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Introduction

Starting from the methodology developed in Friesland province, the methodological work developed in WP2 and the approach in the different CSSs a web-based tools for the assessment of the circular economic approach based on Life cycle theories and applied to the triple bottom line will be developed and presented in this deliverable.

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.

Work Package 2 provided foundational elements through the development of the Regional Circularity Booster Toolkit (RCBT), a critical resource for assessing regional circular economy practices and fostering synergies among stakeholders. The circularity assessment criteria developed in WP2 were adapted to evaluate scenarios and waste recovery processes within Task 7.2. Furthermore, the socio-economic and legislative contexts of regions such as Lodzkie and Friesland were integrated to ensure the Frontsh1p Scenario Optimizer's relevance and applicability. The emphasis WP2 placed on connecting stakeholders inspired a marketplace functionality that is not yet developed in the Digital Platform but will be included in future improvements and will be the basis for work to be finalized in future projects.

The integration of Work Packages 3, 4, 5, and 6 contributed as a unified approach to the implementation and refinement of Circular Systemic Solutions (CSSs). Together, these work packages provided essential methodologies, data, and insights that shaped Task 7.2 and strengthened its alignment with the FRONTSH1P project's goals. The optimization algorithms and models developed for the Scenario Optimizer were informed by the industrial processes and technological innovations modeled 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.

Demonstration activities from CSSs provided real-world applications that validated and refined the methodologies and tools developed within Task 7.2. Feedback from these activities, particularly in regions such as Lodzkie, ensured that the tools addressed practical challenges and met the specific needs of stakeholders. The collaborative efforts emphasized in CSSs played a crucial role in fostering stakeholder engagement and cooperation, which are central to the success of the Digital Platform and the Frontsh1p Scenario Optimizer.

The interconnected methodologies from these work packages ensured that Task 7.2 leveraged a systemic and collaborative approach. By integrating technical innovations, real-world demonstrations, impact assessments, and stakeholder engagement, Task 7.2 bridges theoretical frameworks with practical implementation. This holistic approach advances the circular economy by tailoring solutions to regional contexts while fostering synergies among

stakeholders. The alignment of Task 7.2 with the overarching objectives of the FRONTSH1P project highlights its critical role in driving systemic circularity and innovation.

The Digital Platform, is a web-app, designed to manage waste-recovery processes, i.e. CSS, and geo-referenced waste materials, offering public administration and/or industrial stakeholders the ability to run simulations on those at a regional level. These simulations aim to extract KPIs related to economic, environmental, and social factors, enabling users to identify the best-performing scenarios.

Work Package 8 will play a pivotal role in testing the Digital Platform and the Frontsh1p Scenario Optimizer across diverse contexts to ensure their robustness and applicability. By conducting wide-scale trials in multiple regions, WP8 will validate the platform's performance, gather feedback from various stakeholders, and identify areas for improvement. This iterative testing process is essential for refining the platform and adapting it to meet the unique socio-economic and environmental conditions of other regions. Furthermore, the comprehensive testing under WP8 will serve as a critical step toward advancing the platform's technology readiness level (TRL), bringing it closer to TRL 9. This transition from a functional prototype to a fully deployable system ensures that the platform can support large-scale circular economic initiatives while fostering its adoption across Europe and beyond. WP8's efforts will also contribute to creating a more accessible and scalable tool, driving innovation and collaboration in the circular economy ecosystem. The ultimate goal is to enhance the interconnections between various industrial plants and optimize waste disposal processes.

1. Methodology

The software development followed an Agile methodology following CI/CD best practices in order to follow the identified stakeholders interests and integration with the consortium partners activities. Moreover, an approach based on design thinking has been necessary in the early stage of the task, to capture and formalize the following software developments. From an engineering perspective, the CSS implementation interlinks, has been leveraged in order to correctly model and optimize the overall system. In this context, the developments performed in "Focus group on Circular Systemic Solutions" workshop, by NTUA, have been the base for the designed system model architecture.

2. Modelling

The development of the Frontsh1p Scenario Optimizer required a robust and adaptable modeling approach to address the unique characteristics of various regions, including Lodzkie. The optimization of Circular Systemic Solutions (CSSs) relied on data-driven methodologies that incorporated inputs, outputs, and resource exchanges at the regional

level. However, despite the foundational guidance provided by Work Package 2, the availability of direct regional data was significantly limited, creating challenges in ensuring precise regional customization.

Due to the poor availability of data from WP2, alternative solutions were implemented to advance the work. These included leveraging publicly available datasets, literature reviews, and partial inputs from project partners to simulate and estimate the socio-economic and environmental impacts of the modeled scenarios. For Lodzkie, the process involved synthesizing region-specific information on waste streams, industrial processes, and socio-economic parameters to align with the unique regional context. This workaround allowed the optimization model to remain functional while reflecting regional realities, even in the absence of comprehensive datasets.

The methodology adopted prioritized adaptability and scalability, ensuring that the models could accommodate evolving or incomplete data sets. By incorporating flexible assumptions and modular configurations, the Frontsh1p Scenario Optimizer can integrate additional data as it becomes available, further refining the results and improving accuracy. These efforts ensured the platform's ability to deliver meaningful insights and maintain progress despite initial data limitations, highlighting its potential for application in diverse regional contexts.

“Scenarios” among the 4 different CSS, have been modelled as black-boxes in which several inputs and outputs resources could be quantified and correlated. This assumption allows to focus the Digital Platform development on the system at a higher regional and geographically-distributed level. On 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 considered material.

For sake of clarity, assumptions and definitions are listed in the following:

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

In the following table an example of data collected, related to Scenario 1.1, is shown. A sample of production and consumption of resources in different categories is depicted. For each specific Scenario, the resource quantities are used to extract the linear correlation between the Waste Stream consumption and each input and output value. As an example, the “Paint” resource yield is given by multiplying the “Pallet” consumption by 0.5.

Table 1 Input data catalogue - Scenario example

resource	unit measure	of	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

Moreover, 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 previous 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.

3. Optimization

The Frontsh1p Scenario Optimizer is a software microservice, within the Digital Platform, designed to optimize industrial scenarios material exchanges based on various parameters such as waste streams, resource production, consumption, and transportation costs. It uses linear optimization techniques to find the most cost-effective and efficient solutions for complex industrial processes. The optimization model is built using the following components:

1. **Variables:**
 - Scenario resource production and consumption
 - Scenario exchanges (resource sharing between scenarios)
 - External input and output for scenarios
 - Waste stream usage per scenario
2. **Constraints:**
 - Scenario size limits
 - Waste stream usage balance
 - Resource production and consumption limits
 - Interconnection balances for production and consumption
3. **Objective Function:** The model aims to minimize the total cost, which includes:
 - Scenario building costs (CAPEX and OPEX)

- Resource selling income
- Resource buying costs
- Waste handling costs
- Transportation costs

The optimizer uses the Pyomo library to construct the mathematical model and the GLPK solver to find the optimal solution.

4. Digital Platform User Guide

The Digital Platform has been purposefully developed as a web-based application to facilitate the assessment and optimization of circular economy practices. It aims to be both accessible and practical for a wide range of stakeholders, including public administrations and industrial players. This guide provides an overview of the platform's technical architecture and user engagement features, emphasizing clarity and functionality to enhance usability for diverse users.

Built on a robust and scalable cloud-based infrastructure, the platform integrates user-friendly features with sophisticated optimization tools. A focus on secure data management ensures reliability while enabling extensive customization. The core components include a user interface, backend optimization algorithms, and a geospatial mapping module. The optimization engine, based on linear programming, uses the Pyomo library and GLPK solver, providing advanced capabilities to process complex datasets. This allows the platform to deliver actionable insights into waste stream utilization, resource sharing, and socio-economic impacts, supporting data-driven decision-making.

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.

The platform is designed to address diverse stakeholder needs effectively. Public administrations can leverage the policy tool to simulate the impacts of various incentives or taxes on waste management strategies. Industrial stakeholders, on the other hand, can use the platform to evaluate the economic and logistical benefits of connecting their processes

with other scenarios. Additionally, the inclusion of social impact boosting guidelines provides actionable recommendations to integrate community-focused practices while maintaining economic and environmental benefits.

The design reflects a commitment to transparency, adaptability, and user empowerment. By offering clear technical documentation and an engaging interface, the Digital Platform ensures that stakeholders can effectively use its features to promote circular economy initiatives in their regions. Planned updates and ongoing testing under WP8 will further refine the platform, expanding its functionality and scalability while advancing its readiness for widespread deployment.

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, buying prices, handling costs, and transportation impacts (economic and environmental). Initial efforts focused on partial data collection for the Lodz 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 (gCO₂eq/km · kg) impacts, have been used to estimate the influence of distances between waste streams and CSS locations.

The following sections of this guide provide detailed user-oriented descriptions of the platform's functionalities, guiding users through its various features and interactions to maximize its utility and impact

4.1 Sign-in

When users click on the link <https://frontsh1p.stamtech.dev/>, they are redirected to FRONTSH1P Digital Platform website which redirects to the platform sign-in dialog as in Figure 1. In this page users can click on "Sign-in" to access the platform, if already register.

The registration is manually implemented, such that by having the interested user emails, the password is manually generated and given to the user. The user profile is then enriched by the "region ID" information which establishes for which region each user is referred to. The complete user profile is then uploaded to the Digital Platform database, by the administrator of the platform itself.

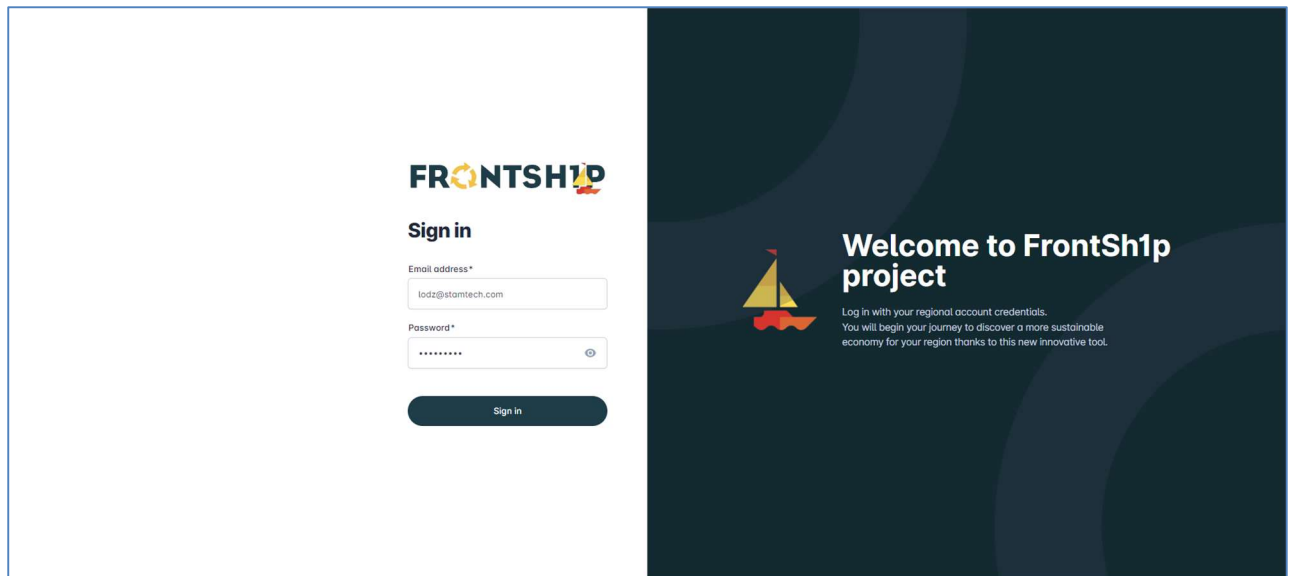


Figure 1 Landing page - user sign-in

4.2 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:

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

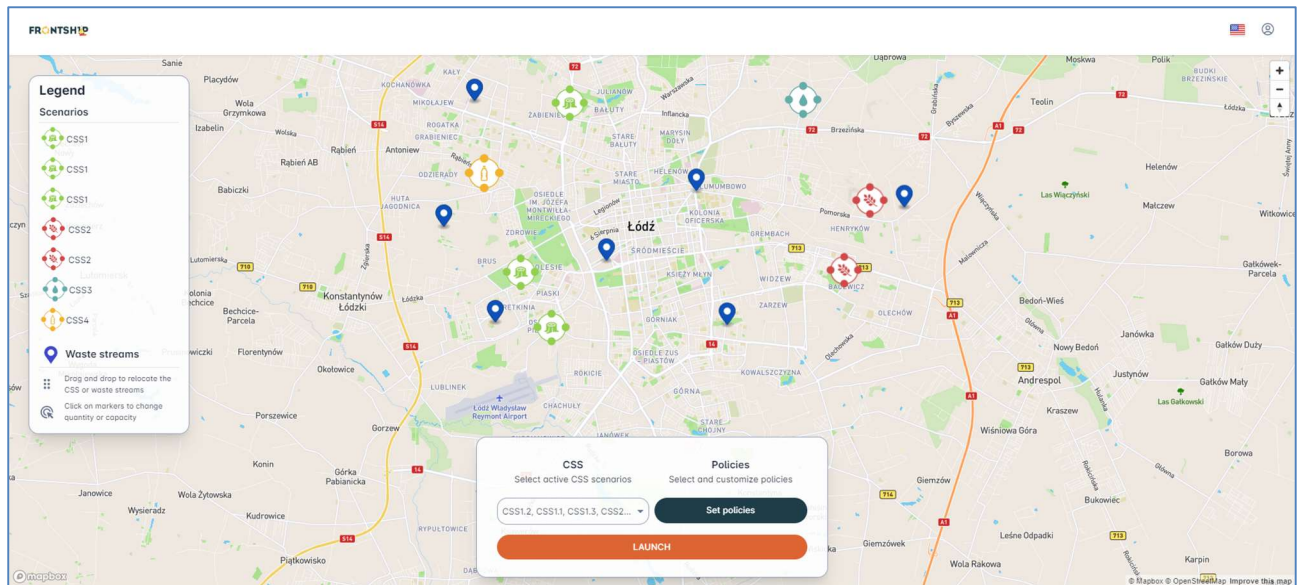


Figure 2 Homepage - CSS and waste streams geo-localization at regional level - Lodz region example

In addition to the overall homepage features, the user is able to interact with the map and dialog with more peculiar ways. In particular, he/she can move the map items freely by dragging and dropping the present icons.

4.3 Map Interaction

Moreover, when each item is clicked a custom dialog is opened and a specific value can be modified. As shown in Figure 3 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.

Change CSS1 capacity

Capacity parameter is the maximum amount of waste that can be processed by a CSS

Capacity

100000C

Cancel Confirm

Change Oil crops quantity

Quantity

500 kg

Cancel Confirm

Figure 3 Homepage – examples of dialogs for modifying CSS capacities and waste stream quantity in the region

Policies setting

By clicking on the “set policies” button, shown in Figure 2, a new dialog box is displayed to the user. In the dialog, shown in Figure 4, 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 economical input, bonus in case of incentive or malus in case of tax, per unit of objective.

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

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

i. 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

ii. Taxes

- “Carbon footprint pricing scheme”: euros per CO₂ consumed added to the financial impact

Your region policies
Pick policies that you want to apply. They will impact simulation results

Incentives

☐ Waste water Recovery Initiative	
☐ CE waste facilities deployment initiative	
☐ CE cross-sectoral waste management initiative	

Taxes

☐ Carbon Footprint Pricing Scheme	
--	----------------------

Cancel **Confirm**

Figure 4 Homepage - policy tool

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

CSS activation/deactivation

By clicking on the CSS section of the homepage dialog, shown in Figure 2, a new dialog box is displayed to the user as in Figure 5. The list of the mapped Scenarios is given to the user, allowing her/him to activate or deactivate each Scenario by clicking on its tick-box. Scenarios that are not active, are then a-priori discarded from the optimization procedure, enabling the user a degree of flexibility in applying constraints to the analysis. This feature can be interesting to study and compare a series of different Scenarios configurations in the region.

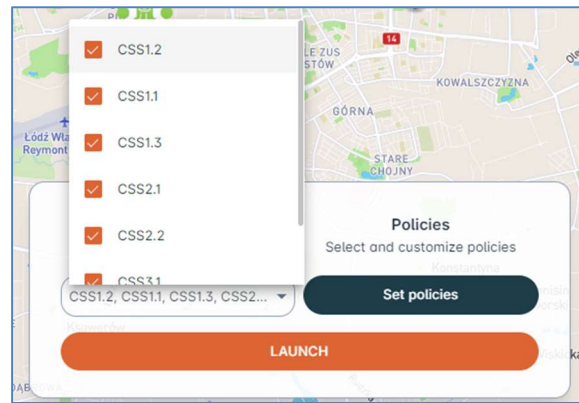
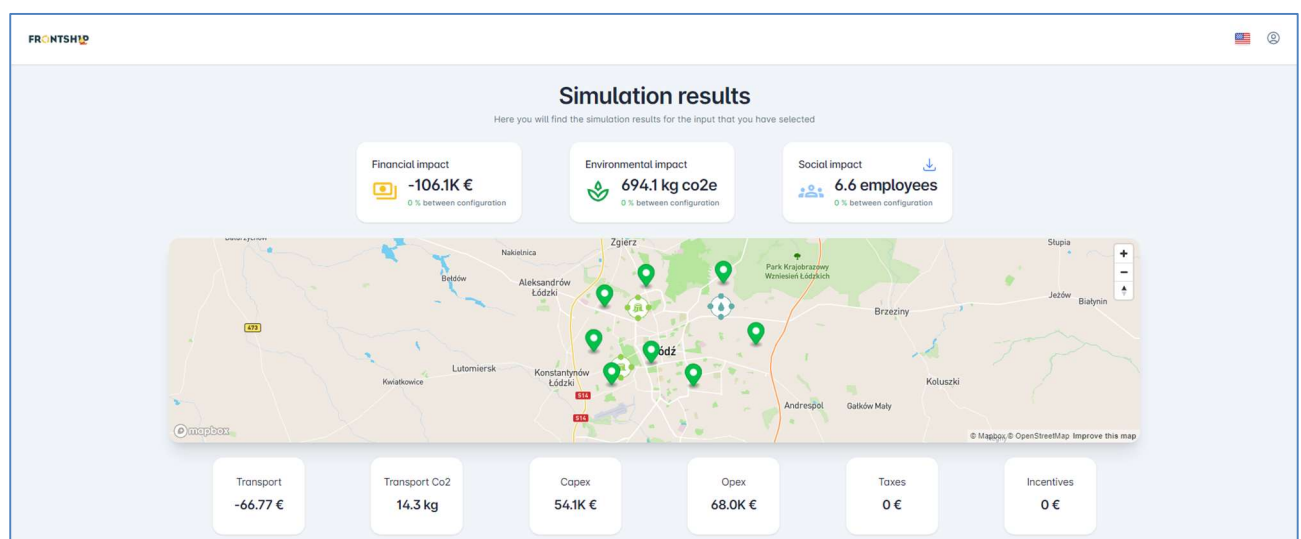


Figure 5 Homepage - dialog for activating or deactivating CSS

Results page

After the user run the optimization, by clicking the “launch” button in the homepage, the web-app is redirected to the results’ page as depicted in the Figure 6. 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



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	5,454.8 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

Figure 6 Results page – overall triple impacts values and specifics on resource production, consumption and exchange

Social impact boosting

Within the results page, the user can encounter a specific card related to the quantitative social impact resulted from the optimization. By clicking the “download” button the user can read offline a specific documentation guidelines that can support the citizen engagement of the implemented processes.

The guidelines provide tips and tricks to boost ones social impact, without compromising the economic and environmental benefits of the CSS but boosting them. The work is performed on the context of WP2 activities and provides to the user a series of examples and good practices applied in the Lodz region.



Figure 7 Results page - social tool