacturing company, it has been assumed that the PaperShell material can be treated similarly to cardboard.
Can PaperShell and cardboard be considered similar in terms of production processes, disposal, and related impacts?

h) For the scenario that assesses biogenic CO_2 with a non-neutral approach (Scenarios 2 and 4), the amount of carbon and the potential CO_2 sequestered in PaperShell, as well as that potentially emitted during the end-of-life phase, have been considered. The data used are as follows:
- Formula: (44/12) * carbon content * ((density * volume)/((1+(% moisture/100)))
- Carbon content: 41%
- Density: 1437.44 kg/m^3
- Volume: 0.002094 m^3
- Moisture: 1.85%
- CO_2 sequestered: 0.019 kg

In this scenario, landfill disposal has been assessed exclusively using the cardboard disposal process (Treatment of waste paperboard, sanitary landfill CH), with adjustments to CO_2 and CH_4 emissions based on the assumptions used in the Ecoinvent dataset.
Do you believe this is the correct approach to adopt?

i) For disposal through incineration, it is assumed that 100% of the sequestered carbon is re-emitted into the atmosphere.
Do you believe this is the correct approach to adopt? If not, could you explain why?

j) For the scenario that includes pyrolysis (Scenarios 3 and 4) to assess impacts, primary data were collected directly from PaperShell. In the proposed scenario, the shell is entirely disposed of via pyrolysis, while average European data are used for the disposal of the rest of the chair. For the shells collected and disposed of through pyrolysis in Sweden, additional transport is accounted for, considering collection from the countries of sale to the storage warehouse (estimated mileage similar to that of distribution) and the transport of the shells to PaperShell in Sweden for treatment. The primary data related to the pyrolysis process at PaperShell are as follows:

INPUT:

- Biomass: 779 g
- Biochar: 268 g
- Electricity: 72 Wh

OUTPUT:

- Carbon content in biochar: 91%
- Biogenic CO_2 uptake: 894 g

Do you believe this is the correct approach to adopt?

k) The Swedish energy mix is used for the pyrolysis process. The carbon sequestered in the form of biogenic CO_2 in the biochar is assessed in line with the primary data presented in Question 10. Ash generation and its subsequent disposal in the pyrolysis process are omitted, as they are considered to be of low relevance.
Do you agree with this approach?

l) The results were evaluated using both the IPCC method (across all four methodological scenarios) and the EF method (only for scenarios with a neutral approach, due to the intrinsic nature of the method).

- *Scenario 1:* Biogenic CO_2 with neutral approach and pyrolysis excluded from system boundaries (BASELINE). Biogenic CO_2 is not accounted for. Pyrolysis is considered a recycling process, whose product (biochar) and the energy required for its generation are assessed in the next life cycle.

- *Scenario 2*: Biogenic CO_2 with non-neutral approach and pyrolysis excluded from system boundaries. End-of-life choices for pyrolysis are aligned with Scenario 1. Biogenic CO_2 capture and emissions are included.

- *Scenario 3*: Biogenic CO_2 with neutral approach and pyrolysis included within system boundaries. Biogenic CO_2 is not assessed. However, the input and output flows related to the pyrolysis process are considered.

- *Scenario 4*: Biogenic CO_2 with non-neutral approach and pyrolysis included within system boundaries. Pyrolysis inputs and outputs are assessed. Biogenic CO_2 is considered, including the sequestration resulting from biochar production, even though its final use is unknown.

Do you believe these four scenarios cover all possible options, even if some may be irrelevant?

m) The figures below show the results obtained using the IPCC method for the scenarios related to pyrolysis and standard disposal in Europe (RER). The IPCC method assesses only one impact category, namely the Global Warming Potential (GWP), which provides a limited view of the product's environmental performance.

	Total	Upstream	Core	Downstream	Packaging
Scenario 1 - Pyrolysis	18,1	11,3	1,3	3,4	2,0
Scenario 1 – RER	16,4	11,3	1,3	1,8	2,0
Scenario 2 - Pyrolysis	14,7	8,7	1,3	3,4	1,3
Scenario 2 - RER	13,2	8,7	1,3	1,9	1,3
Scenario 3 - Pyrolysis	18,1	11,3	1,3	3,4	2,0
Scenario 3 - RER	16,4	11,3	1,3	1,8	2,0
Scenario 4 - Pyrolysis	11,3	8,7	1,3	0,0	1,3
Scenario 4 - RER	13,2	8,7	1,3	1,9	1,3

Do you think there are other relevant impacts or impact categories that we should consider and highlight when assessing and communicating the environmental performance of Catifa Carta?

n) The study addresses three topics—emissions, biogenic carbon sequestration, and the allocation of recycling processes—for which there is no universal consensus within the LCA methodology. Therefore, different approaches were adopted, leading to the creation of four parallel scenarios used for the life cycle analysis of Catifa Carta. The scenarios include the assessment of biogenic carbon using both neutral and non-neutral approaches, as well as the potential inclusion of the pyrolysis process for biochar production within the system boundaries. The scenario assuming a neutral impact of biogenic carbon and excluding the pyrolysis process from the system boundaries was chosen as the baseline scenario, as it aligns with most EPD systems and ISO standards 14064 and 14067 for biogenic CO_2. In terms of results, Scenario 4 shows that, when the sequestration of biogenic CO_2 through biochar is included within the system boundaries, the life cycle including the pyrolysis of the shell has a lower GWP impact compared to the one that considers the average European waste management for the entire chair. The results of this scenario are valid for a pyrolysis process with the same biochar yield, the same biogenic carbon content, and the same electricity mix as those analyzed.

Do you think this statement can be considered reasonably true, consistent, and responsible in terms of fair communication?

o) *Do you have any additional observations, comments, or statements you would like to share with us?*

6.2. Expert Involvement

Seventy industry specialists were invited, selected based on their category of expertise and the professional knowledge of the study's promoters. Figure 4 provides a detailed breakdown of the number of experts in each selected category.

Category	Invited	Accepted
Architects	8	1
End customers	1	1
Competitors	7	2
External consultants	10	6
Dealers	4	1
Journalists	1	0
Institutions	12	2
LCA software companies	3	2
Universities	7	4
Multinational companies	12	1
Medium and large companies	4	2
Finance	1	0
Total	**70**	**22**
		31%

Fig. 4: Number of experts consulted for the open consultation, divided by category

Twenty-two professionals responded to the invitation and agreed to take part in the consultation. However, some later realized they were unable to provide a detailed response and ultimately declined the invitation. Among those who accepted, only nine actually completed the questionnaire.

- Andreas Ciroth (Owner at GreenDelta GmbH)
- Christian Lodgaard (Chief Design Officer at Flokk)
- Christian Steiner (Owner at Multiple Impact by C. Steiner)
- Francesca Manzini (Sustainability Manager at Focus Lab S.r.l.)
- Nicola Fabbri (Senior Consultant at IPLUS SB s.a.s.)
- Samuel Vionnet (Owner at Valuing Impact)
- Silvia Zanazzi (Head Scientist at Nativa S.r.l.)
- Two other experts who preferred not to disclose their names in the document.

6.3 Gathering and Analysing Feedback

The responses received were analysed in detail in order to identify useful insights and suggestions to refine the initial hypotheses. In general, the feedback proved to be consistent in both approach and opinion. Only in two cases was it deemed necessary to further investigate the responses to better understand the underlying motivations. In these instances, the respondents were directly involved and invited to provide additional clarification and details to complement their initial input.

The study coordinators then took responsibility for identifying a definitive response (Yes or No), providing a brief summary for each question in order to offer an overall view of the project and support the planning of next steps.

Below is the result of this in-depth analysis, which also includes a degree of personal evaluation by the authors.

For the sake of clarity and conciseness, the full list of questions previously presented in Section 6.1 is reported below, accompanied—where necessary—by a short contextual paragraph and a summary of the feedback received.

a) *Do you consider Scenario 2 to be a valid option?*
No. While it may be theoretically acceptable, a non-neutral approach is not acceptable unless it is linked to proper end-of-life management.

b) *Do you think updating Scenario 2 to Scenario 4 makes sense?*
Yes. Not only does it make sense, but it is also consistent with the previous answer and with the overall approach of the study. However, the pyrolysis process needs to be described more clearly, with additional technical details and a better understanding of the final destination of the biochar. Moreover, a more conservative approach could include in the LCA calculation the possibility that not all seats will become input for a pyrolysis process.

c) *Is there anything we are overlooking within the system boundaries?*
No. In the vast majority of cases, the system boundaries are considered consistent. The only minor issue concerns a potential inconsistency between the exclusion of the impact of material assets and the standard Ecoinvent processes, which may sometimes include it. However, the impact would be minimal.

d) *Should the chosen approach be attributional?*
Yes. The attributional approach is the one most commonly used in LCA studies and is also relevant for this study.

e) *Do you think the allocation rules are correct?*

Yes. Particular attention has been given to how the co-products of the pyrolysis process are managed, identifying this as an area that requires further clarification. In our case, the syngas is liquefied and reused as fuel for the pyrolysis plant, while the bio-oil was not included in the calculation. Overall, the approach proposed in this study can therefore be considered conservative. It should also be noted that the concerns likely would not have arisen if the calculation model had been included in the LCA study documentation.

f) *Based on your knowledge and the available scientific literature, do you believe that the biochar produced through a pyrolysis process can store CO_2 for more than 100 years, thus allowing for the accounting of biogenic CO_2?*
Yes. In general, the literature confirms that agriculture is the only application that ensures carbon sequestration in the soil for more than 100 years. This has been confirmed, among others, by Project Drawdown[3]. In this context, two aspects require particular attention: the actual use of the biochar, and the fact that the seats will indeed be sent through the pyrolysis process.

g) *Can PaperShell and cardboard be considered similar in terms of production processes, disposal, and related impacts?*
No. This point generated differing opinions. In general, although no specific alternatives were suggested, there is a shared sense that some differences remain—such as in waste management streams. A possible solution could be to model the disposal of PaperShell using only primary data. In our specific case, we used data provided directly by PaperShell, which has, in fact, already updated the data model with some primary data.

h) *Do you believe this is the correct approach to adopt? (Landfilling of Scenarios 2 and 4 calculated by adjusting CO_2 and CH_4 emissions from the cardboard disposal process based on the Ecoinvent dataset)*
Yes. The approach was generally considered appropriate. However, it would be advisable to check for other possible emissions generated by the disposal process (such as nitrogen and sulfur oxides), as well as the geographic resolution (alignment at the RER level).

i) *Do you believe this is the correct approach to adopt? If not, could you explain why? (Incineration with 100% of the sequestered carbon released back into the atmosphere)*
Yes. The assumption was considered correct. Some ashes could technically contain (volatile) carbon, but in this case, the conservative approach is the appropriate choice.

[3] For further details, see: https://drawdown.org/solutions/biochar-production

j) *Do you believe this is the correct approach to adopt? (Scenarios 3 and 4 with shell disposal via pyrolysis based on PaperShell primary data, baseline disposal using RER secondary data, and inclusion of transport emissions for take-back and shipment to the pyrolysis plant in Sweden)*

Yes. The methodological approach is reasonable, but it is advisable to supplement the description of the adopted method with more detailed technical information on the system used to assess the biochar content, particularly regarding the stable carbon fraction.

k) *Do you agree with this approach? (Swedish energy mix, carbon sequestration in line with PaperShell primary data, omission of ash generation and disposal)*

Yes. The approach is acceptable, provided that evidence is given to demonstrate the negligible impact of the ashes (for example, by indicating the ratio between the ash mass and the total biomass weight and/or the carbon content of the ashes).

l) *Do you think these four scenarios cover all possible options, even if potentially irrelevant?*

Yes. However, perhaps in the context of a follow-up study, it would be extremely interesting to explore the capacity and stability of carbon sequestration within biochar under different end-use scenarios.

m) *Do you think we are missing any relevant impacts or impact categories that we should consider and highlight when assessing and communicating the environmental performance of Catifa Carta?*

Yes. A sensitivity analysis could reveal the potential influence that the selection and use of furniture have on overall carbon sequestration capacity, thereby highlighting the consumer's responsibility and how their choices affect the product's overall impact. Additionally, categories such as acidification potential, eutrophication potential, resource depletion, and ecotoxicity could provide a more comprehensive account of environmental impacts. Finally, a breakdown of the various climate change indicators (fossil, biogenic, LUC, LULC) would help illustrate the different contributions. Overall, a more detailed analysis of the results is recommended.

n) *[...] The non-neutral approach scenario that includes pyrolysis (Scenario 4) shows that, by including the sequestration potential of biogenic CO_2 through biochar within the system boundaries, the life cycle involving pyrolysis of the shell has a lower GWP impact compared to the one assuming average European (RER) disposal of the entire seat. Do you think this statement can be considered reasonably true, consistent, and responsible in terms of fair communication?*

Yes. However, the statement would be even more consistent and responsible if it included a disclaimer regarding the specificity of the disposal activities. Additionally, the study would be more balanced if it accounted for the variability in the final application of biochar, which in some cases may fall outside of Arper's control.

o) *Do you have any further observations/comments/statements you would like to share with us?*
As mentioned earlier, it would have been helpful to have access to the calculation model as well, in order to clarify some of the concerns directly at the source.

7. Conclusions and Next Steps

The Catifa Carta project is characterised by a high level of innovation and, as such, breaks away from the conceptual and operational frameworks we are used to—particularly in the context of Product Category Rules (PCR) for product LCA. In this case, it is not only a matter of introducing a new material with high environmental performance, but primarily about developing a business model designed around end-of-life considerations. In practice, the process we have designed—and submitted to a panel of experts through this open consultation—has shown that the material alone is not sufficient to drive substantial change. Rather, the development of a structured and innovative approach to product disposal plays an equally, if not more, critical role. When the issue of greenhouse gas emissions is addressed in its entirety, extending a product's useful life and temporarily storing carbon can only mitigate the problem. The real game-changer at a global level lies in the creation and responsible management of a stable, long-term carbon sink. It is from this belief that Arper has chosen to focus its efforts on building a new system for product development and management—one that opens up new, largely unexplored perspectives. To date, the consultation has confirmed the soundness of the proposed approach, highlighting at least four key areas that should be carefully considered for future development:

a) A sensitivity analysis should be developed with the aim of highlighting the potential influence that the selection and use of furniture can have on the overall carbon sequestration capacity, thus emphasising the responsibility of consumer choices and their impact on the product's overall environmental footprint.
b) The statements contained in the document would be even more consistent and responsible if they included greater detail on the specificity of disposal activities. The study would gain in fairness, for example, by incorporating considerations on the variability of biochar's end-use applications, which in some cases may lie outside Arper's operational control.
c) The analysis should be extended to include additional impact categories such as acidification potential, eutrophication potential, resource depletion, and ecotoxicity, to provide a more comprehensive account of the impacts. In addition, a breakdown of the various climate change indicators (fossil, biogenic, LUC, LULC) would help better identify the different contributions.
d) In line with points a) and c), we believe it would be highly valuable to expand the impact assessment to include aspects related not only to the environmental dimension but

also to the social one—for example, the wellbeing generated by avoided CO_2 emissions, or the positive societal outcomes resulting from the dissemination of circular economy principles. This could be achieved through an ex-post monetary impact assessment using globally recognised methodologies such as IFVI / Value Balancing Alliance, eQualy, or SROI.[4]

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