Grant Agreement number: 101037031
Project acronym: FRONTSH1P
Project title: A FRONTrunner approach to Systemic circular, Holistic & Inclusive solutions for a new Paradigm of territorial circular economy
Type of action: Deployment of systemic solutions with the support of local clusters and the development of regional community-based innovation schemes

Deliverable Number: D7.6

Report of the simulation for each fellow region and roadmap to enhancements

Delivery type:	Report
Lead beneficiary:	32 - VELTHA
Lead author:	32 – VELTHA & UNITUS
Contributions:	UNILODZ, NTUA, INL, CCDR-Norte, STAM, VELTHA
Contractual delivery date:	30/04/2025
Delivery date:	17/09/2025
Dissemination level:	Public

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Partners

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HISTORY OF CHANGES			
Version	Date	Author/Contributor	Changes
V 0.1	31/03/2025	NTUA	V 0.1 ToC
V 0.2	15/07/2025	UNITUS	Author´s version
V 0.3	15/08/2025	VELTHA	Minor revision
V 0.4	19/08/2025	VELTHA	Version for internal review
V 0.5	20/08/2025	INL	Proof reading, internal review
V0.6	26/08/2025	VELTHA	Minor revision following internal review
V0.7	26/08/2025	NTUA	Review, Minor editing
V1.0	27/08/2025	VELTHA	Final version for submission

Disclaimer

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Executive Summary

Deliverable **D7.6, *"Report of the simulation for each fellow region and roadmap to enhancements",*** consolidates the results of regional simulations carried out with the Frontsh1p Scenario Optimiser and integrates direct user feedback through structured questionnaire testing. Together, these elements provide a comprehensive evaluation of the replication potential of four Circular Systemic Solutions (CSSs) across five fellow regions: **Łódzkie (Poland), Campania (Italy), Sterea Ellada (Greece), Região Norte (Portugal), and Fryslân (The Netherlands).**

The simulations assessed each CSS—**CSS-1 Wood Packaging, CSS-2 Food & Feed, CSS-3 Water & Nutrients, and CSS-4 Plastic & Rubber Waste**—both individually and in all feasible combinations. This approach captured the stand-alone performance of each systemic solution and the synergies emerging from integrated deployment. For every simulation run, results were generated for three headline Key Performance Indicators (KPIs): financial performance, environmental impact (CO_2-eq savings), and social contribution (job creation), complemented by detailed cost-structure and material-flow data.

The deliverable also includes **Fellow Regions' Feedback**, which documents the results of questionnaire-based testing. The survey collected the views of public administrations, clusters, and other stakeholders on the usability, clarity, and perceived usefulness of the platform. Responses confirmed the tool's accessibility and relevance while pointing to concrete areas for improvement. These insights complement the quantitative simulations by embedding user experience into the evaluation and refinement of the platform.

-Simulation results demonstrate that climate performance improves almost monotonically with system integration.

-Employment impacts are consistently positive. The roles span logistics, biochemical conversion, polymer reprocessing, and water treatment, aligning with regional skills priorities.

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-Financial viability remains the primary constraint—largely due to high CAPEX requirements, solvent-intensive operations, and logistics costs—variation across CSSs is significant.

-Transport emerged as a critical lever, representing up to 30% of OPEX and a similar share of residual emissions. Route optimisation, modal shift, and alternative-fuel fleets are highlighted as quick wins

The structured SWOT analyses, supported by both simulation data and user feedback, highlight three overarching priorities for regional roadmaps:

- **Closing material and solvent loops**, particularly through solvent recovery, char valorisation, and water treatment modules.
- **Scaling enabling infrastructures**, with an emphasis on CSS-3 capacity and shared logistics hubs.
- **Aligning incentives with outcomes**, shifting from flat grants to performance-based instruments such as differentiated EPR fees, carbon-removal certificates, and Innovation Fund blending.

By integrating simulation evidence with stakeholder insights, D7.6 provides a more holistic assessment of the Frontsh1p platform and the Circular Systemic Solutions. The deliverable confirms the technical and environmental promise of these solutions while underlining the importance of user experience, process optimisation, and tailored policy support in securing financial viability and accelerating large-scale replication.

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List of Abbreviations

- **CAPEX (Capital expenses or expenditure):** refers to money an organization or corporate entity spends to buy, maintain, or improve its fixed assets, such as buildings, vehicles, equipment, or land.
- **CEAP (Circular Economy Action Plan):** The EU policy framework aimed at promoting sustainable resource use by encouraging reuse, recycling, and reduction of waste throughout product lifecycles.
- **CI/CD (Continuous Integration / Continuous Delivery):** Automated practices that keep software development processes efficient, consistent, and collaborative across multiple partners.
- **CO2eq (Carbon Dioxide Equivalent):** Unit of measurement that represents different greenhouse gases in a single unit.
- **CSS (Circular Systemic Solutions):** Integrated approach that design, implement, and manage interconnected circular economy processes.
- **EPR (Extended Producer Responsibility):** A policy approach where producers are legally responsible for the entire lifecycle of their products.
- **FFA (Free Fatty Acids):** A chemical output from biomass/oil processing.
- **FTE (Full Time Equivalent):** A way to measure jobs created and normalized as if they were all full-time positions.
- **HCl (Hydrochloric Acid):** A common acid used in biomass, polymer, and chemical processing for hydrolysis, neutralization, or pH adjustment.
- **KOH (Potassium Hydroxide):** A strong base (alkali) widely used in chemical and biochemical processing.
- **KPI (Key Performance Indicators):** critical, quantifiable measures of progress toward a desired result to help organizations with strategic and operational decision-making.
- **LNG (Liquefied Natural Gas):** Natural gas cooled into a liquid state for easier storage and transport, often used as a lower-emission alternative fuel for vehicles and industry.
- **OPEX (Operating expenses or expenditure):** refers to the costs incurred by any business via the production of goods and services, including materials, labour, machinery, packaging, shipping materials.
- **SME (Small and Medium-sized Enterprise):** A business with a limited number of employees and revenue, typically smaller in scale than large corporations, but vital for economic growth and innovation.

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- **SWOT (Strengths, Weaknesses, Opportunities, and Threats):** A strategic planning tool used to evaluate a situation, project, business, or even a personal goal.
- **CpEAP (Circupuncture Economy Action Plan):** a plan that translates a chosen "Challenges" into actionable circular goals assigning a coordinator and implementers, detailing steps and timelines, specifying budget/funding, and setting results with measurable KPIs. It serves as a replicable blueprint to deploy small, place-based interventions aligned with the CircuPuncture model developed in Deliverable 2.6 within Frontsh1p.
- **RCBT (Regional Circularity Booster Toolkit):** a cloud-based suite of five online tools that collect, process, and share tailored, real-time, geo-located information to accelerate regional circular economy deployment. It supports CSSs with resource and by-product management, circular indicators and eco-design thresholds, brokerage/watch-dog interfaces, a VER scheme, and mapping to integrate technological, social, institutional, and business needs.
- **CBT (Circular Benchmark Tool):** an effective assessment to understand, visualize and compare the transition towards a circular economy for regions and provinces.

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1 Introduction

1.1 Purpose of the deliverable

This deliverable reports the simulation results for each fellow region and sets a clear roadmap for enhancements of the Circular Systemic Solutions (CSSs) and the related Circular Economy Action Plans (CEAPs)[1]. Simulations are carried out with the Scenario Optimizer Digital Platform developed in Task 7.2, testing enabling conditions such as end-of-waste criteria, product certification, and public/private funding options. The work estimates impacts, financing needs, and concrete actions required for a full circular transition in each region.

The outputs guide policy and investment decisions. Quantitative KPIs support the selection of incentive schemes and demonstration projects, and they inform policy and business plans that will feed replication pathways in WP8. Evidence is built using inputs from local stakeholders, the regional governance setup, and Smart Specialisation Strategies, so that measures co-created for each context are fit for purpose.

Scope of D7.6 (fellow regions covered):

- Łódzkie — Poland
- Campania — Italy
- Stereá Elláda — Greece
- Região Norte — Portugal
- Fryslân — The Netherlands

By consolidating these analysis, D7.6 advances WP7 objectives on engagement, impact evaluation, simulation of improvements to the systemic solution, and assessment of replication potential across regions.

1.2 Dimensions of analysis

The five dimensions covered by the analysis with the Scenario Optimizer include the **information within the platform and considered by the simulation algorithm**. The data provided by the simulation platform will include: the financial impact, environmental impact, and social impact. For each simulation, the platform also returns information on the impact of economic and quantitative figures, as well as the type and amount of resources produced, used, and recycled in the systemic solution.

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1.2.1 Innovation potential

This dimension assesses the potential of the region in sustaining innovation processes or technologies which can be exploited within a Circular Economy (CE) strategy[2]. The innovation potential is assessed by the exploitation of different capabilities in the region. The main data source is that on innovation CSSs for which regions report different pilot plants and facilities active on the region or express interest establishing plant in future.

1.2.2 Climate change

This dimension assesses the potential of the region in CO_2 eq. and showcase improvement to baseline practices.

1.2.3 Societal awareness of circular economy

This dimension assesses the level of awareness of stakeholders (citizens, companies, institutions) about sustainability and the opportunities offered by CE within the region.

1.2.4 Regulation

This dimension assesses the existence of regulation – either at regional, national, or international level, and either existing or currently planning – which could foster, or hamper, the development of circular economy.

1.2.5 Available resources

This dimension assesses the presence of waste or by-products in the region that can be exploited in CE applications.
For each focus sector the agreed methodology asked regions to provide data on material and energy purchase prices (see page 13).

1.3 Methodological Local Analysis Framework

For the local analysis, the capabilities can be described across different application domains and enabling technologies. The main source of information is in this case the SWOT[3] analysis in which the region critically evaluates its position towards CE from different perspectives (economic, social, environmental and regulatory).

The analysis is structured in sub-sections, each one containing the report for each specific region. For each fellow region, the analysis compiles a descriptive profile

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that brings together the quantitative and qualitative outcomes of the simulations. These profiles summarise:

1-T**he resource flows produced, used, and recycled;**

2-The performance of **individual Circular Systemic Solutions** (CSSs);

3- The results of **combined configurations**;

4- The **general considerations** that emerge from regional specificities.

By presenting these elements in a coherent narrative, the profiles allow stakeholders to quickly understand both the immediate impacts of single solutions and the added value of integrated portfolios.

2 Digital Platform and Scenario Optimiser

The methodologies underpinning the development of the Frontsh1p Scenario Optimizer and associated tools in Task 7.2 are built upon the insights and approaches developed across multiple work packages, ensuring a cohesive framework for advancing circular economy practices. These contributions form the backbone of the work in Task 7.2 and ensure alignment with the project's broader objectives.

The optimization algorithms and models developed for the Scenario Optimizer were informed by the industrial processes and technological innovations modelled in CSSs. These innovations were complemented by the social, environmental, and economic impact analyses, ensuring that Task 7.2 captured the broader dimensions of circular economy practices[5].

2.1 Methodology

The software development adopted an Agile methodology complemented by Continuous Integration / Continuous Delivery(CI/CD) best practices to address the interests of stakeholders and ensure integration with the activities of the consortium partners. Furthermore, a design thinking approach was necessary in the early stages of the task to capture and formalise the subsequent software developments. From an engineering perspective, the CSS implementation interlinks and has been leveraged to accurately model and optimise the overall system. In this context, the developments carried out in the “Focus group on Circular Systemic Solutions” workshop by NTUA have formed the basis for the designed system model architecture.

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2.2 Modelling

The methodology adopted emphasised adaptability and scalability, ensuring that the models could handle evolving or incomplete data sets. By incorporating flexible assumptions and modular configurations, the Frontsh1p Scenario Optimiser can integrate additional data as it becomes available, further refining the results and improving accuracy. These efforts guaranteed the platform's ability to deliver meaningful insights and sustain progress despite initial data limitations, highlighting its potential for application in diverse regional contexts.
“Scenarios” among the four different CSS have been modelled as black boxes where various inputs and outputs can be measured and linked. This approach allows for focusing the development of the Digital Platform on the system at a higher regional and geographically distributed level. In this regard, by collecting real-application or literature data from the respective CSS owner on the different scenarios, it was possible to estimate the yields for each specific material considered. For clarity, assumptions and definitions are listed below:

a. CSS: container of different Scenarios, assumed to be within the same area
b. Waste Stream (WS): main waste material input that a Scenario consumes
c. Scenario: industrial process or series of industrial processes, assumed to be within the same area.

Impacts for each Scenario have been quantified on the three-levels or categories, environment, economic and social. These values, represented by specific KPIs, shown in below table, are then linearly correlated with the “Process scale”, which refers to the quantity of waste stream that the Scenario elaborates in one year, representing a proxy information of its industrial capacity.

resource	unit of measure	category	sample
Pallet	kg	waste stream	1000
Energy (electrical)	kWh	input	500
Paint	l	input	50
Hardware	kg	input	30
Wood waste	kg	output	100
Furniture	kg	output	980
impacts			
Process scale	kg	input	1000
Employee	# of people	social	2-3
CO2eq	kg	environment	1000
CAPEX	€	economic	30.000-50.000
OPEX	€/y	economic	20.000-30.000

Table 1 Input data catalogue - Scenario example**.** Source: Frontsh1p Deliverable 7.2 p. 6

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2.3 Digital Platform User Guide

The design methodology identified two primary user types: local administration users and industrial stakeholders. Local administrations focus on quantitative analyses of the economic, social, and environmental benefits for communities arising from CSS installations. Industrial stakeholders, by contrast, are interested in uploading and geolocating their facilities or processes to evaluate the profitability of connecting different scenarios. Despite these differences, no major distinctions in functionality were identified, leading to the development of a unified platform that accommodates both user types.

To ensure applicability across regions, a **collection of region-specific data** has been gathered in collaboration with project partners. This data includes average values for mapped resources, waste streams, purchase prices, handling costs, and transportation impacts (economic and environmental). Initial efforts focused on partial data collection for the Łódź and Lazio regions, enabling the configuration of two distinct regional scenarios. Assumed values for transportation costs, both in terms of economic (€/km · kg) and environmental (gCO_2eq/km · kg) impacts, have been used to estimate the influence of distances between waste streams and CSS locations.

Users engage with the platform through an intuitive interface designed to accommodate both technical and non-technical users. The region-specific sign-in process ensures that **tailored datasets are accessible**, making the platform relevant to the user's geographic area. Once logged in, users can interact with an interactive map that visualizes waste streams, CSS locations, and associated impacts. Through the interface, they can modify parameters such as waste stream quantities and process scales, activate or deactivate scenarios, and apply policy settings—all facilitated by a dynamic and visually clear design.

The results page provides a comprehensive analysis of the economic, environmental, and social impacts of the scenarios simulated. Key performance indicators (KPIs) are presented in an accessible format, including geospatial visualizations and detailed data tables, enabling stakeholders to assess outcomes effectively. Users can download these results for offline analysis, further promoting stakeholder engagement and collaboration in developing circular economy strategies.

2.4 Homepage

After logging in on the platform, the user lands on the homepage where the map of the region is displayed on the background and the following elements are displayed on-top:

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- Platform project logo
- Legend: shows the list of mapped items and brief instructions for map functionalities
- Dialog dedicated to the user settings:
    - CSS settings: activation/deactivation of each mapped Scenario (CSSx.x)
    - Policy tool: policies (taxes or incentives) settings
    - Lunch button: to start the optimization algorithm with the set inputs
- The following icons:
    - Flag: shows the platform language, with the possibility of changing it
    - User profile image: Links to the user's profile and allows logout
    - Zoom: shows the map interaction options, zoom in (+), zoom out (-) and compass for north-direction relocation.

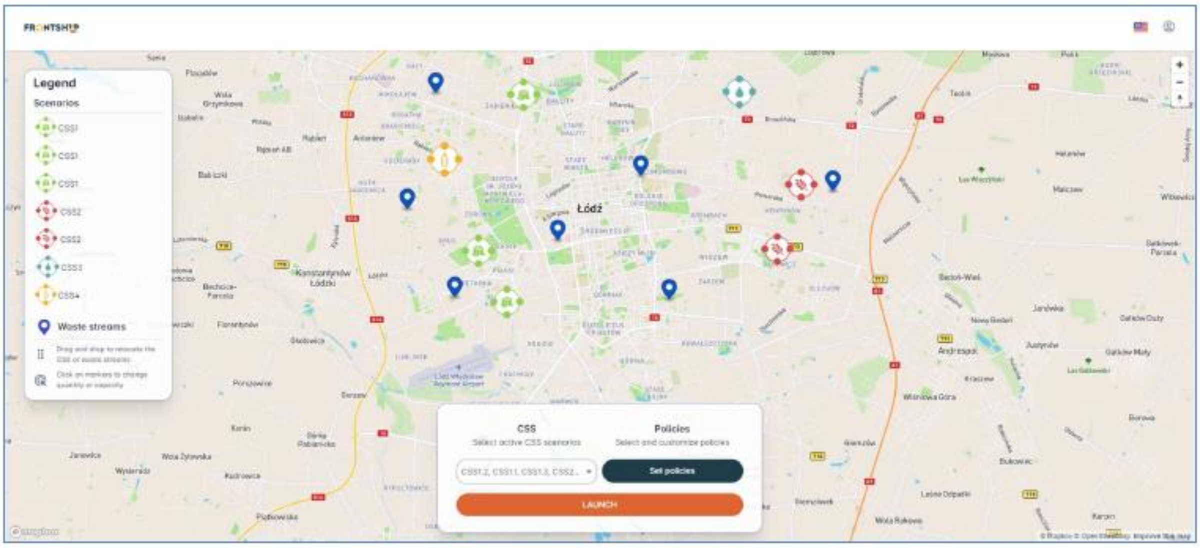

Fig 1. Homepage - CSS and waste streams geo-localization at regional level - Łódź region example. Source: Frontsh1p Digital Platform

Map Interaction

Moreover, when each item is clicked a custom dialog is opened and a specific value can be modified. As shown in Figure 2 examples, in case a **CSS icon** is clicked, it is possible to modify **its capacity**, i.e. changing its "process scale" to be then simulated and optimized. On the other hand, if a waste stream icon is clicked, the user can change the quantity that must be handled **for each year**, expressed in the specific unit of measure of the material.

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Fig 2. Homepage - examples of dialogs for modifying CSS capacities and waste stream quantity in the region.
Source: Frontsh1p Digital Platform.

Policies setting

By clicking on the “set policies” button, shown in Figure 3, a new dialog box is displayed to the user. In the dialog, shown in Figure 3, multiple policy typologies are listed. The user is, thus, able to activate the policy by clicking on the tick-box on the left. Once the policy is activated is possible to insert the value related to the policy.

Depending on the typology, **the value refers to the economic input**, bonus in case of incentive or malus in case of tax, per unit of objective.

Part of the following policies schema is a fraction of the proposed “Policy actions/initiatives for the Digital Platform”, developed by VELTHA partner within D7.5 efforts.

Proposals to integrate further policies into the FRONTSH1P platform were developed through a staged, consultative process in deliverable 7.5, building on the initial beta simulation of the platform. Along with prior analyses (SCREEN, REPLACE, CBT, RCBT) and the platform’s simulated results, a targeted feedback round was utilized through a questionnaire with regional actors, RIC, the Parzęczew Commune, and multiple respondents from the University of Łódź, with OPUS and other partners involved across review and development. The consultation probed which CSSs had highest regional potential, which CpEAP measures would be most impactful, enabling factors for cross-regional uptake, and barriers to implementation. These inputs were synthesized with earlier findings to define proposals that the platform could operationalize and monitor. Three initiatives were then formulated:

- a CE education and training incentive,
- a waste-facility deployment incentive,
- a cross-sector collaboration incentive based on tax reductions.

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After validation with partners, the two latter were selected for near-term integration (facility deployment and cross-sector collaboration) because they offer direct, geolocatable, and contract-based outputs that broaden the platform's policy mix and measurability.

For sake of clarity, the different units of measure are:

- Incentives
  - "Wastewater recovery initiative": euros per litre of consumed wastewater subtracted to the financial impact
  - "CE waste facilities deployment initiative": euros per scenario deployed to the financial impact
  - "CE cross-sectoral waste management initiative": euros per unit of recircled resource to the financial impact
- Taxes
  - "Carbon footprint pricing scheme": euros per CO_2 consumed added to the financial impact

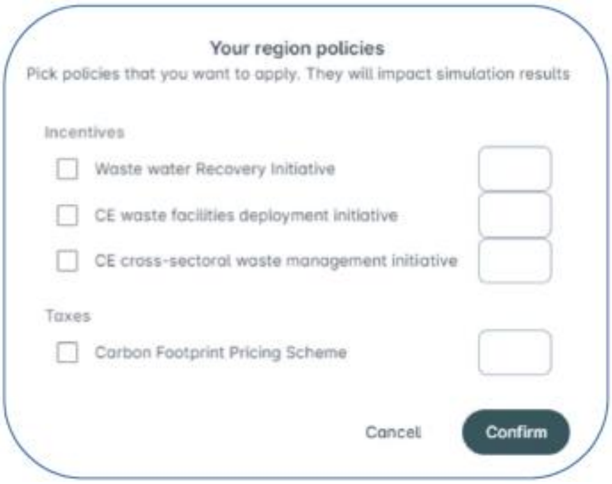

Fig 3. Homepage - policy tool. Source: Frontsh1p Digital Platform.

The policy tool is a powerful instrument which can be used to nudge the simulation calculation to a different economic impact of the chosen configuration, with a high degree of flexibility for the user choice.

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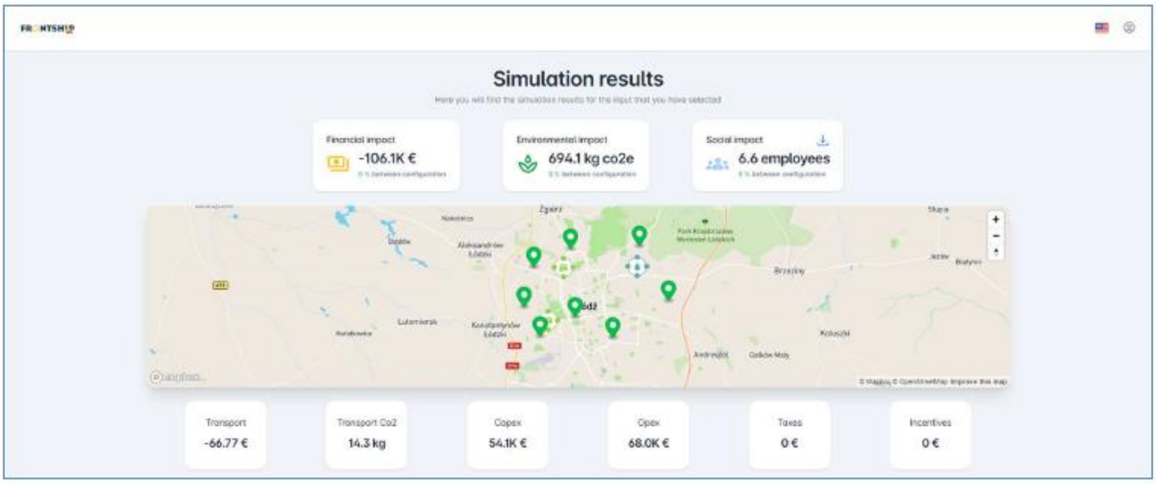
Fig 4. Homepage - dialog for activating or deactivating CSS. Source: Frontsh1p Digital Platform.

2.5 Results page

After the user run the optimization, by clicking the "launch" button in the homepage, the webapp is redirected to the results' page as depicted in the Figure 5. Starting from the top, it shows different sections:

1. High-level quantitative impacts on the three levels, with the percentage of improvement compared to the baseline configuration, i.e. no CSS or scenarios have been deployed.
2. The map of the considered waste streams and activated scenarios, by hovering to the CSS icon, the user can see a brief description of its processes.
3. Cards displaying specific voices for costs and CO_2eq emissions
4. Table with specific descriptions of each resource, purchased, sold to the market or recirculated among mapped waste streams and CSS, with each of the economical values



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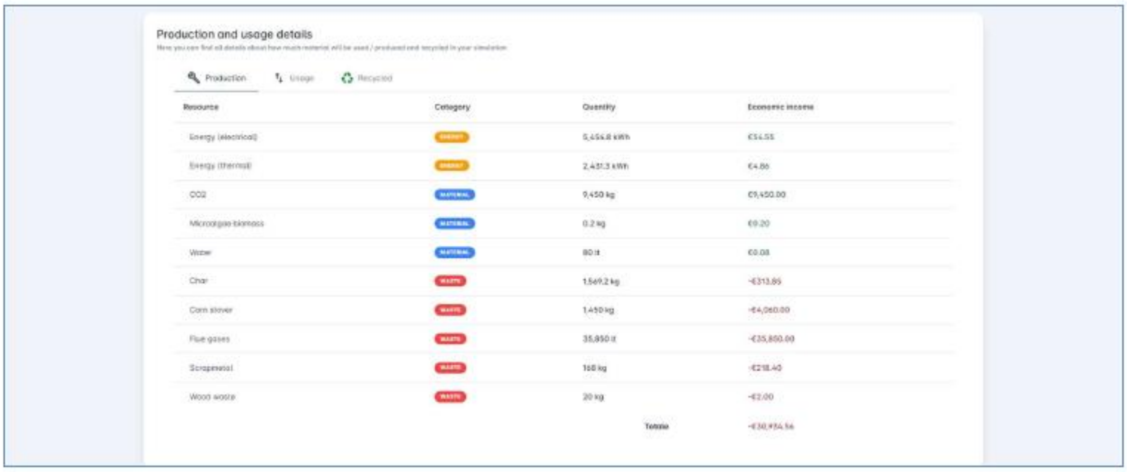

Production and usage details

Production | Usage | Recycled

Resource	Category	Quantity	Economic income
Energy (electrical)	ENERGY	5,456.8 kWh	€54.55
Energy (thermal)	ENERGY	2,431.3 kWh	€4.86
CO2	MATERIAL	9,450 kg	€9,450.00
Microalgae biomass	MATERIAL	0.2 kg	€0.20
Water	MATERIAL	80 lt	€0.08
Char	WASTE	1,569.2 kg	-€313.85
Corn stover	WASTE	1,450 kg	-€4,060.00
Flue gases	WASTE	35,850 lt	-€35,850.00
Scrapmetal	WASTE	168 kg	-€218.40
Wood waste	WASTE	20 kg	-€2.00
		Totale	-€30,934.56

Fig 5. Results page - overall triple impacts values and specifics on resource production, consumption and exchange. Source: Frontsh1p Digital Platform.

2.6 Data extraction process

For the analysis presented in this deliverable, the following steps have been adopted:

- Login with each region's specific credentials
- CSS settings: activation/deactivation (as indicated in Fig.4 p. 18)
- Policies setting (as indicated in Fig. 6 p. 21)
- Extraction of simulation results in an excel datasheet for its elaboration.

Hereby an example of the visualization obtained after the above-mentioned steps:

CSS activated: CSS2
Geographical area: Lodz
Policies activated: Waste recovery initiative (incentives)-Carbon footprint pricing scheme (taxes)
Value assigned to policies: 1

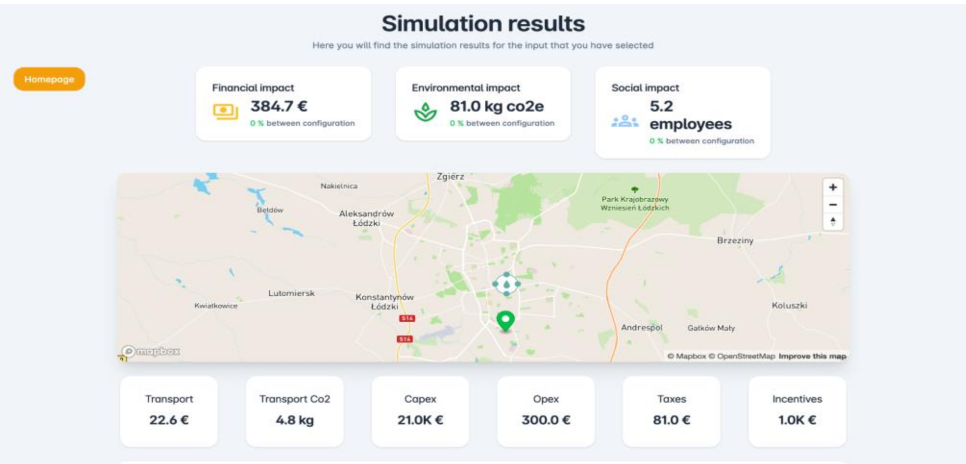

Fig 6. Results page - CSS2 Simulation overview. Source: Frontsh1p D.7.2.

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Production results

Production and usage details

Here you can find all details about how much material will be used / produced and recycled in your simulation

Production | Usage | Recycled

Resource	Category	Quantity	Economic income
Microalgae biomass	MATERIAL	2 kg	€2.00
Water	MATERIAL	800 lt	€0.80
		Totale	€2.80

Fig 7. Results page - CSS2 Production details. Source: Frontsh1p D.7.2.

Usage results

Homepage

Production and usage details

Here you can find all details about how much material will be used / produced and recycled in your simulation

Production | Usage | Recycled

Resource	Category	Quantity	Economic income
Energy (electrical)	ENERGY	150 kWh	-€324.00
Azodicarboxamide	MATERIAL	15 kg	-€1,935.00
Bio-lubrificant	MATERIAL	30 lt	-€174.00
CO2	MATERIAL	150 kg	-€10.95
FFA	MATERIAL	30 lt	-€50,640.60
Rubber mixture	MATERIAL	3,000 kg	-€30,000.00
Vegetable oil	MATERIAL	60 lt	-€78.60
		Totale	-€83,163.15

Fig 8. Results page - CSS2 Usage details. Source: Fronthsh1p D.7.2.

Recycled results

Production and usage details

Here you can find all details about how much material will be used / produced and recycled in your simulation

Production | Usage | Recycled

Resource	Category	Quantity	Economic income
Corn stover	WASTE	1,450 kg	€7.54
		Totale	€7.54

Fig 9. Results page - CSS2 Recycled details. Source: Frontsh1p D.7.2.

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Table 2 below presents a summary of all the available resources, variables and parameters and specifies the ones that are controllable by the users.

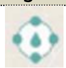
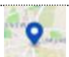
Legend	Controllable		Definitions
	Yes	CSS	container of different Scenarios, assumed to be within the same area
	Yes	CSS capacity	maximum amount of waste that can be processed by a CSS (process scale)
		Waste Stream (WS)	main waste material input that a Scenario consumes
	Yes	Waste Stream quantity	quantity of waste in the region (specific Unit of Measure/year)
		Scenario	industrial process or series of industrial processes, assumed to be within the same area
	Yes	Policies	Incentives: Economic input (BONUS)
	Yes		Taxes: Economic input (MALUS)
		Impacts	Financial Impact (€);
			Environmental Impact (CO2eq)
			Social Impact (full-time equivalents)
		Scenario categories	Waste stream e.g. (wood pallet; oil crop); Input; output;
		Cost variables	Transport cost, Transport CO_2, CAPEX, OPEX, taxes, incentives
		Production resources	amount of resource produced and its economic impact
		Usage resources	amount of resource consumed and its economic impact
		Recycled resources	amount of resource exchanged and its economic impact

Table 2: Summary of parameters, variables and resources within the Frontsh1p Digital Platform. Source: Own compilation

3 Fellow regions feedback on Digital Platform and Scenario Optimiser

The Frontsh1p Scenario Optimizer, as part of the project's Digital Platform, was designed not only as a technical tool but also as an accessible decision-support system for regional stakeholders. While Deliverable 7.4 (Public) and Deliverable 7.5 (Confidential) documented the platform's technical testing and simulation outputs, additional feedback was collected directly from the Replication regions namely **Campania, Sterea Ellada, Região Norte, Fryslân** to validate its usability, clarity, and perceived usefulness in practice. This input was gathered through a structured questionnaire distributed across participating regions, targeting public administrations, industrial stakeholders, researchers, and other potential users.

The questionnaire aimed to capture first-hand impressions of the platform's interface, functionalities, and simulation results. It complements the technical validation with

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user-centred insights, thereby ensuring that future enhancements respond to both system requirements and real-world stakeholder needs.

3.1 Methodology

The questionnaire was structured with multiple-choice and open-ended questions covering five thematic areas:
1. Access and Usability – ease of login, intuitiveness of the user interface, and responsiveness of the map functions.
2. Interactive Features – ability to modify parameters, activate/deactivate Circular Systemic Solutions (CSS), and adjust policy levers.
3. Simulation Results – clarity and interpretability of economic, environmental, and social indicators, including supporting guideline documents.
4. User Experience – overall satisfaction, perceived usefulness of features, and identification of the most valued components.
5. Improvement Priorities – suggestions for enhancing flexibility, performance, and visualization.

The responses were anonymised and categorised according to user type (public administration, industrial stakeholders, researchers, or other).

3.1.1 Frontsh1p Digital Platform Questionnaire sample

The following sample illustrates the questionnaire format provided to participants, which served as the basis for collecting and analysing user responses reported in Chapter 3.

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FrontSH1P Digital Platform Questionnaire

1. **Country of origin:**

☐ Portugal
X☐ Greece
☐ Netherlands
☐ Italy
☐ Other: __________

2. **Type of user:**

X☐ Public administration
☐ Industrial stakeholder/company
☐ Researcher/Expert
☐ Other: __________

3. **How easy was it to access the platform?**

X☐ Very easy
☐ Quite easy
☐ Difficult
☐ Very difficult

4. **Was the user interface intuitive?**

X☐ Yes, completely
☐ Partially
☐ No
☐ Not sure

5. **How was the performance of the map interface (loading and interaction)?**

X☐ Smooth and problem-free
☐ Some delays or minor issues
☐ Slow or had major issues
☐ I did not use the map

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6. **Did you try changing parameters such as waste stream quantity or process scale?**

☐ Yes
X☐ No

7. **How easy was it to modify parameters in the interactive map?**

☐ Very easy
☐ Fairly easy
☐ Complicated
X☐ I didn't use this function

8. **How much was it intuitive to click the marker to adjust the CSS size or waste quantity?**

X☐ Very intuitive
☐ Somewhat intuitive
☐ Neutral
☐ Not very intuitive
☐ Not intuitive at all

9. **Did you use the CSS activation/deactivation feature?**

☐ Yes
X☐ No

10. **Was the ability to enable or disable the CSS scenario useful for tailoring results to your business needs?**

X☐ Very helpful
☐ Somewhat helpful
☐ Neutral / Not sure
☐ Not very helpful
☐ Not helpful at all

11. **Were the simulation results (after clicking "Launch") easy to understand?**

X☐ Very clear
☐ Fairly clear
☐ Not very clear

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☐ I didn't use this function

12. **Were the simulation results on environmental, economic, and social impacts understandable?**

X☐ Easy to interpret
☐ Partially clear
☐ Difficult to understand
☐ I didn't check the results

13. **Did you find the social impact guidelines useful?**

X☐ Yes, very useful
☐ Somewhat useful
☐ Not useful
☐ I didn't download or read them

14. **Overall, how would you rate your experience with the platform?**

☐ Very positive
X☐ Positive
☐ Neutral
☐ Negative

15. **Which features did you find most useful? (Select up to 2)**

☐ Interactive map
☐ Simulation with KPIs
☐ Policy and incentive tools
X☐ Social impact guideline document
☐ Visualization and export of results

16. **Which areas would you suggest for improvement?**

☐ User interface
☐ Platform performance
☐ Result visualization
X☐ Simulation flexibility
☐ Other: __________

17. **Do you have any suggestions or comments to improve the platform?**
✎ __No____

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3.2 Results Overview- Campania - ITALY

The Campania researcher found the platform very easy to access and intuitive, valued the **interactive map** and the clarity of simulation results, but highlighted the need for **greater simulation flexibility** and the ability to **customise country-specific input data** for more accurate analyses.

Results Overview

User profile:

- **Country:** Italy (Campania)
- **Type:** Researcher/Expert

Access & Usability:

- Access rated **"very easy"**.
- User interface considered **completely intuitive**.

Map Interface:

- Performance was **smooth and problem-free**.
- User did attempt to change parameters (waste stream/process scale) and found it **very easy**.
- Clicking markers to adjust CSS size/waste quantity was judged **very intuitive**.

Scenario Features:

- CSS activation/deactivation feature was used.
- Usefulness of this feature was rated **"somewhat helpful"** for tailoring results.

Simulation Results:

- Simulation results (after "Launch") were judged **very clear**.
- Environmental, economic, and social impacts were considered **partially clear**.
- Social impact guidelines were rated **somewhat useful**.

Overall Experience:

- Rated as **positive**.

Most Useful Features Identified:

- **Interactive map**

Areas for Improvement:

- Suggested **simulation flexibility** as the main improvement area.
- Comment: it would be useful to allow updating predefined input data (e.g., specific costs for chemical components in each country).

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3.3 Results Overview- Stereá Elláda - GREECE

The user had a **very smooth and intuitive experience**, valued the **clarity of results** and especially the **social impact guidelines**, and suggested **greater flexibility in simulations** as the key area for improvement.

User profile:

- **Country:** Greece
- **Type:** Public administration

Access & Usability:

- Access rated **"very easy"**.
- User interface considered **completely intuitive**.

Map Interface:

- Performance was **smooth and problem-free**.
- User did **not** attempt to change parameters (waste stream/process scale).
- Modifying parameters was **not used**.
- Clicking markers to adjust CSS size/waste quantity was judged **very intuitive**.

Scenario Features:

- CSS activation/deactivation feature was **not used**.
- Still, the ability to enable/disable CSS scenarios was considered **very helpful**.

Simulation Results:

- Simulation results (after "Launch") were judged **very clear**.
- Environmental, economic, and social impacts were **easy to interpret**.
- Social impact guidelines were found **very useful**.

Overall Experience:

- Rated as **positive**.

Most Useful Features Identified:

- **Social impact guideline document**

Areas for Improvement:

- Suggested **simulation flexibility** as the main improvement area.
- No additional comments provided.

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3.4 Results Overview Região Norte – PORTUGAL

The user provided extensive written feedback. The main concerns revolve around **clarity, definitions, data transparency, navigation guidance, and alignment with regional contexts and FRONTSH1P goals**.

User profile:

- **Country:** Portugal
- **Type:** Public Administration

Access & Usability:

- Access rated **"difficult"**.
- User interface considered only **partially intuitive**.

Map Interface:

- User did not use the map.

Scenario Features:

- CSS activation/deactivation feature was used, but its usefulness was rated **neutral/not sure** for tailoring business needs.

Simulation Results:

- User did not use the feature for modifying the parameters in the interactive map.

Overall Experience:

- The overall rating provided was negative.

Most Useful Features Identified:

- None selected.

Areas for Improvement:

- Marked as "Other": **Simulation with KPIs, Policy and incentive tools, Social impact guideline document**.

Additional Comments:

The user provided detailed qualitative feedback highlighting areas to improve:

- Need for **clear identification of symbols and icons** (nomenclature).
- Clarification of **waste streams, locations, and data sources**.
- Clear **definitions of parameters and key terms**.
- Better explanation of **which regions are included**.
- Guidance on **how to navigate the platform** (tutorials/guidelines).
- Clarification on **what information is available** and **how it links to the CircuPuncture Model / FRONTSH1P project**.
- Stronger focus on **support for regional needs**.
- Clarify the **link between data entry/changes and regional outputs**.

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3.5 Results Overview Fryslân - THE NETHERLANDS

The Dutch cluster user found the platform accessible and liked the interactive map and result visualization features. However, they highlighted gaps in **data trustworthiness, real-time data availability, and value chain/interregional collaboration**, leading to a neutral overall experience.

User profile:

- **Country:** Netherlands
- **Type:** Cluster representative (not administration, company, or researcher)

Access & Usability:

- Access rated **"quite easy"**.
- User interface considered only **partially intuitive**.

Map Interface:

- Performance was **smooth and problem-free**.
- User did attempt to change parameters (waste stream/process scale) and found it **very easy**.
- Clicking markers to adjust CSS size/waste quantity was judged **somewhat intuitive**.

Scenario Features:

- CSS activation/deactivation feature was used, but its usefulness was rated **neutral/not sure** for tailoring business needs.

Simulation Results:

- No clear response on general ease of understanding ("Launch" results not used/unclear).
- Environmental, economic, and social impacts were **partially clear**, but not fully easy to interpret.
- Social impact guidelines were found **somewhat useful**, not very useful.

Overall Experience:

- Rated as **neutral**.

Most Useful Features Identified:

- **Interactive map**
- **Visualization and export of results**

Areas for Improvement:

- Noted as **trustworthiness of data** (rather than interface, performance, or flexibility).
- Specific comments: the platform currently lacks **important real-time data**; circular economy requires **value chain collaboration**, which is **not fully integrated**; further improvement could come from adding **interregional collaboration functionalities**.

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The responses collected through this questionnaire provided valuable insights into how stakeholders interact with the platform, highlighting both its strengths and areas where further refinement is needed. These results form the basis of the regional feedback analysis presented in the following sections, ensuring that the evaluation of the Scenario Optimiser integrates both technical performance and user experience perspectives. In turn, these insights complement the simulation outputs presented in Chapter 4, creating a coherent link between user feedback and the quantitative data analysis.

4 Data analysis and Results

Different regions have different preconditions, best practices, and internal factors that can guide the prioritisation of specific CE initiatives that align more closely with existing regional capabilities and policies. Furthermore, regions may possess sectoral strengths that influence decisions on investment areas for the circular economy[4].

The assessment draws on quantitative data exported directly from the Frontsh1p Digital Platform. It covers five regions participating in the project: Łódzkie (Poland), **Campania (Italy), Stereá Elláda (Greece), Região Norte (Portugal), and Fryslân (The Netherlands).** To ensure consistency across regions, all policy levers within the platform were set to a value of one, following the configuration established in Deliverable D7.5. This uniform set-up guarantees that all policy scenarios contributed equally to the outcomes (see Figure 10).
Once exported, the datasets were cleaned and screened for completeness and accuracy. Missing values were acknowledged but not replaced, to preserve the integrity of the original data.
The exported datasets included both individual systemic solutions and their combinations—two-way, three-way, and four-way—thereby reflecting the integrated nature of circular economy initiatives, where synergies and trade-offs often emerge only when solutions are combined.
The outcomes of this exercise are presented in the form of summarized tables for each region. These tables consolidate the quantitative results of the simulations into a compact and accessible format, enabling stakeholders to quickly grasp regional positions and identify potential areas for strategic action.
The results are presented for each region individually.

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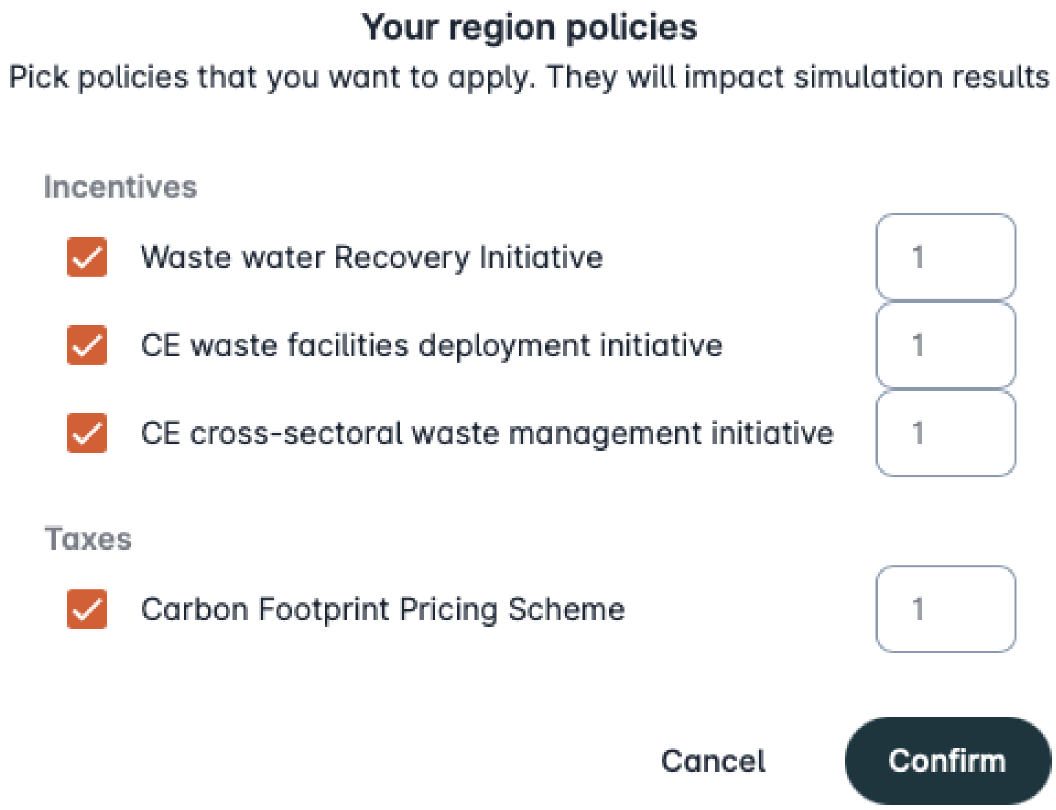

Fig 10. Policies set-up for the SWOT analysis. Source: Frontsh1p Digital Platform.

4.1 Łódzkie – POLAND

The Polish pilot region of Łódź is endowed with four individual Circular Systemic Solutions (CSS 1 to CSS 4). These can be deployed singly or in any combination, generating 14 simulations in total that explore every feasible configuration—from a lone facility to the full four-way bundle. The solutions are:

- **CSS 1:** wood packaging
- **CSS 2:** food and feed
- **CSS 3:** water and nutrients
- **CSS 4:** plastic and rubber waste

Table 3 summarises the average impacts and cost structure as a function of the **number of CSS simultaneously activated** (financial and CAPEX values expressed in € million; OPEX, taxes and transport costs in € thousand; incentives in €; figures rounded as indicated).

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Table 3. Summary of simulations: POLAND (data rounded to one decimal place for € million and to whole units elsewhere). Source: Own Compilation.

# CSS activated	1	2	3	4
Avg. financial impact (€ million)	-0.5	-0.9	-1.2	-1.9
Avg. environmental impact (t CO_2-eq)	**-2 386**	**-4 798**	**-6 415**	**-9 600**
Avg. social impact (FTE)	7.8	15.6	23.4	31.1
Avg. transport cost (€ k)	65	131	182	261
Avg. transport CO_2 (t)	14	28	39	56
Avg. CAPEX (€ million)	8.6	17.2	23.0	34.4
Avg. OPEX (€ k)	715	1 420	1 886	2 800
Avg. taxes (€ k)	2 469	4 959	6 625	9 900
Avg. incentives (€)	250	500	1 000	

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4.1.1 Resources production, usage, and recycling

This section documents the physical streams handled by each Circular Systemic Solution (CSS) activated in the Łódź regional model, distinguishing what is **generated**, **internally consumed** and **re-introduced as secondary inputs**. All figures come directly from the simulation platform, refer to one model year, and follow the platform's unit conventions (tonnes for solids and liquids, Nm³ for gases, kWh for electricity unless otherwise stated).

4.1.2 Individual systemic solutions

The following table summarises the materials produced, consumed and recycled by each CSS run in stand-alone mode.

Table 4. Summary of the materials produced, used, and recycled in the individual systemic solutions: POLAND. Source: Own Compilation.

CSS	Principal outflows	Main internal consumptions	Recycled streams returned to the system
CSS 1 – Wood Packaging	Flue gases ≈ 26 040 t CO_2 ≈ 5 826 t	Electricity ≈ 1.36 MWh Thermal energy import ≈ 9.1 MWh	Wood waste ≈ 6 000 t

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	Thermal energy exported ≈ 14.8 MWh Char ≈ 72 t Scrap metal ≈ 168 t	Amines ≈ 12 t	
CSS 2 – Food & Feed	FFA ≈ 2 010 t Waste-water ≈ 4 501 t	Electricity ≈ 0.14 GWh Process water ≈ 5 842 t Hexane ≈ 4 441 t HCl ≈ 235 t; KOH ≈ 23 t Enzymes ≈ 33 t	Corn stover ≈ 1 450 t
CSS 3 – Water & Nutrients	Micro-algal biomass ≈ 13 t Process water ≈ 1 t	Electricity ≈ 2 kWh (laboratory scale) CO_2 ≈ 3 t	Treated wastewater ≈ 1 000 t
CSS 4 – Plastic & Rubber Waste	Pyrolytic vegetable oil ≈ 7 650 t	Electricity ≈ 0.06 GWh CO_2 ≈ 5 985 t Azodicarboxamide ≈ 5 985 t Rubber mixture feedstock ≈ 4 883 t FFA make-up ≈ 197 t; vegetable-oil make-up ≈ 162 t	Char ≈ 1 500 t

The data in the table 4 allow for the following considerations:

- **CSS 1** acts primarily as an energy-oriented module: flue gases and CO_2 dominate exports, while solid co-products (char and scrap) offer modest circular value.
- **CSS 2** supplies high-value FFA but is solvent- and acid/base-intensive; its electricity demand (0.14 GWh) sets the power baseline for most combined runs.
- **CSS 3** functions chiefly as a polishing loop: the mass of new products is small, yet it returns one kilotonne of treated effluent, underlining its role in water-cycle closure.
- **CSS 4** is the main provider of secondary raw materials: the 7.7 kt bio-oil accounts for more than 70 % of the mass of valuable outputs in stand-alone simulations, while its 1.5 kt char stream adds a carbon-rich co-product.

4.1.3 Combined systemic solutions

The following table shows the most representative multi-CSS configurations and the deviations from stand-alone behaviour.

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Table 5. Summary of the materials produced, used, and recycled in the combined systemic solutions: POLAND. Source: Own Compilation.

Combination	Activated CSS	Key changes relative to stand-alone cases
CSS 1 + 2 (Łódź_12)	1 & 2	Outputs are essentially additive: FFA 2.0 kt, wastewater 4.5 kt, flue gases 26 kt, CO_2 5.8 kt plus the small char (72 t) and scrap-metal (168 t) fractions from CSS 1. Electricity settles at ≈ 0.14 GWh, confirming that CSS 2 drives the power demand. Wood-waste recovery (6 kt) and corn-stover recycling (1.45 kt) run in parallel, showing synergy between ligno-cellulosic and agri-food residues.
CSS 2 + 4 (Łódź_24)	2 & 4	Delivers both bio-oil 7.7 kt and FFA 2.0 kt while retaining the 4.5 kt waste-water loop. Electricity rises to ≈ 0.20 GWh—the highest Łódź scenario—as the electro-intensive food chain is coupled with auxiliary power for pyrolysis. Char recovery reaches 1.5 kt, confirming that the plastic-to-oil step remains carbon-positive even when solvent-rich streams are present.
CSS 1 + 4 (Łódź_14)	1 & 4	Combines the energy-rich flue-gas stream of CSS 1 with the 7.7 kt bio-oil from CSS 4 while keeping electricity demand low (≈ 0.06 GWh). Char (1.5 kt) and scrap metal (168 t) form a diversified solid by-product basket without additional solvent load.
CSS 2 + 3 (Łódź_23)	2 & 3	Adding the water-nutrient loop does not increase electricity (still ≈ 0.14 GWh) but recycles an extra 1 kt of treated effluent, cutting net aqueous discharge intensity by ~22 % relative to CSS 2 alone. Micro-algal biomass (13 t) enters the product portfolio, though at a modest scale.

The data in the table allows for the following considerations on the systemic solutions synergic effect:

- **Electricity leverage:** Whenever CSS 2 is present, total electricity approaches 0.20 GWh; adding CSS 1 or 4 does **not** appreciably increase this figure, indicating that power-intensive steps are localised in the Food-&-Feed chain.
- **Carbon recovery:** Inclusion of CSS 4 guarantees at least 1.5 kt of char per year, whereas configurations without CSS 4 yield negligible char.
- **Water looping:** The one-kilotonne waste-water return is preserved whenever CSS 3 operates but does not exceed the single-CSS figure; scaling CSS 3 would therefore be needed to enhance water closure further.

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4.1.4 General considerations

The Łódź simulation shows that coupling the Wood-Packaging and Plastic-to-Oil chains with the Food-&-Feed solution can broaden the product spectrum without a proportionate increase in electricity consumption. Three improvement levers emerge for the next roadmap iteration:

1. **Solvent circulation in CSS 2** – closing the hexane and acid/base loops would address both costs and solvent-related emissions.
2. **Scale-up of CSS 3** – even a small water-nutrient loop already trims freshwater intake by one kilotonne per year; expanding it would enhance water security and lower discharge fees.
3. **Char valorisation pathway** – the 1.5 kt char generated whenever CSS 4 operates merits a dedicated valorisation route (e.g. activated carbon or soil-improvement biochar) to unlock further financial and environmental benefits.

Addressing these priorities is expected to improve and reinforce the systemic circularity objectives of the Frontsh1p project.

4.2 Campania – ITALY

The Campania region has three individual solutions available – CSS 2, CSS 3 and CSS 4 – hence leading to six simulations in total, each one representing a distinct configuration of the combination of Circular Systemic Solutions (CSS).
The systemic solutions active on the Campania region are:

- CSS 2: food and feed
- CSS 3: water and nutrients
- CSS 4: plastic and rubber waste
-

Table 6 summarises the average impacts (financial, environmental, and social) as well the cost structure, taxes and incentives consequent to the activation of the different combinations of the systemic solutions.

Table 6. Summary of simulations: ITALY (data rounded to one decimal place for € million and to whole units elsewhere). Source: Own Compilation.

# CSS activated	1	2	3
Avg. financial impact (€ million)	-4.4	-6.7	-13.3
Avg. environmental impact (t CO_2-eq)	391	586	1 200
Avg. social impact (FTE)	41.6	84.5	124.9

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# CSS activated	1	2	3
Avg. transport cost (€ k)	423	708	1 300
Avg. transport CO_2 (t)	90.9	152	273
Avg. CAPEX (€ million)	90.5	136.2	271.4
Avg. OPEX (€ k)	163	345	490
Avg. taxes (€ k)	391	586	1 200
Avg. incentives (€)	3 333	10 000	10 00

4.2.1 Resources production, usage, and recycling

This section documents the physical streams handled by each Circular Systemic Solution (CSS) activated in the Campania regional model, distinguishing what is generated, internally consumed and re-introduced as secondary inputs. All figures come directly from the simulation platform output and refer to one model year; units follow the internal convention of the platform (tonnes for solids/liquids, Nm^3 for gases, and kWh for electricity unless otherwise stated).

4.2.2 Individual systemic solutions

The following table summarises the data on the materials produced, consumed, and recycled by the individual systemic solutions and their internal processes.

Table 7. Summary of the materials produced, used, and recycled in the individual systemic solutions: ITALY. Source: Own Compilation.

CSS	Principal outflows	Main internal consumptions	Recycled streams returned to the system
CSS 2 – Food & Feed	FFA ≈ 13 860 Waste-water ≈ 31 040	Electricity ≈ 0.98 GWh HCl 1 620 t, Hexane 30 630 t, KOH 162 t Enzymes 230 t	
CSS 3 – Water & Nutrients	Micro-algal biomass ≈ 130 Process water 10 t	Electricity only 20 kWh (lab-scale cultivation)	Treated wastewater returned 10 000
CSS 4 – Plastic &	Pyrolytic vegetable oil ≈ 62 954	Electricity ≈ 0.46 GWh CO_2 (process gas) ≈ 49 253	Char 12 344

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Rubber Waste		Rubber mixture feedstock ≈ 40 180 t	

The data allows for the following considerations:

- CSS 2 provides a significant bio-based chemical output (FFA) but is chemically intensive: acids, bases and solvents dominate internal demand, giving it the highest operating material intensity per tonne of product.
- CSS 3 behaves primarily as a water-polishing loop: net production is minor, but it returns a large volume of treated effluent (10 kt) back into the process chain, demonstrating its role in closing the water cycle rather than generating new products.
- CSS 4 is clearly the major contributor to secondary raw material generation. The 63 kt of pyrolytic oil correspond to ~72 % of all secondary outputs in single-CSS runs. Char recovery offers an additional carbon-rich co-product.

4.2.3 Combined systemic solutions

The following table summarises the data on the materials produced, consumed, and recycled by the combined systemic solutions and their internal processes.

Table 8. Summary of the materials produced, used, and recycled in the combined systemic solutions: ITALY. Source: Own Compilation.

Combination	Activated CSS	Key changes relative to stand-alone cases
CSS 2 + 3 (Campania_23)	2 & 3	Output profile is additive (FFA 13.9 kt + water 10 t + micro-algae 130 t) but electricity demand remains that of CSS 2 (≈ 0.98 GWh); the joint configuration shows that coupling the water-nutrient loop does **not** increase power demand, while it recycles an extra 10 kt of effluent, lowering the net aqueous discharge intensity by ~25 %.
CSS 3 + 4 (Campania_34)	3 & 4	Vegetable-oil output from CSS 4 is preserved (62.9 kt), while micro-algae and a small process-water output from CSS 3 are layered on top. Electricity demand rises marginally to 0.456 GWh because the low-load algal loop is almost power-neutral. Char recovery and the 10 kt water loop both appear, illustrating complementary valorisation of both solid carbon and process water.

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Combination	Activated CSS	Key changes relative to stand-alone cases
CSS 2 + 3 + 4 (Campania_234)	2, 3 & 4	The full portfolio delivers the **broadest material basket**: FFA 13.9 kt, wastewater 31 kt, vegetable oil (re-processed internally so reported as 0 kt net export), micro-algae 130 t and 10 t of process water. Internal electricity demand remains anchored at the CSS 2 level (0.985 GWh), confirming that CSS 2 dominates the power draw. Recycled flows are limited to the 10 kt water loop; char yield drops to zero because the oxygen-rich conditions of CSS 2 suppress solid-carbon formation in the joint pyrolysis–esterification chain.

The data allows for the following observations on the synergic effects:

- **Water looping:** Whenever CSS 3 is present, 10 k of wastewater is reclaimed and re-used internally, cutting freshwater make-up needs for the whole cluster by approximately 20 % relative to the CSS 2-only configuration.
- **Char vs. FFA trade-off:** Introducing CSS 2 into a pyrolysis configuration (moving from 34 → 234) diverts part of the solid carbon into esterification reactions, eliminating char export but raising the share of liquid bio-intermediates.
- **Energy balance:** Because CSS 2 fixes the bulk of electricity consumption and CSS 3 adds almost none, the 234 portfolio achieves the **highest material diversity without additional electrical burden**. Conversely, CSS 4 on its own is less power-intensive than CSS 2 but produces considerably larger high-value outputs.

4.3 Stereá Elláda – GREECE

The Greek case study includes four individual Circular Systemic Solutions (CSS-1 to CSS-4), yielding 14 distinct simulations that explore every feasible combination, from stand-alone deployments to the full four-way bundle.

The solutions available are:

- CSS 1: wood packaging
- CSS 2: food and feed
- CSS 3: water and nutrients
- CSS 4: plastic and rubber waste

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Table 9 condenses the average impacts and cost structure by the number of CSS simultaneously activated (values rounded to one decimal place for € million and to whole units elsewhere).

Table 9. Summary of simulations: GREECE (data rounded to one decimal place for € million and to whole units elsewhere). Source: Own Compilation.

# CSS activated	1	2	3	4
Avg. financial impact (€ million)	-0.2	-0.4	-0.5	-0.8
Avg. environmental impact (t CO_2-eq)	**+2 500**	**-1 350**	**-5 667**	**-8 600**
Avg. social impact (FTE)	7.8	15.6	23.4	31.1
Avg. transport cost (€ k)	1	2	3	5
Avg. transport CO_2 (t)	261	522	743	1 000
Avg. CAPEX (€ million)	8.6	17.2	23.0	34.4
Avg. OPEX (€ k)	1	1	2	3
Avg. taxes (€ k)	2	5	7	10
Avg. incentives (€)	250	500	1 000	

4.3.1 Resources production, usage, and recycling

This section documents the physical streams handled by each Circular Systemic Solution (CSS) activated in the Greek regional model, distinguishing what is **generated**, **internally consumed** and **re-introduced as secondary inputs**. All figures are direct outputs from the simulation platform and refer to one model year; units follow the platform convention (tonnes for solids / liquids, Nm^3 for gases and kWh for electricity unless otherwise stated).

4.3.2 Individual systemic solutions

The following table summarises the materials produced, consumed and recycled by every CSS that was run in stand-alone mode.

Table 10. Summary of the materials produced, used, and recycled in the individual systemic solutions: GREECE. Source: Own Compilation.

CSS	Principal outflows (Production)	Main internal consumptions (Usage)	Recycled streams returned to the system
CSS 1 – Wood Packaging	Flue gases ≈ 26 040 t	Electricity ≈ 1.36 MWh Thermal energy import ≈ 9.1 MWh	Wood waste ≈ 6 000 t

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	CO_2 ≈ 5 826 t Thermal energy exported ≈ 14.8 MWh Char ≈ 72 t Scrap metal ≈ 168 t	Amines ≈ 12 t	
CSS 2 – Food & Feed	FFA ≈ 2 010 t Wastewater ≈ 4 501 t	Electricity ≈ 0.14 GWh Water ≈ 5 842 t Hexane ≈ 4 441 t HCl ≈ 235 t KOH ≈ 23 t Enzymes ≈ 33 t	Corn stover ≈ 1 450 t
CSS 3 – Water & Nutrients	Micro-algal biomass ≈ 13 t Process water ≈ 1 t	Electricity ≈ 2 kWh (laboratory scale)• CO_2 ≈ 3 t	Treated wastewater ≈ 1 000 t
CSS 4 – Plastic & Rubber Waste	Pyrolytic vegetable oil ≈ 7 650 t	Electricity ≈ 0.06 GWh CO_2 ≈ 5 985 t Azodicarboxamide ≈ 5 985 t Rubber mixture ≈ 4 883 t FFA ≈ 197 t Vegetable-oil make-up ≈ 162 t	Char ≈ 1 500 t

The data in the table allows for the following considerations:

- **CSS 1** behaves mainly as an energy and gas module: flue gases and CO_2 dominate exports, while the solid fractions (char and scrap metal) offer modest circular opportunities.
- **CSS 2** supplies high-value FFA but is solvent- and acid/base-intensive; its 0.14 GWh electricity demand is the largest of any single solution and therefore fixes the electrical baseline in most combined runs.
- **CSS 3** works primarily as a polishing loop: its material outputs are minor, yet it recovers one kilotonne of effluent, underlining its role in water-loop closure rather than product generation.
- **CSS 4** is the leading provider of secondary raw material in Greece: the 7.7 kt bio-oil equals more than 70 % of the mass of valuable outputs in stand-alone simulations, while the 1.5 kt char fraction adds a carbon-rich co-product.

4.3.3 Combined systemic solutions

The following table reports the main streams for three representative multi-CSS configurations and highlights the deviations from stand-alone behaviour.

Table 11. Summary of the materials produced, used, and recycled in the combined systemic solutions: GREECE. Source: Own Compilation.

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Combination	Activated CSS	Key changes relative to stand-alone cases
CSS 1 + 2 (Greece_12)	1 & 2	Output profile is additive: FFA 2.0 kt, wastewater 4.5 kt, flue gases 26 kt, CO_2 5.8 kt plus the small char and scrap-metal fractions from CSS 1. Electricity use settles at ≈ 0.14 GWh, confirming that CSS 2 drives the power demand. Corn-stover recycling (1.45 kt) and wood-waste recovery (6 kt) run in parallel, demonstrating synergy between ligno-cellulosic and food side-streams.
CSS 2 + 4 (Greece_24)	2 & 4	Delivers both bio-oil 7.7 kt and FFA 2.0 kt while retaining the 4.5 kt wastewater loop. Electricity demand climbs to ≈ 0.20 GWh – the highest Greek scenario – as the electro-intensive food chain is coupled with auxiliary power for the plastic-to-oil operation. Char recovery rises sharply to 1.5 kt, illustrating that the pyrolysis step remains carbon-positive even in a chemically active environment.
CSS 1 + 4 (Greece_14)	1 & 4	Retains the energetic flue-gas stream of CSS 1 and the 7.7 kt bio-oil from CSS 4 while keeping electricity demand low (≈ 0.06 GWh). Char recovery (1.5 kt) and scrap metal (168 t) create a diversified solid by-product basket, and no additional solvents are required.

The data in the table allows for the following considerations:

- **Electricity leverage:** When CSS 2 is present, total electricity use approaches 0.20 GWh; adding CSS 1 or CSS 4 does **not** significantly increase this figure, confirming that electro-intensive steps are localised in the Food-&-Feed chain.
- **Carbon recovery:** Introducing CSS 4 into any configuration guarantees at least 1.5 kt of char per year, whereas configurations without CSS 4 yield negligible char.
- **Water looping:** Wastewater return of 4.5 kt is preserved whenever CSS 2 operates, but volumes do not exceed the single-CSS figure. Deploying CSS 3 alongside larger systems would therefore be necessary to enhance water-loop closure at scale.

4.3.4 General considerations

The Greek simulation confirms that merging the Wood-Packaging and Plastic-to-Oil chains with the Food-&-Feed solution broadens the product spectrum without a proportionate rise in power demand. Three levers stand out for the next roadmap iteration:

1. **Solvent circulation in CSS 2**– closing the hexane and acid/base loops would markedly reduce both operating costs and solvent-related emissions.

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2. **Scale-up of CSS 3**– even a small water-nutrient loop already trims freshwater intake by one kilotonne a year; expanding this module would improve water security and lower discharge fees.
3. **Char valorisation pathway**– the sizeable 1.5 kt char stream produced whenever CSS 4 operates merits a dedicated valorisation route (e.g., activated carbon or soil-improvement biochar) to unlock further financial and environmental benefits.

4.4 Região Norte – PORTUGAL

The Portuguese pilot for **Região Norte** currently features data for **three individual Circular Systemic Solutions (CSS-1, CSS-2 and CSS-4)**, giving rise to **seven simulations**: three stand-alone runs, three two-way bundles and one three-way bundle. CSS-3 (water & nutrients) is not yet represented and therefore no four-solution configuration is available.
The systemic solutions simulated in the region are:

- **CSS 1:** wood packaging
- **CSS 2:** food and feed
- **CSS 4:** plastic and rubber waste

For sake of clarity, even if simulations have been conducted for the three above mentioned CSSs, **only CSS-2 and CSS-4** are being implemented and developed in the region.

Table 12 summarises the average impacts and cost structure by the **number of CSS simultaneously activated** (financial and CAPEX values in € million; OPEX, taxes and transport in € thousand; incentives in €; figures rounded as shown).

Table 12. Summary of simulations: PORTUGAL (data rounded to one decimal place for € million and to whole units elsewhere). Source: Own Compilation.

# CSS activated	1	2	3
Avg. financial impact (€ million)	-0.4	-0.8	-1.3
Avg. environmental impact (t CO_2-eq)	-2 950	-5 883	-8 900

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# CSS activated	1	2	3
Avg. social impact (FTE)	7.7	15.4	23.1
Avg. transport cost (€ k)	1 236	2 467	3 700
Avg. transport CO_2 (t)	265	531	796
Avg. CAPEX (€ million)	11.4	22.9	34.3
Avg. OPEX (€ k)	946	1 880	2 800
Avg. taxes (€ k)	3 183	6 383	9 500
Avg. incentives (€)	0	0	0

4.4.1 Resources production, usage, and recycling

This section documents the physical streams handled by each Circular Systemic Solution (CSS) activated in the Portuguese regional model, distinguishing what is **generated**, **internally consumed** and **re-introduced as secondary inputs**. All figures are direct outputs from the simulation platform and refer to one model year; units follow the platform convention (tonnes for solids/ liquids, Nm^3 for gases, kWh for electricity unless otherwise stated).

4.4.2 Individual systemic solutions

The following table summarises the materials produced, consumed and recycled by every CSS that was run in stand-alone mode. (CSS 3 – *Water & Nutrients* is only present in coupled scenarios for Portugal).

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Table 13. Summary of the materials produced, used, and recycled in the individual systemic solutions: PORTUGAL. Source: Own Compilation.

CSS	Principal outflows	Main internal consumptions	Recycled streams returned to the system
CSS 1 – Wood Packaging	Flue gases ≈ 26 040 t CO_2 ≈ 5 826 t Thermal energy exported ≈ 14.8 Scrap metal = 168 Char ≈ 72	Electricity ≈ 1.36 MWh Thermal energy ≈ 9.1 MWh	—
CSS 2 – Food & Feed	Waste-water ≈ 4 501 t FFA ≈ 2 010	Electricity ≈ 0.14 GWh Water ≈ 5 841 Hexane ≈ 4 441 HCl ≈ 235 KOH ≈ 23 Enzymes ≈ 33	Corn stover ≈ 1 450 t
CSS 4 – Plastic & Rubber Waste	Pyrolytic vegetable oil ≈ 7 650 t	Electricity ≈ 0.06 GWh CO_2 ≈ 5 985 Azodicarboxamide≈ 5 985 Rubber mixture ≈ 4 883 FFA ≈ 197 Vegetable-oil make-up ≈ 162	Char ≈ 1 500 t

The data allows for the following observations:

- **CSS 1** behaves primarily as an energy- and gas-intensive module: flue gases and CO_2 dominate its exports, while solid co-products (scrap metal and a limited char fraction) provide minor additional value.
- **CSS 2** supplies a high-value biochemical (FFA) but is solvent-intensive (hexane) and acid/base-intensive (HCl, KOH). Electricity demand (0.14 GWh) is the highest of any single solution and therefore sets the electrical baseline for most combined runs.
- **CSS 4** is the main source of secondary raw material in Portugal: 7.7 kt of pyrolytic vegetable oil represent more than 70 % of the mass of valuable outputs in stand-alone simulations. Significant CO_2 and speciality-chemical demand characterise its consumption profile.

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4.4.3 Combined systemic solutions

Table 14 summarises the material streams for each multi-CSS configuration and highlights the principal deviations from stand-alone behaviour.

Table 14. Summary of the materials produced, used, and recycled in the combined systemic solutions: PORTUGAL. Source: Own Compilation.

Combination	Activated CSS	Key changes relative to stand-alone cases
CSS 1 + 2	1 & 2	Outputs are essentially additive: flue gases 26 kt, CO_2 5.8 kt, wastewater 4.5 kt, FFA 2.0 kt. Electricity demand remains anchored at the CSS 2 level (≈ 0.14 GWh). Corn-stover recycling (1.45 kt) continues, while the limited char from CSS 1 (72 t) is still recovered.
CSS 2 + 4	2 & 4	Delivers both bio-oil (7.65 kt) and FFA (2.0 kt), plus wastewater 4.5 kt. At 0.20 GWh the pair shows the **highest electrical load** of all Portuguese scenarios, reflecting the cumulative draw of CSS 2 and increased auxiliary power for the plastic-to-oil operation. Char recovery rises to 1.5 kt, demonstrating that the pyrolysis step remains carbon-positive even in the more chemically active mixed setting.
CSS 1 + 4	1 & 4	Retains the energy-rich flue-gas stream of CSS 1 and the 7.65 kt bio-oil from CSS 4 while keeping electricity demand low (≈ 56.8 MWh). Char recovery (1.5 kt) and scrap metal (168 t) create a diversified solid-by-product basket.
CSS 1 + 2 + 4	1, 2 & 4	Provides the **broadest material portfolio**: bio-oil 7.65 kt, flue gases 26 kt, CO_2 5.8 kt, wastewater 4.5 kt and FFA 2.0 kt. Electricity demand (0.20 GWh) matches the 2 + 4 case, confirming that CSS 2 dominates the power draw while CSS 1 adds little additional load. Both char (1.5 kt) and corn stover (1.45 kt) are recycled, illustrating parallel valorisation of ligno-cellulosic and carbon-rich residues.

The data allow for the following considerations:

- **Energy leverage:** Where CSS 2 is present, total electricity use approaches 0.20 GWh; adding CSS 1 or CSS 4 does **not** significantly increase this figure, suggesting that the electro-intensive steps are localised in the Food-&-Feed chain.
- **Carbon recovery:** Introducing CSS 4 into any configuration guarantees at least 1.5 kt of char per year, whereas configurations without CSS 4 yield negligible char.
- **Waste-water looping:** Waste-water return is maintained in every scenario where CSS 2 operates, but volumes do not exceed the single-CSS figure (4.5 kt). Up-scaling CSS 3 in future work would therefore be necessary to enhance water-loop closure in Portugal.

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4.4.4 General considerations

The Portuguese simulation demonstrates that coupling the Wood-Packaging and Plastic-to-Oil chains with the Food-&-Feed solution widens the product spectrum without a proportional rise in power demand. The principal optimisation levers for the next roadmap iteration are (i) solvent recovery in CSS 2, (ii) enhanced water-treatment capacity via CSS 3, and (iii) further valorisation of the char fraction generated by CSS 4. Tackling these points is expected to improve both the environmental footprint and the net economic balance of the Portuguese pilot.

4.5 Fryslân – THE NETHERLANDS

The Frisian pilot in the Netherlands is at an **early stage of systemic deployment**: the dataset records just one simulation, featuring a single Circular Systemic Solution (CSS-4) that targets the *plastic and rubber-waste* stream. No evidence of CSS-1 (wood packaging), CSS-2 (food & feed) or CSS-3 (water & nutrients) is yet present, and, consequently, there are no multi-solution bundles to compare. This snapshot nevertheless provides a useful baseline against which future rollouts can be benchmarked.
Table 13 gives the key performance indicators for the lone configuration (values rounded to one decimal place for € million and to whole units elsewhere).

Table 15. Summary of simulations: The NETHERLANDS (data rounded to one decimal place for € million and to whole units elsewhere). Source: Own Compilation.

# CSS activated	1
Avg. financial impact (€ million)	-0.5
Avg. environmental impact (t CO_2-eq)	66
Avg. social impact (FTE)	10
Avg. transport cost (€ k)	388
Avg. transport CO_2 (t)	83
Avg. CAPEX (€ million)	30.0
Avg. OPEX (€ k)	16
Avg. taxes (€ k)	66
Avg. incentives (€)	0

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4.5.1 Resources production, usage, and recycling

This section documents the physical streams handled by each Circular Systemic Solution (CSS) activated in the Frisian regional model, distinguishing what is **generated**, **internally consumed** and **re-introduced as secondary inputs**. All figures come directly from the simulation platform, refer to one model year, and follow the platform's unit conventions (tonnes for solids and liquids, Nm^3 for gases, kWh for electricity unless otherwise stated).

4.5.2 Individual systemic solutions

The following table summarises the materials produced, consumed and recycled by every CSS that was run in stand-alone mode.

Table 16. Summary of the materials produced, used, and recycled in the individual systemic solutions: The NETHERLANDS. Source: Own Compilation.

CSS	Principal outflows (Production)	Main internal consumptions (Usage)	Recycled streams returned to the system
CSS 4 – Plastic & Rubber Waste	Pyrolytic vegetable oil ≈ 7 650 t	Electricity ≈ 0.055 GWh (55 400 kWh) CO_2 ≈ 5 985 t Azodicarboxamide ≈ 5 985 t FFA make-up ≈ 197 t Vegetable-oil make-up ≈ 162 t	Char ≈ 1 500 t

The data in the table allow for the following considerations:

- **Material generation.** The pyrolysis step yields 7.7 kt of liquid bio-oil, representing the single largest secondary raw-material flow in the Frisian simulation.
- **Internal demand.** Operation is chemically intensive: equal masses of CO_2 and Azodicarboxamide (6 kt each) are injected as processing agents, while moderate quantities of fatty-acid and vegetable-oil make-up streams sustain the reaction environment.
- **Energy usage.** Electrical demand is modest at 0.055 GWh per year, equating to roughly 0.8 % of the annual consumption reported for CSS 2 in other regions, highlighting the comparative energy-efficiency of the plastic-to-oil pathway.

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- **Carbon recovery.** A substantial char fraction (1.5 kt) is recovered and re-introduced as a solid carbon carrier, reinforcing the circular potential of the module.

4.5.3 Combined systemic solutions

Since only one systemic solution is mapped for the region Fryslân, no combined effects can be simulated.

4.5.4 General considerations

The Frisian simulation demonstrates that deploying **CSS 4 alone can already create a significant secondary-raw-material stream with a favourable energy footprint and a positive net income**. The 7.7 kt of bio-oil represents a substantial contribution to regional renewable-feedstock supply, while the 1.5 kt char flow offers an additional valorisation route as a solid fuel or precursor for activated carbon. Future optimisation work should focus on:

1. **Reagent loop closure** – identifying opportunities to recover and recycle Azodicarboxamide and process CO_2, thereby reducing virgin-chemical demand and associated costs.
2. **Char upgrading** – exploring higher-value applications (e.g. soil-improvement biochar or carbon black substitute) to lift the economic return on the solid fraction.
3. **Integration with water-and-nutrient loops (CSS 3)** – although not active in the present run, coupling CSS 4 with a water-polishing module could mitigate the small process-water footprint and further enhance the circularity profile.

5 Region level SWOT analysis

5.4 Łódzkie, POLAND

The Łódź pilot in central Poland stands out within the Frontsh1p portfolio because every combination of its four Circular Systemic Solutions (CSS-1 Wood Packaging, CSS-2 Food & Feed, CSS-3 Water & Nutrients and CSS-4 Plastic & Rubber Waste) already delivers a net climate benefit, even in the one-facility case.

Summary Table of SWOT Dimensions for Łódź
The following table contains a summary of the SWOT analysis dimensions for the Łódź region.

Table 17. Summary of SWOT analysis: Łódź. Source: Own Compilation.

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Dimension	Strengths	Weaknesses	Opportunities	Threats
Environmental	Proven net CO_2 reduction in every configuration; diversion of plastics and organics; nutrient recycling closes loops	Rising haulage emissions with scale; solvent losses in CSS-2	Biochar valorisation could deepen sequestration; scale-up of CSS-3 boosts water reuse	Stricter solvent-emission limits; diesel restrictions could raise transport footprint
Economic	Moderate deficit suggests break-even within reach; significant revenues from bio-oil and FFA; growing tax contribution supports public value	Persistent negative financial impact; high CAPEX/OPEX; flat incentives; under-utilised char	Closed-loop solvent recovery cuts costs; EPR fees and carbon credits can add income; new char markets	Electricity-price volatility; commodity swings affect bio-oil value; higher landfill levies without matching credits
Social	Steady job creation (≈8 FTE per CSS); diversified roles across collection and processing	Skills shortage in advanced bioprocessing; coordination complexity across four chains	Training programmes and university partnerships strengthen workforce; rural jobs from char application	Ageing workforce; competition for technicians from other green industries
Policy	Taxes scale predictably, underpinning fiscal legitimacy; potential alignment	Incentives symbolic; regulatory fragmentation across waste streams	Upcoming EPR and Innovation Fund calls can improve cash flow; voluntary carbon	Policy inconsistency or delayed enactment; stricter environmental norms raise

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Dimension	Strengths	Weaknesses	Opportunities	Threats
	with EU funding		markets reward CO_2 savings	compliance costs

5.5 Campania, ITALY

The Campania pilot in southern Italy activates three Circular Systemic Solutions — CSS-2 (Food & Feed), CSS-3 (Water & Nutrients) and CSS-4 (Plastic & Rubber Waste). Six scenarios were simulated, from a single CSS to the full three-CSS bundle.

Summary Table of SWOT Dimensions for Campania
The following table contains a summary of the dimensions of the SWOT analysis for the region Campania.

Table 18. Summary of SWOT analysis: Campania. Source: Own Compilation.

Dimension	Strengths	Weaknesses	Opportunities	Threats
Environmental	Wastewater loop cuts freshwater use; large supply of bio-oil and char diversifies secondary outputs	Net footprint remains positive; transport CO_2 rises sharply; solvent losses in CSS-2	Closed-loop solvent recovery and char valorisation can invert footprint and unlock credits	Diesel restrictions, electricity-price spikes and landfill-tax hikes raise emissions and cost
Economic	High-value bio-oil and FFA streams; growing tax contribution supports public finance	Persistent losses (up to –€13 m); €271 m CAPEX hurdle; flat incentives; under-valued char	EPR revenues, Innovation Fund grants and bio-oil premium pricing could improve cash flow	Commodity price swings for bio-oil and solvents; policy support may shrink or shift
Social	Up to 125 new jobs across logistics and processing; supports	Skills gap in bioprocess control; legacy mistrust from	Training partnerships and “Made in Campania” branding can	Labour shortages or wage inflation; community

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Dimension	Strengths	Weaknesses	Opportunities	Threats
	regional employment goals	past waste issues	build local pride and capacity	opposition if nuisance impacts arise
Policy	Taxes scale with activity, demonstrating fiscal contribution	Incentives symbolic and uneven; regulatory fragmentation across waste streams	Upcoming EU waste-package reform and carbon markets favour circular bio-refinery models	Policy discontinuity or stricter compliance rules could deter investors

5.6 Sterea Ellada, GREECE

The Sterea Ellada pilot in central Greece examines every permutation of the four Circular Systemic Solutions developed in FrontSH1P: CSS-1 Wood Packaging, CSS-2 Food & Feed, CSS-3 Water & Nutrients and CSS-4 Plastic & Rubber Waste. Fourteen model runs, from stand-alone deployments to the full four-CSS bundle.

5.6.1 Summary Table of SWOT Dimensions for Sterea Ellada

The following table summarises the results of the SWOT analysis for the Sterea Ellada region.

Table 19. Results of SWOT analysis: Sterea Ellada. Source: Own Compilation.

Dimension	Strengths	Weaknesses	Opportunities	Threats
Environmental	Early flip to net CO_2 savings with two CSSs; significant diversion of plastics, organics and nutrients	Transport emissions rise to 1 000 t CO_2; solvent losses from CSS-2	Char valorisation and expanded CSS-3 deepen sequestration and water reuse	Stricter solvent-emission rules; diesel restrictions inflate logistics footprint
Economic	Deficits modest (≤ € 0.8 m); high-value bio-oil and FFA	Persistent negative returns; € 34 m CAPEX hurdle; flat	Solvent recovery, EPR fees and carbon credits can close the	Electricity and commodity-price volatility; policy support could lapse;

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Dimension	Strengths	Weaknesses	Opportunities	Threats
	streams; scaling taxes evidence fiscal benefit	incentives; under-priced char	gap; Innovation Fund grants available	landfill-tax hikes without recycling credits
Social	Up to 31 new jobs spanning rural and industrial roles	Skills shortage in advanced bioprocessing; community sensitivities to waste projects	Training partnerships and char-based agri-programmes build local acceptance	Labour scarcity, wage inflation or public opposition delay deployment
Policy	Taxes scale predictably, signalling public-finance value	Incentives symbolic and static; fragmented regulation across waste streams	EU waste-package transposition and carbon-removal certification bolster revenues	Regulatory inconsistency or sudden compliance costs deter investors

5.7 Região Norte, PORTUGAL

Região Norte, Portugal's most industrialised northern cohort, tested three of the four Front-SH1P Circular Systemic Solutions—CSS-1 Wood Packaging, CSS-2 Food & Feed, and CSS-4 Plastic & Rubber Waste—across seven scenarios that ranged from stand-alone deployments to a full three-way bundle.

5.7.1 Summary Table of SWOT Dimensions for Região Norte

The following table contains the results of the SWOT analysis for the Região Norte.

Table 20. Results of the SWOT analysis: Região Norte. Source: Own Compilation.

Dimension	Strengths	Weaknesses	Opportunities	Threats
Environmental	Immediate net CO_2 savings that deepen with scale; high diversion of wood,	Transport emissions climb to 800 t CO_2; solvent losses from CSS-2	Char valorisation and future CSS-3 integration could boost	Diesel restrictions and solvent-emission rules could raise footprint

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Dimension	Strengths	Weaknesses	Opportunities	Threats
	organics and plastics		abatement further	
Economic	Deficits modest (≤ €1.3 m); strong revenues from bio-oil and FFA; rising taxes show fiscal contribution	Persistent negative returns; €34 m CAPEX; no incentives; under-valued char	Solvent recovery, EPR fees, Innovation Fund grants, carbon credits	Power- and commodity-price volatility; policy support may lag
Social	Up to 23 local jobs across collection and processing	Skills gap in bioprocessing; potential community concern over waste projects	Training programmes, biochar agriculture links, SME supply chains	Labour shortages, wage inflation, or local opposition could delay rollout
Policy	Taxes align public interest with project success	Zero incentives; fragmented regulation across waste streams	Imminent EU waste-package transposition favours circular revenues	Policy inconsistency or early landfill-tax hikes could hurt cash flow

5.8 Fryslân

Fryslân, the northernmost province of the Netherlands, enters the Front-SH1P programme with a single Circular Systemic Solution on the ground: CSS-4 for plastic- and rubber-waste pyrolysis.

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5.8.1 Summary Table of SWOT Dimensions for Fryslân

The following table contains the summary of the SWOT analysis for the Fryslân region.

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Table 21. Results of SWOT analysis: Fryslân. Source: Own Compilation.

Dimension	Strengths	Weaknesses	Opportunities	Threats
Environmental	Large bio-oil and char outputs; low energy use	Net footprint still +66 t CO_2; haulage emissions 83 t	Add CSS-2/3 to flip balance; reagent recycling; water-borne logistics	Stricter recycled-content rules; diesel bans inflate footprint
Economic	€ 20 m bio-oil revenue; OPEX only € 16 k; taxes already positive	€ 30 m CAPEX drives € 0.5 m loss; no incentives; transport € 388 k	Grants under Dutch Circular Economy plan; char up-grading; carbon credits	Bio-oil price swings; reagent-cost spikes; higher interest rates
Social	10 new industrial jobs; alignment with regional SME skill set	Limited scale limits job growth; potential community concerns	Job expansion via extra CSS; green-skills training funded by EU	Labour competition with hydrogen sector; local opposition delays
Policy	Fiscal contribution (€ 66 k) builds legitimacy	Zero incentives; single-stream regulation	CAPEX vouchers, EPR income, carbon-removal certification	Policy delays or reclassification of pyrolysis oil as non-circular

6 Conclusions

The simulations undertaken with the Frontsh1p Scenario Optimiser confirm that **systemic circular solutions are technically feasible and environmentally desirable across diverse European territorial contexts**, yet **economic resilience and policy alignment remain pivotal for large-scale roll-out**.

Across the five fellow regions analysed, the deployment of even a single CSS initiates measurable progress—whether through diversion of plastics from landfill (CSS-4), valorisation of ligno-cellulosic residues (CSS-1), biogenic nutrient recovery (CSS-3) or the up-cycling of agri-food side streams (CSS-2). When two or more solutions operate in concert, synergistic gains multiply: shared utilities dampen

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incremental energy demand, secondary outputs broaden revenue bases, and cumulative CO_2 abatement accelerates. The model therefore validates the **Frontsh1p design principle that circularity must be pursued as an integrated portfolio rather than isolated interventions**.

The financial analyses highlight opportunities to better align societal value with private profitability. Enhancing the management of up-front CAPEX, solvent-intensive processes, and transport expenditures could improve the performance of most configurations. Regions such as Sterea Ellada and Região Norte benefit from existing industrial assets, dense feedstock availability, or favourable gate-fee regimes that help reduce marginal costs. At the same time, the experience of Campania demonstrates that **additional strategies—such as addressing embedded emissions and optimizing logistics—could strengthen overall viability**.

To bridge this gap, three strategic imperatives emerge:

1. **Process optimisation and loop closure**– Retrofitting solvent-recovery, char-valorisation and water-polishing modules can convert cost centres into revenue or credit streams, simultaneously improving environmental scores.
2. **Smart logistics and infrastructure sharing**– Hub-and-spoke collection networks, low-carbon transport modes (rail, electric or bio-CNG fleets) and multi-solution processing parks offer rapid returns by flattening transport curves that currently erode margins and dilute abatement gains.
3. **Performance-based policy instruments**– Flat incentives of €1 000–€10 000 provide limited leverage in supporting large-scale circular economy investments. Policymakers are encouraged to adopt outcome-linked instruments—such as differentiated EPR fees, carbon-removal certificates for biochar, and Innovation Fund grants for integrated bio-refineries—to more effectively de-risk projects, attract private capital, and ensure that financial flows are aligned with societal and environmental objectives.

Implementation of these levers should be anchored in **region-specific roadmaps** that respect unique resource endowments, industrial capacities and governance landscapes while adhering to the common Frontsh1p methodology. Continuous stakeholder engagement—particularly with SMEs, local authorities and citizens—remains critical to secure social licence, refine data quality, and steer iterative optimisation rounds.

In sum,**Frontsh1p's replication simulations demonstrate both the promise and the conditions for success of circular systemic solutions**. By coupling targeted technological upgrades with evidence-based policy design and inclusive governance, the fellow regions can transform pilot insights into scalable blueprints

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for Europe's transition to a climate-neutral, resource-efficient and socially inclusive circular economy.

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