Kaunas University of Technology

Faculty of Mechanical Engineering and Design

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Implementing Circular Economy Measures in Jonava Municipality Using the 'Living Lab' Approach

Master's Final Degree Project

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Summary

As urban areas increasingly contribute to environmental challenges, it is essential to integrate sustainable development goals to improve their resilience and sustainability. For cities to experience the advantages of these initiatives, they need to operate as communities that collaborate to achieve environmental objectives, partnering with researchers, government entities, and the business sector. This research seeks to explore the feasibility of integrating circular economy practices into urban management systems in Jonava. To accomplish this objective, a literature review is conducted, a material flow analysis of the Jonava municipality's waste management system is modeled using the STAN program, budget allocations for sectors are assessed through Microsoft Excel, an LCA is performed with CCaLC2 program, and discussion and feedback is done with the public organisations.

The focus of this research is on 39 public organisations and institutions located in the Jonava municipality, which have been categorised into seven sectors: education, health, social services, sports, municipal services, public governance, and culture. Data for this analysis is derived from public procurement records for the year 2023. This project evaluates the environmental impact of purchased goods, alongside electricity, heating, water, and waste management.

Findings indicate that Jonava municipality recycles only 2 thousand tons of waste annually, with a total of 10 thousand tons classified as mixed municipal waste, highlighting opportunities for improved sorting methods. In terms of budget allocation across the examined sectors, it has been determined that more than half of the total budget is dedicated to the Education and Municipal Services sectors, and for most sectors, the largest share of the budget is spent on product purchases.

The functional unit used for the life cycle assessment represents the items purchased by each sector for the year 2023. Each sector possesses a unique functional unit due to the varying quantities of items purchased. The results reveal that the most significant environmental impacts are found in the Municipal Services sector (primarily from energy and fuel), the Education sector (largely resulting from food products and electronics), and the Sports sector (mainly due to wastewater treatment), indicating major areas for potential improvement for the municipality. Other recognised challenges in adopting circularity initiatives include a lack of awareness, difficulties in altering behavior, and insufficient funding for circularity efforts.

Suggested actions for the Jonava municipality include enhancing energy efficiency (particularly in the Education and Municipal Services sectors), modernizing transportation and optimizing driving routes (especially in the Municipal Services sector), establishing self-catering systems (for the Education and Social Services sectors), and promoting electronic document storage rather than printing (for the Education and Municipal Services sectors).

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Santrauka

Miestai vis labiau prisideda prie aplinkosaugos iššūkių, tampa svarbu integruoti darnaus vystymosi tikslus, siekiant pagerinti jų atsparumą ir tvarumą. Siekdami pasinaudoti miesto žiediškumo iniciatyvų teikiama nauda, miestai turi veikti kaip vieningos bendruomenės, bendradarbiaujančios siekiant aplinkosauginių tikslų, kartu dirbdamos su mokslininkais, valdžios institucijomis ir verslo sektoriumi. Šio tyrimo tikslas – ištirti žiedinės ekonomikos praktikos integravimo į miesto valdymo sistemas galimybes Jonavos rajono savivaldybėje. Siekiant šio tikslo, atliekama literatūros apžvalga, modeliuojama Jonavos rajono savivaldybės atliekų tvarkymo sistemos medžiagų srautų analizė, naudojant STAN programą; įvairių sektorių biudžeto paskirstymai, analizuojami naudojant Microsoft Excel; atliekamas būvio ciklo vertinimas su CCaLC2 programa, bei taikoma diskusija, bei grįžtamaiss ryšis organizacijoms.

Tyrimas sutelktas į 39 viešąsias organizacijas ir įstaigas, esančias Jonavos rajono savivaldybėje, kurios suskirstytos į septynis sektorius: švietimo, sveikatos, socialinių paslaugų, sporto, savivaldybės paslaugų, viešojo valdymo ir kultūros. Duomenys analizei buvo surinkti iš 2023 metų viešųjų pirkimų įrašų. Projektas vertina įsigytų prekių, taip pat elektros energijos, šildymo, vandens ir atliekų tvarkymo aplinkosauginį poveikį.

Rezultatai rodo, kad Jonavos rajono savivaldybė per metus perdirba tik 2 tūkst. tonų atliekų, kai tuo tarpu 10 tūkst. tonų yra klasifikuojamos kaip mišrios komunalinės atliekos, kas rodo, kad yra galimybių gerinti rūšiavimo metodus. Analizuojant biudžeto paskirstymą tarp tiriamų sektorių, nustatyta, kad daugiau nei pusė viso biudžeto skiriama švietimo ir savivaldybės paslaugų sektoriams, o daugelyje sektorių didžiausia biudžeto dalis skiriama prekių ir energijos įsigijimui.

Gyvavimo ciklo vertinimui naudotas funkcinis vienetas atspindi kiekvieno sektoriaus 2023 metais įsigytas prekes. Kiekvienas sektorius turi unikalų funkcinį vienetą dėl skirtingų įsigytų prekių kiekių. Rezultatai parodė, kad didžiausias aplinkosauginis poveikis yra savivaldybės paslaugų sektoriuje (daugiausia dėl energijos ir kuro), švietimo sektoriuje (daugiausia dėl maisto produktų ir elektronikos), bei sporto sektoriuje (dėl nuotekų valymo), kas rodo pagrindines tobulintinas sritis savivaldybei. Kiti nustatyti iššūkiai, įgyvendinant žiedinės ekonomikos iniciatyvas, – informuotumo stoka, elgsenos keitimo sunkumai ir nepakankamas finansavimas.

Siūlomi veiksmai Jonavos rajono savivaldybei apima: energijos vartojimo efektyvumo didinimą (ypač švietimo ir savivaldybės paslaugų sektoriuose), transporto modernizavimą ir maršrutų optimizavimą (ypač savivaldybės paslaugų sektoriuje), savitarnos maitinimo sistemų diegimą (švietimo ir socialinių paslaugų sektoriuose), bei elektroninių dokumentų saugojimo skatinimą vietoj spausdinimo (švietimo ir savivaldybės paslaugų sektoriuose).

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Introduction

Novelty of the topic

Urban areas serve as centres for innovation, where sectors such as industry, culture, science, social, and economic development thrive. In 2008, the population in urban regions surpassed that in rural regions for the first time, and projections suggest that by 2050, approximately two-thirds of the global population will reside in cities [1]. Urban activities significantly contribute to climate change, accounting for 70% of worldwide CO_2 emissions [2]. As cities become influential in increasing environmental issues, it is vital to incorporate sustainable development objectives to enhance their resilience and sustainability. For cities to feel the benefits of these efforts, they must function as cohesive communities that collaborate towards achieving environmental goals, partnering with researchers, government, and the business sector. Smaller cities have an advantage in adapting to changes, as they typically operate as communities committed to improving their local environments.

Problem

Lithuania aims to achieve a completely circular economy by 2050 [3]. To accomplish these objectives, the governance of municipalities needs to develop initiatives targeting key environmental groups, increase community awareness to encourage behavioral changes, and promote industrial circularity through projects and regulatory measures. However, municipalities face challenges due to a lack of communication and knowledge, making their environmental plans difficult to implement. Additionally, when governments do not prioritize environmental issues, it tends to discourage community engagement in initiatives. Therefore, a proposal package should be created for municipalities that includes recommendations for governance, community involvement, and business engagement to achieve better outcomes.

Aim of work

To investigate the potential for incorporating circular economy practices into the urban management frameworks of Lithuania by utilizing the "Living Lab" approach in the Jonava city ecosystem. This study evaluates the consumption patterns of goods and energy in Jonava's public sector, as well as the sustainability-related decisions made. Additionally, the research assesses the environmental impact of consumption to pinpoint the primary sources of resource utilization and pollution. The goal is to uncover the existing challenges in resource management and identify opportunities for circular transformation. Following the findings, a set of recommendations is to be developed for the municipality of Jonava, aimed at enhancing the effective implementation of circular economy principles in urban management.

Tasks of work:

- Perform an analysis of environmental legislation in urban areas at the Lithuanian and EU levels;
- Examine good practice examples and scientific articles of cities aiming for climate neutrality;
- To evaluate the material and energy flows of municipal enterprises and assess their environmental impact, along with conducting a disscusion and feedback to organisations;
- To develop a set of tailored recommendations for the Jonava city government to facilitate the transition to a circular economy;
- To formulate recommendations and conclusions based on the results of the analysis.

1. LITERATURE REVIEW AND AN ANALYSIS OF LEGAL REGULATIONS FOR URBAN ENVIRONMENTS, POLLUTION PREVENTION PRINCIPLES

Urban areas account for more than 70% of the world's CO_2 emissions and utilize over 66% of global energy consumption [4]. This is why they are a key focus for efforts to minimize environmental damage. Achieving climate objectives and reaching Sustainable Development Goal (SDG) 11, which aims to make cities inclusive, safe, resilient, and sustainable [1] benefits urban systems not just environmentally, but also in terms of socio-economic factors. There are three dimensions to grasping the concept of a circular economy:

- Technocratic – an idealistic vision of perfect circularity and material recovery;
- Geographical – global recycling systems can be detrimental for resource recovery, as unprotected labour is often exploited under hazardous conditions in the Global South to benefit the Global North;
- Economic – the European Union should prioritise the use of secondary resources to foster circularity, particularly when it comes to critical raw materials [5].

1.1. Circular cities characterisation

The prevailing economic structure is referred to as a linear system: resources are extracted, utilised to create products, consumed, and ultimately discarded as waste. This exerts significant pressure on our planet as limited resources are depleted. With the population on the rise and consumption escalating, the limits of Earth's resources are approaching their threshold. At the end of their lifecycle, approximately 60 per cent of materials end up incinerated or in landfills, while only 40 per cent are recycled or repurposed. This necessitates the adoption of new models to take precedence, such as a circular model [6].

Embracing a circular model involves not just increasing recycling and reuse but also:

- The removal of harmful substances from products;
- Developing strategies for reuse, remanufacturing, repair, and recycling (for instance, implementing eco-design in products);
- Creating strategies for new consumption behaviours (like enhancing environmental awareness and promoting sharing initiatives for both consumers and businesses);
- Introducing new business models (such as leasing materials to other companies and products to consumers) [7].

A circular city is characterised by its departure from a linear economy model in favour of a circular one. This involves separating resource consumption from economic growth by prolonging the life and preserving the quality of products, materials, components, and nutrients. By achieving this, the cycle of materials is completed, resulting in the use of fewer harmful resources and generating less waste. As a result, cities evolve into safer environments for both humans and biodiversity, while also lowering emissions and aligning with sustainable development goals [2].

One effective approach to establishing circular cities is by developing a network of urban industrial symbiosis, and this system enables industries and urban areas to share waste and energy resources. A waste product from one company can serve as a necessary resource for another's production, and through these synergies, the generation of waste can be reduced, and the need for logistics associated with material transport is minimised, as the materials are sourced regionally. There are also lower costs tied to receiving materials since they are essentially waste that requires treatment for a particular company [8].

A prime illustration of industrial symbiosis can be found in the city of Kalundborg, Denmark, and in this symbiosis, four industrial entities are involved: a power station, an oil refinery, a facility that manufactures plasterboard, and a biotechnology production plant. In addition to these four companies, the local municipality also plays a role in the symbiotic relationship.

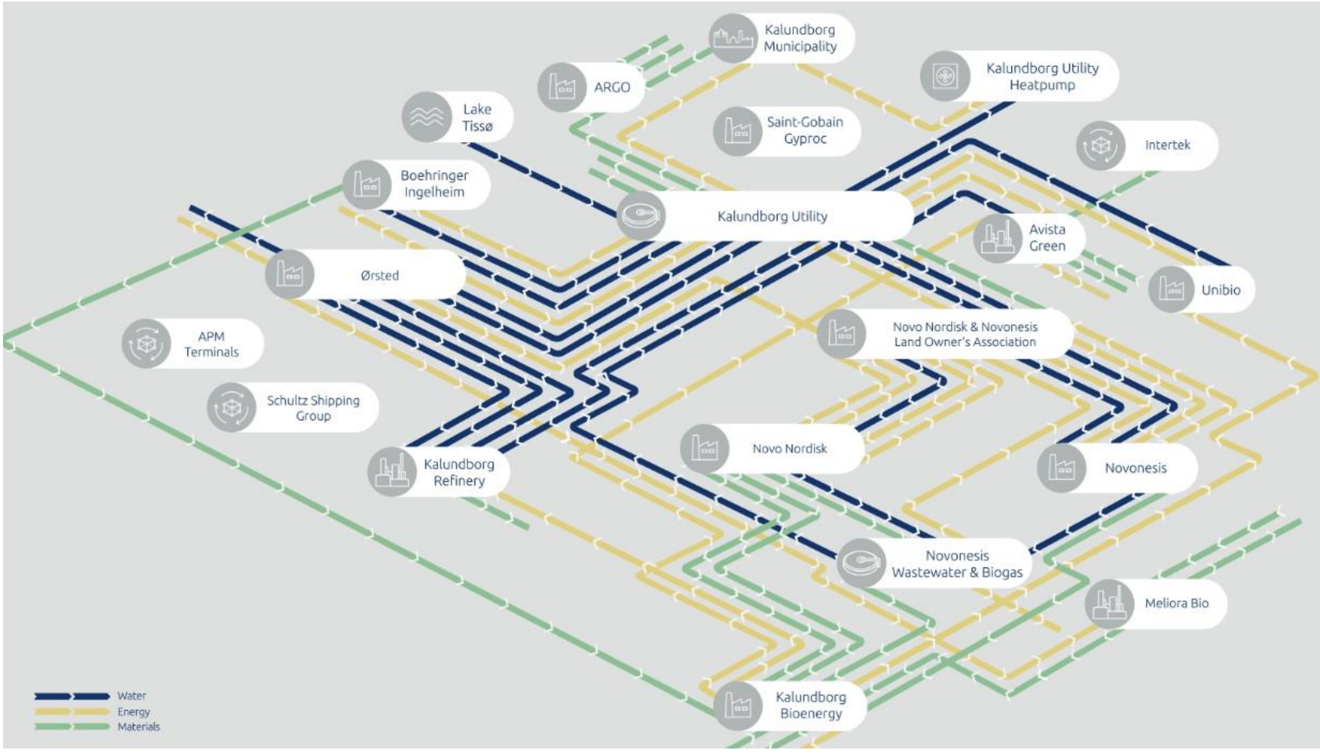

Fig. 1. Industrial symbiosis in Kalundburg, Denmark [9]

Industrial symbiosis has demonstrated significant advantages for the environment by aiding in the reduction of required resources, waste, and emissions. The following examples illustrate the exchanges occurring in Kalundborg:

- Excess steam generated by the power plant is sent to the heat station, which then sells it to Statoil and Novo Nordisk as a heat source for their oil refining operations;
- Treated wastewater from Statoil is returned to the power plant, where it is utilised as cooling water and converted into condensed steam;
- Gyproc, a company specialising in plasterboard production, receives industrial plaster from the power plant and incorporates it into its plasterboard manufacturing. Additionally, they obtain excess gas from the oil refinery to serve as an energy source;
- Novo Nordisk, a producer of insulin, markets the by-product of its yeast fermentation process to local farmers as fertilizer or creates a yeast slurry that can be sold as part of an animal feed mix [10].

Table 1. Results of the Kalundborg symbiosis [11]

Sources of reduction	**Total reduction (tons/year)**
Resources	
Oil	19 000
Coal	30 000
Water	1 200 000
Emissions	
CO_2	130 000
SO_2	25 000
Waste	
Fly ash	135 000
Sulfur	2 800
Gypsium	80 000
Nitrogen from biosludge	800
Phosphorus from biosludge	400

From a wider viewpoint, the circular economy encompasses various strategies illustrated in the figure below. Transitioning from a linear to a circular economy requires different levels of engagement (micro, meso, and macro) as well as diverse participation from national, regional, and local authorities. The micro level targets consumers and individual businesses; an example of the meso level is industrial symbiosis, where connections and relationships are established among industrial ecosystems. Finally, the macro level concentrates on the broadest issues, such as legislative changes at the national, regional, and local levels [6].

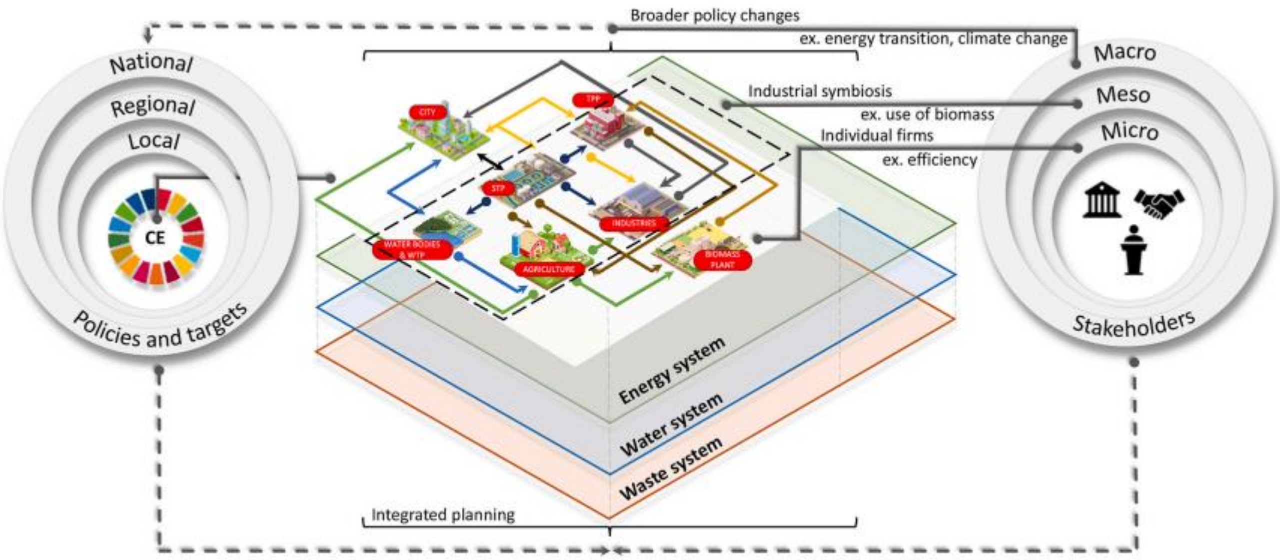

Fig. 2. Conceptual framework for a circular economy approach to integrating local and national targets and policies [6]

1.1.1. Circularity indicators

Circularity indicators serve to assess the advancements made concerning the city's circularity, and these indicators are defined by five primary sectors within the environmental dimension: waste, energy, water, built environment, and mobility. These sectors are chosen because they are significant contributors to environmental issues, particularly in urban areas, and the indicators presented below demonstrate how each sector can be quantified and how they are interlinked across different dimensions using these indicators. This enables comparisons, such as relating energy usage to mobility, and additionally, the indicators are structured to be applicable at various levels, including regional, city, and neighborhood scales. They facilitate the evaluation of progress from a tangible standpoint, beyond merely looking at carbon emissions, air and water quality, or the decrease in greenhouse gas emissions (GHG). Examples of the indicators can be found in the table below [12]:

Table 2. Indicators of circularity [12]

Indicators for key sectors					
Theme	Waste	Energy	Water	Built Environment	Mobility
Waste	Per capita waste production [tons/person *year]	Conserving energy by utilizing recycled products [kWh/year]	Water usage per person [l/year/person]	Proportion of recyclable demolition materials that are reused or recycled [%]	The quantity of waste generated in the city and processed within its borders [tons/year or %/year]
	Recycling percentage (recycling, repair, reuse, recovery, and upcycling activities) [%]	Renewable energy use [%/year or kWh/year]			
Energy		Overall energy usage [kWh per inhabitant per year]		Energy usage in residential structures [kWh/m^2 or kWh per resident]	Percentage of the overall passenger car fleet powered by electric, hybrid fuel cell, liquefied petroleum gas, and compressed natural gas sources [%]
		Energy demand per individual [GJ/person/year]		Electricity consumption in commercial structures [kWh/m^2 or kWh per occupant]	
				Proportion of buildings heated primarily by renewable energy sources [% of total buildings]	
Water			Average number of hours of uninterrupted water supply per household per day over the year [h/day]	Percentage of dispersion from municipal water supply [%]	
Built Environment				Proportion of deteriorating buildings	Density of public spaces: percentage of pedestrian zones, plazas,

Indicators for key sectors					
Theme	Waste	Energy	Water	Built Environment	Mobility
				[%/total buildings]	and green areas [% of municipal area/ neighborhood]
				Percentage of retrofitting efforts on buildings [%/overall buildings]	Kilometers of roadway allocated solely to public transportation per 100,000 residents [km]
Mobility					Usage of public transportation [% of population utilizing public transport]

Circularity indicators can encompass not just environmental aspects but also economic and social factors. For a city to operate effectively as a circular city, it is essential to take all these dimensions into account. Neglecting the economic aspect could result in circular city initiatives placing a financial strain on the municipality, leading to the abandonment of these projects. If the social aspect is overlooked, the community might remain uninformed or uninterested in the concept of a circular city, causing initiatives to fail due to a lack of engagement [12].

Indicators related to the economic dimension that can be utilised include the ratio of green investments to the city's overall budget, the time it takes to recoup the investments, and the return on investment for each period. These metrics would enable the urban area to assess its capacity for implementing specific circular projects, and by evaluating the economic dimension, it becomes easier to realistically meet the established objectives for the city.

Social dimension indicators include the quantity of jobs created through circularity initiatives, the number of events focused on raising awareness or promoting circular activities, and the number of participants at these events (encompassing governance, residents, universities, businesses, etc.). Analysing the social dimensions will allow for yearly comparisons of community engagement in the urban area regarding their support for circularity through participation in events and job creation. An increase in these indicators suggests that the community is engaged and informed about the ongoing projects, and conversely, a decrease indicates a need for adjustments in strategies to enhance community involvement.

1.1.2. “Living Lab” methodologies

When the social, economic, and environmental aspects are interconnected, cities are more likely to achieve circularity, and one method that can facilitate this involvement is the “Living Lab” approach. The “Living Lab” approach is a flexible and creative strategy that engages various stakeholders to address the complex challenges faced by urban environments, and unlike conventional laboratory techniques, “Living Labs” incorporate the end-users for testing solutions in real-world settings. The main features of a “Living Lab” include:

- Ensures that solutions align with the needs of end-users by centering them in the innovation process;
- Collaboration among diverse stakeholders: businesses, communities, government, and researchers;
- Implementation of solutions in actual environments for testing;
- Input for innovation typically comes from various fields of expertise;
- Enhancing solutions is crucial, and consistent feedback is gathered from end-users [13].

One approach within the “Living Lab” methodology is the iLab.o living lab method (Fig. 3). This method comprises four steps that link social constructs with technological frameworks, illustrating that social factors are paramount as they influence user interactions with changes. The first step is contextualization, where information about the topic under study is gathered, which is then used to define the target group for participation in the project. The second step, known as concretisation, involves measuring the initial product for comparison with the new product at the project's conclusion, alongside introducing the existing product to the target group. The third step is implementation, during which tests are conducted, and immediate measurements of the results are obtained. In this phase, it is crucial to observe how the target group responds to the changes and what the outcomes are. The fourth phase is feedback, where the outcomes of the concretisation and implementation stages are evaluated, leading to recommendations for implementation [14]. The graphical representation of iLab.o living lab methodology:

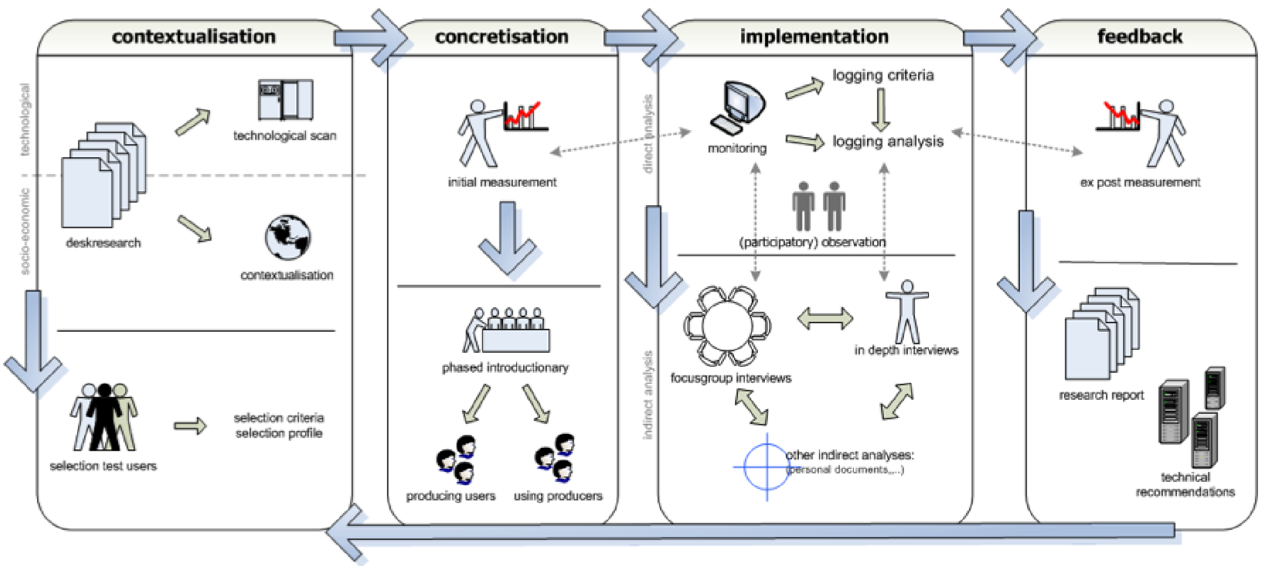

Fig. 3. iLab.o living lab methodology [14]

“Living labs” can be established by emphasizing the connection between businesses and the public sector, which are keen to collaborate. One example of this is the living labs in Helsinki. Unlike the iLab.o living lab model, which has four phases, the “Living Lab” operates in three phases. The initial phase is Grounding, where key stakeholders and users from the community are identified. The second phase is Interactive and Iterative Co-Design, during which community users investigate the proposed concepts and prototypes. The final phase is Appropriation and Implementation, where the outcome is tested, and feedback is collected [14]. The graphical representation of Helsinki Living Lab methodology (Fig. 4):

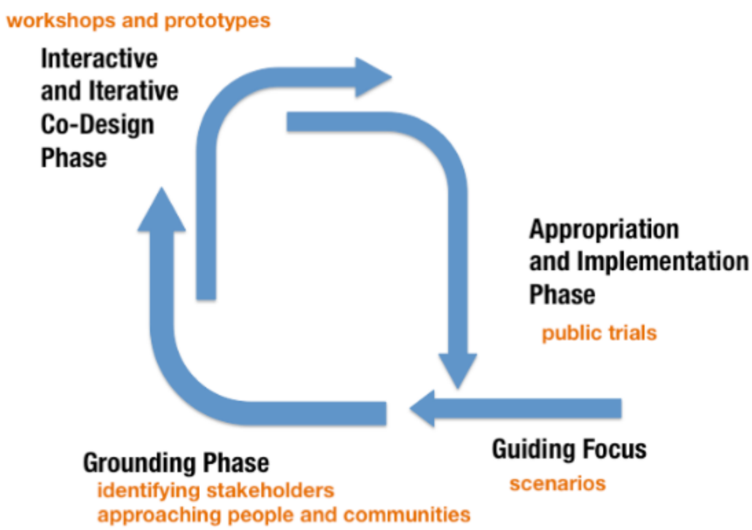

Fig. 4. Helsinki Living Lab methodology [14]

In every "Living Lab", users are involved from the onset of the project, and the target demographic is determined because their feedback significantly influences the outcomes. For instance, if the project pertains to a community initiative, the target group may primarily consist of residents from the area, as they possess the most relevant insights and motivation for the project's execution. Another common aspect of all "Living Labs" is the emphasis on real-world scenarios, as this is essential for genuinely understanding how to enhance the implementation of various projects or to view the entire ecosystem, rather than just a single component. The final shared characteristic among all "Living Labs" is the collaboration of public and private sectors; since the entire ecosystem must work together, the lab can assist the community in focusing on improving the overall situation.

1.1.3. Barriers in a circular economy

The main obstacles to achieving a circular economy can be categorised into four types: cultural, technological, market, and regulatory, all of which are interconnected. Cultural barriers arise from a lack of knowledge and the willingness to participate in the circular economy. Technological challenges stem from the absence of technologies needed to implement a circular economy. Market barriers relate to the economic factors of circularity and the inadequate performance of business models within the circular economy, and regulatory barriers consist of insufficient policies that facilitate the shift from a linear to a circular economy. Upon deeper examination of these barriers, it becomes evident that cultural obstacles have the most significant effect, as engagement begins at the community and business levels; without interest from people, progress towards circularity cannot commence. The cultural barriers identified in the EU include company culture, the willingness to collaborate within the value chain, consumer awareness and interest, and operating within a linear framework. The second most significant barrier is market-related, where the primary concern is the high initial investment required, and this hesitation is often due to insufficient knowledge among businesses, leading them to wait for others to set precedents and share best practices. Another significant market-related issue is the low cost of virgin materials, making it more economical for companies to procure these materials instead of opting for recycled or biobased alternatives. The third most critical barrier involves regulations; for instance, companies may wish to utilise certain recycled materials but are hindered by outdated regulations that remain unchanged. Finally, when it comes to technological barriers, the predominant challenges are associated with circular design and the limited number of large-scale pilot projects related to the circular economy. While these challenges must be addressed, it is important to note that technological capabilities are improving daily, which makes this category the least concerning [15].

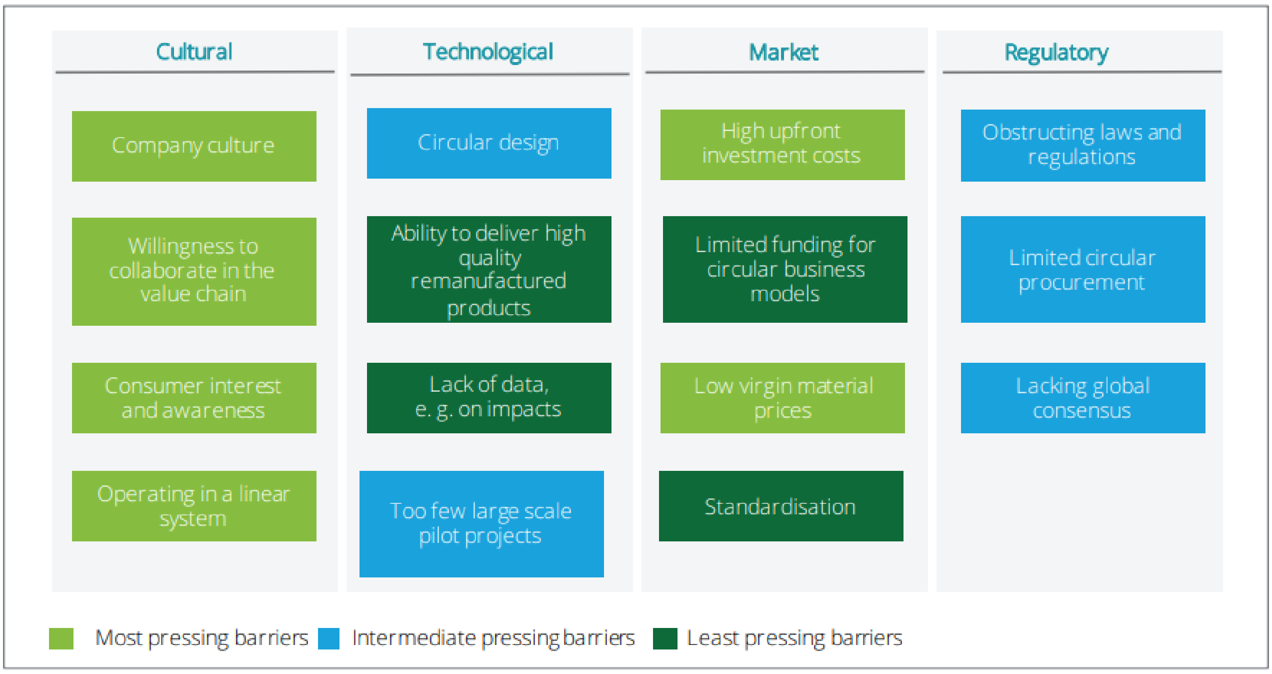

Fig. 5. Heatmap of circular economy barriers [15]

Achieving a circular economy is challenging due to regulatory obstacles throughout the entire economic value chain, and across the complete product lifecycle (cradle-to-grave), various barriers exist:

- Extraction and Production: Existing laws mainly concentrate on the extraction of virgin raw materials, and there is insufficient pricing for externalities.
- Production and Internal Loops: Regulations often favour waste generation over strategies like industrial symbiosis, internal loops, or resource-efficient production methods.
- Production and Use: Legislation tends to view the relationship between production and the use phase as a linear process, lacking consideration for product-service systems.
- Collection: There is a deficiency in legislation for specific waste streams, leading to inappropriate waste treatment methods such as disposal or incineration, along with a shortage of high-quality treatment facilities.
- Production and Circular Waste Management Activities: Regulations hinder products from being more suitable for reuse or recycling because there are no requirements imposed on manufacturers.
- Circular Waste Management Activities: Legislation fails to preserve the economic value and utilised resources of products, or at least to ensure technical possibilities for acceptable recovery rates.
- Circular Waste Management Activities and Production: There is an absence of legislation that promotes the use of recycled or secondary materials markets instead of relying on the extraction of new materials [7].

The figure below (Fig. 6) shows the framework of conventional and circular streams, where regulatory barriers are explained in the text above.

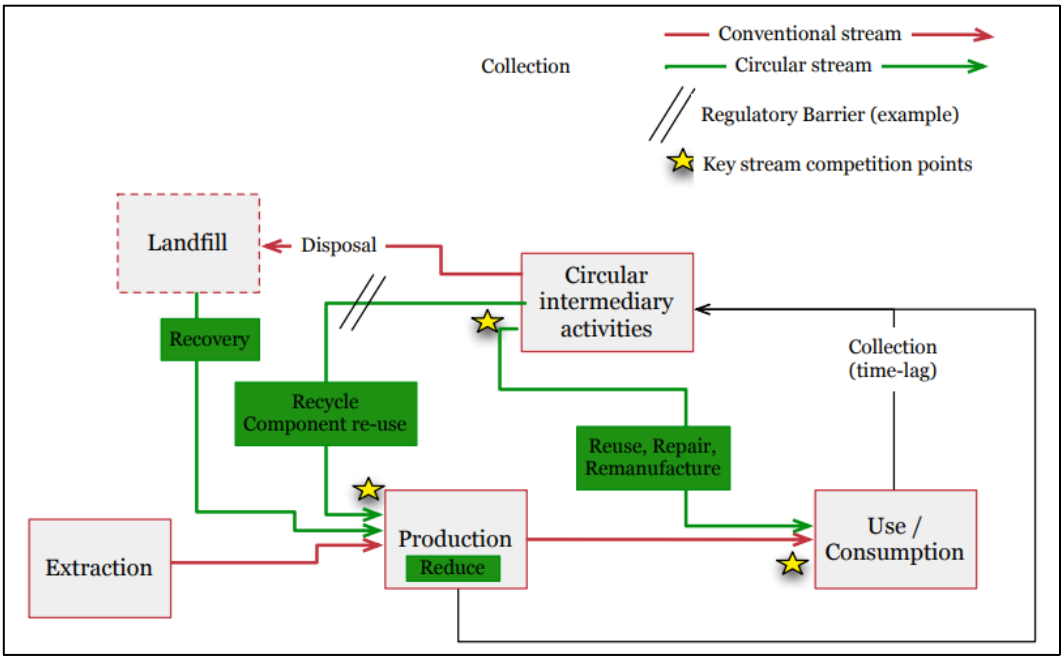

Fig. 6. Conceptual framework for regulatory barriers in a circular economy [7]

1.2. Jonava municipality

The Jonava municipality is home to approximately 40,000 residents and features Jonava, the ninth-largest city in Lithuania. Roughly one-third of the municipality's population resides in the city, with 65 percent living in rural areas, and this represents the second-largest rural population in the Kaunas region, which highlights the city's potential for mitigation efforts [16].

Due to its central location in Lithuania, the municipality serves as a key logistical route, and the two largest cities in Lithuania, Kaunas and Vilnius, are situated relatively close to Jonava, at distances of 30 km and 90 km, respectively. The municipality is home to three railway lines that are significant for local transport: Palemonas – Gaižiūnai, Jonava – Rizgonys, and Kaišiadorys – Radviliškis – Kužiai. Furthermore, the “Rail Baltic” railway track is currently being constructed to connect the Baltic states to the European rail network [16].

In July 2023, the municipality of Jonava granted 22 integrated prevention and control pollution permits, marking one of the highest counts in the Kaunas region. Additionally, the presence of the company “Achema” along with its departments and other businesses situated in rural areas positions Jonava municipality as one of the top contributors to air pollution among rural municipalities in Lithuania.

In Jonava municipality, all residents have access to waste collection services; however, it also records one of the highest rates of municipal waste generated per person in the Kaunas region as in the year 2021, each person disposed of an average of 298 kg of municipal waste [17].

Since 2022, the Lithuanian environmental ministry has been evaluating municipalities based on their environmental protection standards. In 2022, Jonava municipality achieved 3rd place among all 60 municipalities in the country. The municipality excelled particularly in environmental quality (3rd place) and construction and territorial planning (4th place), and conversely, it received low ratings in energy (38th place) and climate change management (17th place). Since 2022, Jonava municipality has seen a decline in its ratings each year, indicating that other municipalities are advancing at a faster pace compared to Jonava. In 2024, the category of climate change and control was the lowest for Jonava, ranking it at 55th place, as this category aligns with the strategic plans of the municipality and its objectives regarding environmental protection, the extent of green procurement, and the execution of an environmental management system (such as the ISO 14001:2015 standard or EMAS regulation). Other challenging areas include waste management and circularity, which relate to the quantity of waste collected per resident, the establishment of goals aimed at achieving a waste-free municipality, and the separation of food waste and textiles. This indicates that Jonava municipality must make progress towards Lithuania's objectives of becoming circular [18].

Table 3. Environmental protection rating of Jonava municipality [18]

Criteria	2024		2023		2022	
	Place	**Points**	**Place**	**Points**	**Place**	**Points**
Waste and circularity	32	23.55	15	24.5	14	23.8
Energy	11	22.77	9	20.6	38	22.2
Construction and territory planning	22	16.79	4	25.1	4	26.8
Transportation	12	13.46	9	13	10	10.9
Climate change control and policy	55	6.06	7	10.4	17	7.6
Environment quality, prevention and comfort	19	22.73	24	21.9	3	29.2
Water quality	28	15.35	21	17.8	9	25.4
Biodiversity and landscape	28	10.9	18	15.9	7	18.9
Environmental awareness	7	22.23	23	4.4	7	11.5
Sum of points	-	153.84	-	153.60	-	176.30
Overall rating from 100 points	15	48.73	9	48.79	3	47.75

1.3. Legal requirements regarding climate change in urban areas

The legal requirements in Lithuania and the European Union overlap, and municipalities are responsible for the handling of their waste, creating waste prevention plans and to have a continuous improvement for environmentally friendly solutions.

1.3.1. Legal requirements in the Republic of Lithuania

In the National Climate Change Control Agenda, the objectives for urbanised areas include:

- To plan territories and urban spaces according to sustainable development and green infrastructure principles;
- In the territory planning documents to acknowledge a resilient to climate change transportation infrastructure, green spaces, etc.;
- At the municipality level to evaluate the impact of climate change consequences and prepare management strategies for risks and threats in municipal plans;
- For cities with populations exceeding 20,000, to create and implement city greening plans in collaboration with the community;

- To establish requirements for climate change adaptation for all new and renovated buildings and infrastructure [19].

The National Climate Change Control Agenda focuses on enhancing the role of municipalities as well:

- By 2030, reduce the CO_2 emissions by one-third in urban areas;
- By 2030, Lithuania should establish the first climate-neutral and waste-free city in the country;
- Increase community awareness and develop initiatives focused on environmental issues. By 2030, ensure that at least half of the residents engage in environmental protection projects [19].

In the Waste Handling Law, it is the responsibility of municipalities to develop municipal waste management systems that are essential for their areas, ans this management system must also address the disposal of other types of waste, including textiles and electronics. Additionally, municipalities are tasked with ensuring the effectiveness of the waste management system, which includes organising the processing of waste for which the owner cannot be traced [20].

The municipality is responsible for the following essential requirements, as outlined in the National Waste Prevention and Treatment Plan:

- All residents must have access to municipal waste treatment that is of high quality, financially viable, and compliant with environmental, technical, economic, and safety standards;
- The sorting of secondary materials must be facilitated;
- Biodegradable waste should be sorted;
- Textile waste should be sorted;
- There should be systems in place for sorting and separately collecting household construction waste, and a dedicated collection station for bulky waste should be established. Additionally, alternative methods for organising bulky waste collection that suit the municipality must be implemented;
- Each municipality is responsible for creating conditions to treat municipal biodegradable waste through composting or anaerobic processes;
- It must be ensured that only non-suitable waste is sent to the landfill after proper sorting has taken place [20].

1.3.2. Legal requirements in the European Union

The Paris Agreement is a global treaty focused on addressing climate change, and the primary objectives of the agreement include:

- Ensuring that the rise in average global temperature stays significantly below 2 °C compared to pre-industrial levels.
- Limit the temperature increase to 1.5 °C above pre-industrial levels [21].

One of the pivotal documents that initiated the shift towards circularity within the European Union is the Pact of Amsterdam. Established in 2016, its goal was to tackle urban challenges by incorporating three components: member states, municipalities, and stakeholders. The Pact of Amsterdam advocated for dialogue and the sharing of knowledge, ultimately aiming to cultivate resilient and vibrant cities for enduring prosperity, and this document is significant as it established the foundation for the EU Urban Agenda [22].

The Kyoto Protocol, established in 1997, functions under the United Nations Framework Convention on Climate Change, and it represents a commitment for developed nations and economies to alter their practices and decrease greenhouse gas emissions (GHG). The objectives are detailed for each nation on an individual basis, as Lithuania has a target for emission reduction quantified at 92 percent from the base year [23].

The EU Urban Agenda is not a mandatory document to adhere to; nevertheless, it serves as an action plan that countries can adopt to promote a more circular economy. The Urban Agenda for the EU ensures that the challenges faced by urban areas are considered in EU regulations, funding, and knowledge exchange. The "better regulation" aspect aims at creating legislation that is coherent and effective, providing tools for revising existing laws to meet urban needs. The "better funding" component focuses on evaluating best practices and the efficiency of financing for urban regions, striving for optimal implementation of interventions in those areas. Finally, the "better knowledge" element is tasked with disseminating acquired knowledge and successful practices among stakeholders. The collection of reliable data is crucial as it can accurately represent the realities of urban regions, enabling urban authorities to customize solutions for significant challenges [24].

In 2020, the European Commission adopted the New Circular Economy Action Plan (CEAP), which serves as a key document within the framework of the European Green Deal, emphasising the following points:

- Creating sustainable products for the EU market;
- Targeting sectors with the greatest potential for circular practices: electronics, batteries, transportation, packaging, plastics, construction, food, and water;
- Minimising the amount of waste produced;
- Making circularity appealing for communities, regions, and cities to facilitate easy adoption;
- Taking a leading role in the movement towards a circular economy [25].

Directive on repair of goods – for manufacturers of products that can be repaired are obligated to have opportunities for repairing those products in a reasonable timeframe and cost. This directive supports the enforcement of the Ecodesign Directive and the Regulation on Ecodesign for Sustainable Products, and member states are required to implement at least one initiative that encourages repairs within their jurisdictions [26].

The EU directives regarding urban wastewater treatment establish obligatory standards [27]:

- Nations are required to collect and treat wastewater in urban regions with a population of at least 2000 residents and to implement secondary treatment processes for the wastewater collected;
- Advanced treatment must be conducted in urban areas with populations exceeding 10,000 inhabitants situated in sensitive regions (areas that could soon face eutrophication if no measures are undertaken);
- It is essential to ensure that wastewater treatment facilities are properly maintained and operate effectively under typical weather conditions;
- In times of extreme weather, pollution from stormwater overflows must be controlled;

– Regular monitoring of the performance of treatment facilities and the volume of water processed is compulsory;
– The disposal and re-use of sewage sludge must also be monitored.

In 2026, a new Circular Economy Act from the EU is set to introduce additional requirements as it emphasises obligations related to the right to repair, mandates criteria for green public procurement, proposes standards for sustainable product design, seeks to improve consumer information, and aims to implement stricter waste management regulations. Additionally, it will revise the EU WEEE Directive 2012/19/EU, concentrating on four primary challenges: collection, recovery of essential raw materials, extended producer responsibility, and waste treatment.

Under the Waste Framework Directive, aligned with Sustainable Development Goal target 12.3 (from goal 12 – promote sustainable consumption and production patterns), member states must decrease food waste by the conclusion of 2030 [28]:

– By 10 percent for processing and manufacturing;
– By 30 percent (per capita), through a combined assessment of retail and consumption involving households, food service providers, and restaurants.

1.3.3. Sustainable development goals

The 2030 Agenda for Sustainable Development consists of international development objectives set for the period from 2016 to 2030, and this agenda was adopted by the United Nations during the Sustainable Development Summit in 2015. The objectives aim to inspire action on issues related to inequality, poverty, environmental protection, justice, health, and prosperity, and the goals that are significant for circularity in urban areas emphasise clean water and sanitation, with a target aimed at reducing water pollution. For the decent work and economic growth objective, it is crucial to enhance economic growth while minimizing the environmental impacts of economic activities. Target 9.4, which pertains to industry, innovation, and infrastructure, focuses on processes and innovations that promote sustainability in both industry and infrastructure, and Goal 11, which pertains to sustainable cities and communities, is particularly vital for urbanised regions, as it strongly emphasises creating sustainable cities by addressing not only environmental factors but also social and economic dimensions. Another critical goal is Goal 12, which focuses on responsible consumption and production, encompassing targets aimed at promoting environmental awareness, encouraging businesses to release sustainability reports, and reducing pollution and waste generation, and the sustainable development goals that are under focus for this work include [29]:

Table 4. Sustainable development goals [29]

Goal	Target	Indicators
6. Clean water and sanitation	6.3. By the year 2030, enhance water quality by decreasing pollution, stopping illegal dumping, and reducing the discharge of harmful chemicals and materials, cutting the share of untreated wastewater in half, and significantly boosting recycling and the safe reuse of water worldwide.	The percentage of household and industrial wastewater that is treated safely. The percentage of water bodies that have satisfactory ambient water quality.
	6.b. Back and empower local communities to take an active role in enhancing the management of water and sanitation services.	Percentage of local administrative units that have developed and implemented policies and procedures for involving local communities in the management of water and sanitation.

Goal	Target	Indicators
8. Decent work and economic growth	8.4. Gradually enhance global resource efficiency in consumption and production by 2030, and aim to separate economic growth from environmental harm, in line with the 10-year Framework of Programmes on Sustainable Consumption and Production.	Material usage, material usage per person, and material usage relative to GDP. National material use, national material use per person, and national material use to GDP.
9. Industry, innovation, and infrastructure	9.4. By 2030, enhance infrastructure and adapt industries to become sustainable, ensuring improved resource-use efficiency and a higher adoption of clean and environmentally friendly technologies and industrial processes.	Carbon dioxide emissions for each unit of value created.
11. Sustainable cities and communities	By 2030, ensure that everyone has access to transportation options that are safe, affordable, accessible, and sustainable, with a focus on enhancing road safety, particularly through the growth of public transport.	The percentage of the population that has easy access to public transportation.
	11.3. By the year 2030, improve inclusive and sustainable urban development and strengthen the ability for participatory, integrated, and sustainable planning and management of human settlements.	The comparison between the rate of land use and the rate of population. The percentage of cities that have a civil society participation framework in urban planning and management that functions consistently and democratically.
	11.6. By the year 2030, aim to lessen the negative environmental impact per person in urban areas, particularly focusing on air quality as well as the management of municipal and other types of waste.	The share of municipal solid waste that is collected and processed in regulated facilities compared to the total municipal waste produced in various cities. Average annual concentrations of fine particulate matter (such as PM2.5 nd PM10) in urban areas, adjusted for population.
	11. a. Foster beneficial economic, social, and environmental connections among urban, peri-urban, and rural regions by enhancing national and regional development strategies.	The quantity of nations that possess national urban policies or regional development strategies that (a) address changes in population, (b) promote balanced territorial development, and (c) expand local fiscal capacity.
12. Responsible consumption and production	12.2. Attain sustainable management and effective utilisation of natural resources by the year 2030.	Material footprint, material footprint per person, and material footprint per unit of GDP. Domestic material use, domestic material use per person, and domestic material use per unit of GDP.
	12.3. By the year 2030, the aim is to reduce per capita global food waste at both the retail and consumer levels by 50% while also decreasing food losses throughout production and supply chains, including those occurring after harvest.	Food loss index and Food waste index.
	12.5. By the year 2030, aim to significantly decrease waste production by focusing on prevention, reduction, recycling, and reuse.	The rate of recycling at the national level is measured by the tons of materials that have been recycled.
	12.6. Urge businesses, particularly large and multinational corporations, to embrace sustainable practices and incorporate sustainability information into their reporting processes.	The number of companies releasing reports.
	12.8. By the year 2030, guarantee that all individuals possess the necessary information and understanding	The degree to which global citizenship education and education for sustainable development are integrated into national

Goal	Target	Indicators
	for sustainable development and lifestyles that are in sync with nature.	education policies, curricula, teacher education, and student assessment.
13. Climate action	13.3. Enhance education, increase awareness, and strengthen human and institutional capabilities regarding climate change mitigation, adaptation, impact reduction, and early warning.	The level to which global citizenship education and education for sustainable development are incorporated into national education policies, curricula, teacher education, and student assessment.

1.4. Examples of circular cities

Circular cities implement circularity projects across the urban areas in different fields, for example, Amsterdam focuses on 7 different areas, while Paris focuses on the construction sector and food waste, and Osaka is implementing extraordinary waste sorting initiatives.

1.4.1. Amsterdam, The Netherlands case

Amsterdam is widely recognised as a leader in circular economy practices, as the city began its journey towards becoming circular in 2015 when it launched a "Circular Economy Action Plan." The aim of the "Circular Economy Action Plan" initiative is to achieve a fully circular economy by the year 2050, and to facilitate this goal, the city has outlined seven key focus areas: construction, electrical equipment, office supplies, food waste, plastics, textiles, and organic waste. As a trailblazer in the circular city movement, Amsterdam sets a benchmark for other cities by showcasing effective practices.

The projects initiated in Amsterdam are detailed below (Table 5), aligning with the ReSOLVE model, which includes:

Table 5. Circular city principles from the ReSOLVE framework [30]

Letter	Circular city principle	Top–down example	Bottom–up example
Re	Regenerate	Green spaces for biodiversity, rooftop solar panels	Urban farming, electric and biogas-fuelled mobility
S	Share	Policy for the support of the collaborative economy, tax for encouraging sharing	Car and appliance sharing, repair, and reuse
O	Optimise	LED as city lighting, renovating old buildings	Smart communities, smart grids
L	Loop	Waste separation and recycling, bio-based economy	Upcycling initiatives, community recycling initiatives
V	Virtualise	A paperless municipality, virtualisation of public libraries, and autonomous public transport	Citizen-science climate monitoring
E	Exchange	Circular construction materials, electric-powered public transportation	Organic and local markets, eco-fashion

Many of these initiatives (Fig. 7) in Amsterdam target all relevant sectors, with some addressing every aspect of the ReSOLVE model. For instance, the Circle Economy City Scan serves as a knowledge development initiative in which a circular economy consultancy assessed existing waste and resource flows, pinpointing areas with the greatest potential for improvement. Other implemented projects focus on construction, such as the Circular Area Buiksloterham real estate development, where stakeholders collectively agreed to apply circular economy solutions wherever feasible. Additionally, experimentation free-zones for living labs have been established, allowing partners to test innovative approaches in waste collection, water treatment, and other environmental domains under newly created legislative "free-zones."

	Re	S	O	L	V	E	
A1: Circular Economy City Scan				●			Knowledge Development
A2: City Dashboard					●		Knowledge Development
A3: Pakhuis de Zwijger	●	●	●	●	●	●	Knowledge Development
A4: AMS Institute	●	●	●	●	●	●	Knowledge Development
A5: Construction Green Deal				●		●	Collaboration Platforms
A6: Circular Area Buiksloterham	●	●	●	●	●	●	Collaboration Platforms
A7: Metro Region Amsterdam Industrial Park	●	●	●	●	●	●	Collaboration Platforms
A8: The Ceuvel Sustainable Community	●	●	●	●	●	●	Collaboration Platforms
A9: Amsterdam Smart City			●				Business Support Schemes
A10: Sustainability Fund	●	●	●	●	●	●	Business Support Schemes
A11: Amsterdam Economic Board	●	●	●	●	●	●	Business Support Schemes
A12: CTO Office Start-up in Residence	●	●	●	●	●	●	Business Support Schemes
A13: Sharing Economy Legislation		●					Regulatory Framework
A14: Retrofitting			●			●	Procurement & Infrastructure
A15: Alliander Smart Grid			●			●	Procurement & Infrastructure
A16: District Heating				●			Procurement & Infrastructure
A17: "Free-zones" Living Labs	●	●	●	●	●	●	Regulatory Framework
A18: Building Renovation Standards			●			●	Regulatory Framework
A19: Circular Procurement						●	Procurement & Infrastructure
A20: Household Waste Plan				●			Procurement & Infrastructure

Fig. 7. Initiatives identified in Amsterdam [30]

Amsterdam's city administration is dedicated to adhering to the following principles:

- There will be no waste; all materials should remain within technological or organic cycles;
- Energy will be sourced entirely from renewable sources;
- Natural resources are utilised to generate both economic and non-economic benefits;
- The flexible design of products and supply chains will support adaptation of the new system;
- New business models will be employed in production, distribution, and consumption sectors to shift from ownership to service-based models of providing products;
- Human activities should enhance ecosystem services, contributing to the regeneration and preservation of "natural capital" [5].

1.4.2. Paris, France case

Paris is committed to a city-regional strategy for circular economy, particularly concerning construction materials, food (ranging from urban agriculture to bio-waste), and waste management. Since 2014, Paris has implemented strategic initiatives for reusing materials from construction sites and buildings, and the city has also embraced temporary planning permissions to facilitate pop-up activities, such as urban farming. Furthermore, a gray-water recycling system is in place, which allows the municipality to utilise 98 percent of collected gray water for public infrastructure maintenance.

The circular food system is another critical focus area, with numerous initiatives aimed at food redistribution in Paris, as legally mandated food reuse has led to the establishment of food reuse cafes and community fridges. By prioritising the necessity of feeding the underprivileged, the city has developed rooftop urban gardens, and although Paris had set a target of achieving 100 hectares of greenery by 2020, it reached 30 hectares by 2023. Nonetheless, it remains a frontrunner in urban gardening, thereby increasing the city's capacity for growing fruits and vegetables, and any surplus food that isn't reused is converted into biogas, contributing to residents' local energy supply [31]. In 2015, France enacted a legal requirement regarding food waste, stipulating that supermarkets with over 400 square meters of retail space are prohibited from discarding food approaching its best-before date and must instead donate it. Non-compliance with this law could result in fines of up to 75,000 euros or two years in prison for supermarket operators [5].

1.4.3. Osaka, Japan case

Osaka, located in the Soo District of Kagoshima Prefecture, has implemented an "Osaka Recycling System" that has achieved an impressive 83.1 per cent recycling rate through its separation, collection, and processing approach. The community is also environmentally conscious, with residents separating 27 different types of products, and the city aims to eliminate single-use plastics entirely by 2030 [32].

Osaka began its initiative in 1998 after recognising that relying on landfill disposal was no longer sustainable due to imminent overcapacity, due to this, the city faced three options: constructing an incinerator, establishing a new landfill, or extending the lifespan of the existing landfill. Given the high costs associated with an incinerator and substantial community opposition to a new landfill, the only viable choice was to enhance the efficiency of the current landfill.

This system's success hinges on the cooperation among residents, businesses, and local governance, as initially, individuals separate their waste into the 27 designated categories and deliver it to collection stations, then the recycling center examines the waste before categorising it as a "product." With food waste constituting 24.5 per cent and wood waste making up 39.4 per cent of the total, both types are processed into compost [33].

To motivate the community for its commitment to achieving a waste-free environment, a portion of the revenue generated from selling recycled materials is allocated to provide scholarships for students who cannot afford tuition, as well as gift certificates redeemable at local businesses for all residents [33].

Osaka serves as an excellent model for not just consuming and creating goods, but also for taking an extra step by recycling its waste to transform into a circular city that engages the entire community.

1.5. Urban Metabolism Analyst (UMAn) model

The Urban Metabolism Analyst (UMAn) model provides a structured approach to analysing complex systems, aiding in the identification of resource usage and evaluating efficiency. It is based on the concepts of urban metabolism and material flow analysis, both of which have limitations due to the extensive data required without insights into environmental impacts arising from processes that occur outside city or system boundaries (such as transportation, end-of-life disposal, extraction, and production). Therefore, UMAn focuses not only on the flow of resources and products but also on the environmental consequences accompanying these flows. The UMAn framework has advanced urban metabolism research by [34] :

- It builds upon economy-wide material flow accounts (EW-MFA), which are appropriate for EU regions and cities, establishing a comprehensive MFA-based methodology;
- There are 28 harmonised material types assigned to different product compositions, expanding the categorisation of material types;
- Data are categorised by distinct economic sectors and different life cycle phases of products, providing insights into the origins and destinations of the flows being analysed.

The model consists of 4 distinct steps, derived from the EW-MFA model [34]:

System boundaries – it is essential to consider two types of system boundaries. The first is the boundary between the economy and the natural environment, where inputs and outputs must be analysed, particularly in areas like domestic extraction, and the second boundary to examine is that which separates different economies, such as imports and exports. It is important to clearly define the system boundaries not only on a city, regional, or national level but also in relation to specific geographical areas, as various data may be significant for different locations.

Compilation and processing of data – the primary tables required for data gathering include the domestic extraction of key sectors within the area, international trade (comparing the volume of imports into the region with imports to the rest of the country, and the same for exports), inter-regional trade between the analysed area and the rest of the country (considering modes such as road, rail, air, and water), and industrial production (data related to manufactured goods within each industry sector is utilised to model product transformation). Additional tables can be included to enhance the understanding of the area, such as the number of employees and residents within the analysed region.

Analysis of data and classification by material type – the data undergoes analysis to gain insights into the resource flows within the area, and domestic material inputs in the area are estimated alongside all accessible resources. Additionally, resources are examined through their life-cycle phases (whether they are intermediate products or final products), and a scenario is created to model how intermediate products will evolve into final products within the economy and during the consumption phase. Finally, using the UMAn method, domestic material consumption is categorised according to various material types.

Calculation of indicators – one must sum the domestic extraction and imports to determine the direct material input. Additionally, the process of transforming the intermediate product into the final product is performed using data from industrial production. Subsequently, domestic material consumption is established by considering the final products while excluding exports.

This method provides insights into where the largest resource flows are concentrated within the analysed region and how these flows affect the area, such as the quantity of waste generated in various sectors and the environmental impacts of transportation.

2. METHODOLOGY OF RESEARCH

In this section, the used methods for the research are described, such as material flow analysis, cost allocation analysis, life cycle assessment, and the discussion and feedback method.

2.1. Methods used for research

During research various programs were used, such as Microsoft Excel, STAN 2.7.101, CCaLC2 and the meeting with public organisations where a discussion and feedback are received , and the methods used are described below (Fig. 8):

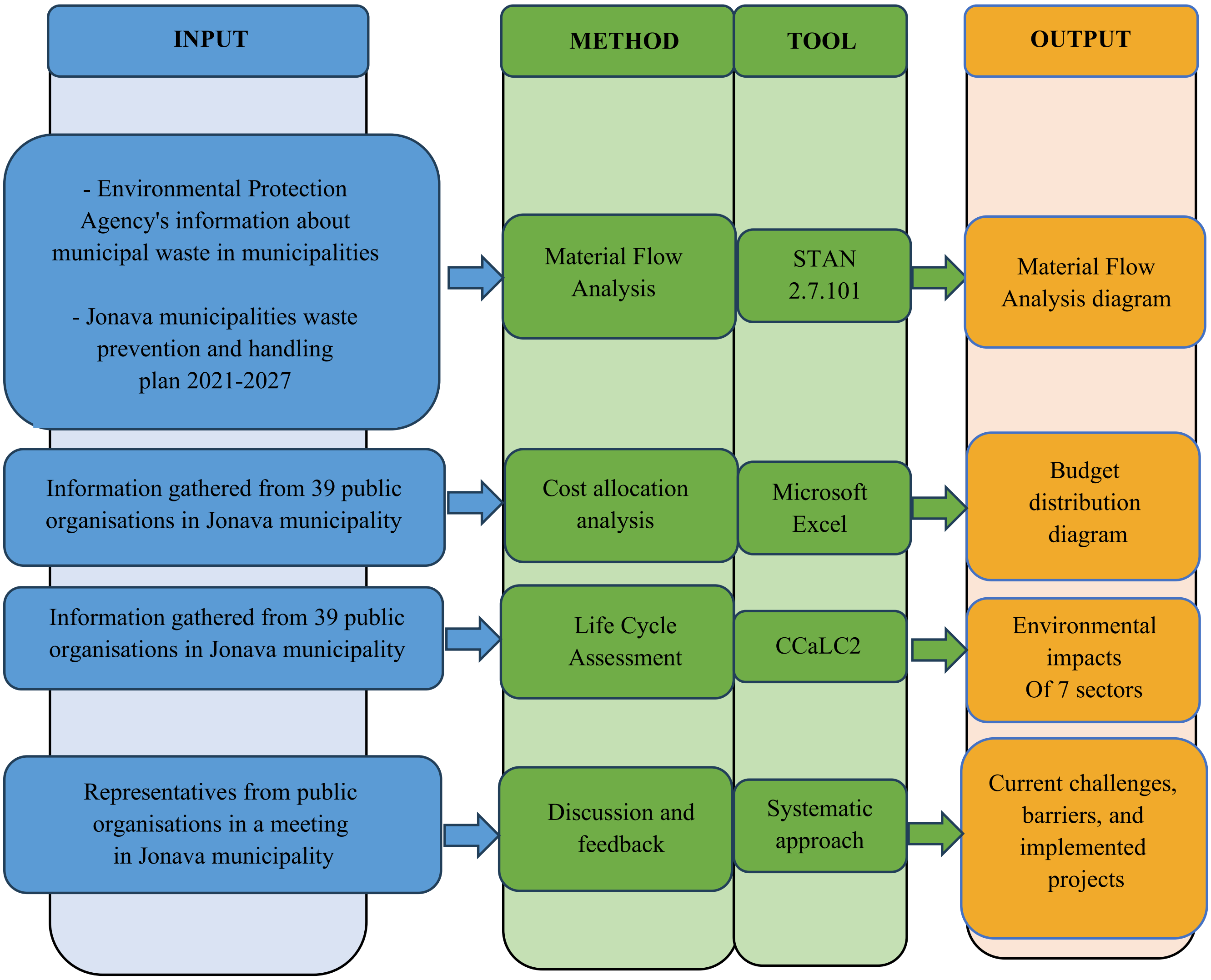

Fig. 8. Methodology of Jonava municipality's environmental assessment

Microsoft Excel is a spreadsheet editor with features for calculating, computation, pivot tables, and many other applications, as it is possible to analyse large amounts of data by adding and multiplying the needed values and depicting them in graphical charts, which helps research paper readers better understand the provided material.

The cost allocation method is valuable for examining how costs are distributed across various entities, including products, projects, services, and more. This method entails pinpointing the relevant costs and deciding how they should be allocated, which helps organisations identify areas with the highest expenses, thereby enhancing accountability and financial discipline.

The software STAN is created to perform material flow analysis, which is an application in waste management, and STAN enables the users to build graphical models with adding different components (processes, flows, system boundary, text fields, etc.). To work efficiently with the program, the necessary inputs and outputs need to be known, which can be added as mass flows, stocks, concentrations, and it can be done at the different layers (good, substance, energy), and one of the graphical benefits of the software is that all the flows can be displayed in a Sankey-style, which shows the biggest flows in wider lines.

The material flow analysis is a method used to illustrate the balance of material and energy flows, as it helps identify inefficiencies and opportunities for optimizing resource use, thereby enhancing efficiency. MFA consists of a systematic evaluation of material and inventory flows, which is based on the principles of mass balance while considering the limitations of space and time.

A discussion is a method used to explore the ideas of an analysed group, where the key features are active participation of the attendants, as their opinion is crucial to receive, and everyone is encouraged to contribute to the discussion. During this discussion, different opinions regarding different topics can be found, and it is beneficial, as it increases the engagement and motivation of the participants. It also helps the participants think about the topics, they might not have considered before.

A feedback method is an approach used to give a constructive response to someone's performance or results in order to make improvements. It is important that the feedback is specific, as it is of interest that the receivers of the feedback understand what is being addressed. It also needs to be constructive, as the aim of feedback is to encourage growth and not only to point out flaws. Besides that, the feedback needs to be respectful, therefore a professional outlook needs to be maintained.

The methodology makes it possible to understand the problem and possible solutions through the economic, environmental, and social aspects of the Jonava municipality.

2.2. Life cycle assessment methodology

The life cycle assessment is a method that enables users to analyse environmental impacts throughout the whole life cycle of a product, and it consists of 4 stages (Fig. 9):

– Goal and scope definition;
– Inventory analysis;
– Impact assessment;
– Interpretation [35].

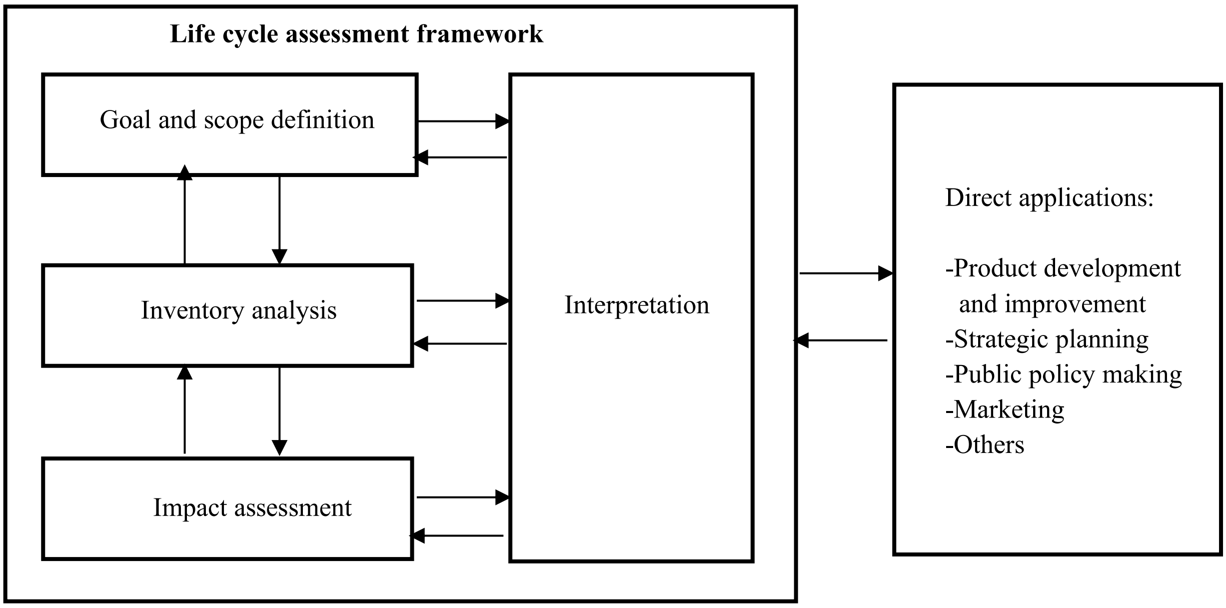

Fig. 9. Four stages of life cycle assessment under the ISO 14040 guidelines

2.2.1. Goal and scope definition

The first stage of life cycle assessment is the Goal and Scope phase, where information regarding what, why, how, and for whom the LCA is being performed. The goal needs to be clearly defined, why the LCA is being conducted, and who will benefit from it (for example, the public, government, customers, etc.). During this phase the scope of the work is also defined, which shows how broad or narrow the LCA will be:

- Functional unit – a quantifiable unit in which it is possible to measure the impact;
- System boundaries – the definition of what will be assessed and what will not (for example, Cradle-to-Gate, Cradle-to-Grave, or Cradle-to-Cradle)

2.2.2. Inventory analysis

Inventory analysis is the second step, where all the environmental inputs and outputs are gathered about the product or service, which are needed to reach the described goal, and within the scope. The environmental input is something that is taken from the environment and added to the product or service, for example, the use of water or raw materials, and the environmental outputs are something that the product puts into the environment during its life cycle, like emissions of pollutants and waste. From the inventory data, it is possible to see the complete picture of the product's life cycle, and during this phase, critical information regarding further steps is collected.

2.2.3. Life cycle impact assessment

During life cycle impact assessment, potential environmental impacts are modeled from the gathered inventory analysis data, and during LCIA, the inputs and outputs are multiplied by factors, which convert them to the common unit by the analysed impact category. Details of the categories of environmental impacts evaluated in the research are described below.

a. <u>Global Warming Potential (GWP)</u>

GWP, alternatively known as Carbon footprint, is the measure of the amount of carbon dioxide released into the atmosphere due to the activities for which humanity is responsible, and GWP emissions have a variety of sources – transportation, energy, food, textiles, waste, etc. Carbon dioxide equivalents (kg CO_2-eq.) are used for gases other than CO_2 as the unit of GWP.

b. Acidification Potential (AP)

The AP is associated with processes that form acidity in the environment, such as soil, water, and air, and compounds that have an acidification potential include sulfur dioxide (SO_2), nitrogen oxides (NO_x), nitrogen monoxide (NO), nitrogen dioxide (N_2O), and other substances. AP usually has the sulfur dioxide equivalent (kg SO_2 -eq.) as its unit.

c. Eutrophication Potential (EP)

EP refers to the process of overstimulating nutrients to water bodies, which leads to excessive plant growth, as phosphates and nitrates are produced in the water, and it becomes polluted. When there is an excess of nutrients, algae grow rapidly, which depletes the available oxygen in the water. The unit for EP is usually the phosphate equivalent (kg PO_4 -eq).

d. Photochemical Ozone Creation Potential (POCP)

POCP corresponds to quantifying emissions, which can contribute to low-level smog, as POCP is created when nitrogen dioxide reacts with volatile organic compounds in the presence of ultraviolet light. The air emissions are created, and the sunlight converts those air emissions to photochemical smog, and the formed smog is very dangerous to health and the environment. The unit, which is used to calculate the POCP, is ethene equivalent (kg C_2H_4 -eq.)

e. Ozone Depletion Potential (ODP)

ODP is the depletion of the upper layer of the atmosphere, and tt measures how much damage can be done from chemicals to the ozone layer compared to the similar mass of trichlorofluoromethane (CFC-11). Ozone depletion potential is caused due to human activities from halogen source gases that contain chlorine and bromine atoms. The unit, which is used to calculate ODP, is kg CFC-11 -eq.

f. Human Toxicity Potential (HTP)

HTP is a measure of potential harm to human health from certain substances that get through ingestion, inhalation, or dermal exposure, and it is calculated based on the known substance characteristics and their ability to cause harmful effects. The unit of HTP is kg 1,4 dichlorobenzene eq.

3. RESULTS OF JONAVA MUNICIPALITIES' PUBLIC ORGANISATIONS' ENVIRONMENTAL ASSESSMENT

After the literature analysis was conducted to comprehend the legal obligations and the current landscape of best practices globally, as well as the conditions within Jonava municipality regarding its environmental impacts, the practical part of the research was done using Microsoft Excel, STAN 2.7.101, CCaLC2 softwares, and a discussion and feedback method.

Information about material and energy inputs and outputs was gathered from public organisations for the year 2023, and this data was examined using the Microsoft Excel program to identify the most significant influences by sector, product quantities, and the largest contributing areas.

The STAN 2.7.101 software was utilised to assess waste distribution in the municipality, as waste directly correlates to the circularity of the urban environment, and with the STAN 2.7.101 program, it is possible to illustrate the various waste flows collected in Jonava municipality along with the amounts that were treated or sent to landfills. The results obtained reflect the municipality's environmental awareness and its potential for reducing waste generation.

The CCaLC2 program is employed to further analyse material and energy inputs and outputs through an environmental lens, as the quantities of products purchased, as well as the consumption of water, heat, and electricity, were examined concerning their environmental impacts. This analysis provides insight into which sectors have the most significant effects on the environment. Subsequently, the focus shifted to products and waste, as this information could more accurately illustrate possible daily modifications that companies could implement to lessen their environmental impact, since reducing electricity or heating usage may entail substantial expenses.

Another analysis was made using the discussion and feedback session with the public organisation representatives. Public organisations in Jonava municipality discussed what are their current challenges and opportunities regarding the urban circularity implementation. This information is helpful to understand what can be possible to do in the municipality and what may not be at the moment.

In this research, 39 organisations from the Jonava municipality were examined and categorised into seven sectors: public governance, education, culture, social services, health, sports, and municipal services. Public organizations were selected because their material and energy flows could be measured more accurately, and additionally, this demonstrates to the community that the governance is concerned about the environment, which may enhance their sense of inclusion. The organizations that were examined are depicted below (Table. 6):

Table 6. List of analysed public organisations in Jonava municipality

No	Sector	Public organisation (coded)	Public organisation
1	Public governance	Municipality administration	Jonava district municipal administration
2		Municipality control and audit office	Jonava District Municipality Control and Audit Service
3		Education support service	Jonava district education support service
4	Education	School	Jonava Primary School
5			Jonava Panerio Primary School

No	Sector	Public organisation (coded)	Public organisation
6			Jonava “Neries” Primary School
7			Jonava “Lietava” Primary School + Upninkai department
8			Jonava “Neries” Primary school’s department for the Education of Children with Special Needs
9			Jonava Raimundo Samulevičiaus progymnasium
10			Jonava Old Town Gymnasium
11			Jonava Justinas Vareikis progymnasium
12			Jonava Jeronimo Ralio gymnasium
13			Jonava district Šveicarija school
14		School – multifunctional centre	Bukonių school – multifunctional center
15			Rūkla Jonas – Stanislauskas school – multifunctional center
16			Žeimių school – multifunctional center Jonava district. Žeimių school – multifuctional center Barupė branch
17		Art school	Jonava Janina Misčiukaitė Art school
18		Kindergarten	Jonava kindergarten “Pakalnutė”
19			Jonava kindergarten “Žilvitis”
20			Jonava kindergarten “Bitutė”
21			Jonava kindergarten “Dobilas”
22			Jonava kindergarten “Lakštingalėlė”
23			Jonava kindergarten “Saulutė”
24	Culture	Library	Grigorijus Kanovičius public library of Jonava district
25		Culture centre	Jonava culture centre
26	Social	Social services centre	Jonava district social services center
27		Activity centre for people with disabilities	Jonava district activity center for the disabled
28		Temporary care housing	Jonava’s homeless shelter
29			Jonava’s elderly care home
30		Public healthcare office	Public Health Office of Jonava District Municipality
31	Health	Primary healthcare centre	Jonava Primary Health Care Center
32		Hospital	Jonava hospital
33	Sport	Sport centre	Jonava sports center
34		Swimming pool	Jonava swimming pool
35	Municipal services	Water Supply	Closed joint-stock company “Jonava Water”
36		Fire service	Jonava district fire service
37		Public transport	Jonava Buses

No	Sector	Public organisation (coded)	Public organisation
38		Heating	Closed joint-stock company “Jonava heating networks”
39		Cleaning and maintenance	Closed joint-stock company “Jonava services”

3.1. Material flow analysis of waste in Jonava municipality

Jonava municipality belongs to the Kaunas region waste management centre, and as reported by the Environmental Protection Agency, Jonava municipality produced a total of 12 thousand tons of waste in 2023, which is depicted in the diagram below (Fig. 10), from which 10 thousand tons were collected as mixed municipal waste [36]. From this amount, 4 600 tons were incinerated to generate energy, resulting in the production of 3.35 GWh of electricity and 8.19 GWh of heat, based on the statistics of the burned waste to energy ratio from the overall generation [37]. Regarding biological waste, food waste comprised over 1 000 tons, making up 9% of the overall waste generated in the municipality [38], and the total biological waste collected amounted to over 4 600 tons, which was biologically treated to produce technical compost that is used in the landfill. If technical compost is not considered as waste, then only 187 tons of waste are landfilled, which is 1.55% of the total waste; however, if technical compost is considered as waste, then 38.8% of the waste is landfilled. From the total collected waste, around 2 thousand tons are brought back into the market after recycling.

The collected mixed municipal solid waste from Jonava municipality is brought to Kaunas region mechanical biological treatment facility, where waste from the mechanical treatment can be separated and brought to recycling of secondary materials (735 tons), and what is not possible to recycle goes to biological treatment (4 670 tons), incinerator (4 652 tons), or are being landfilled (20 tons). Other waste is collected through designated systems, for example, sorting containers. The amounts of sorted waste brought back to market materials are difficult to assess, as the municipality does not provide such values, therefore, there is a gap in knowledge about the waste management system.

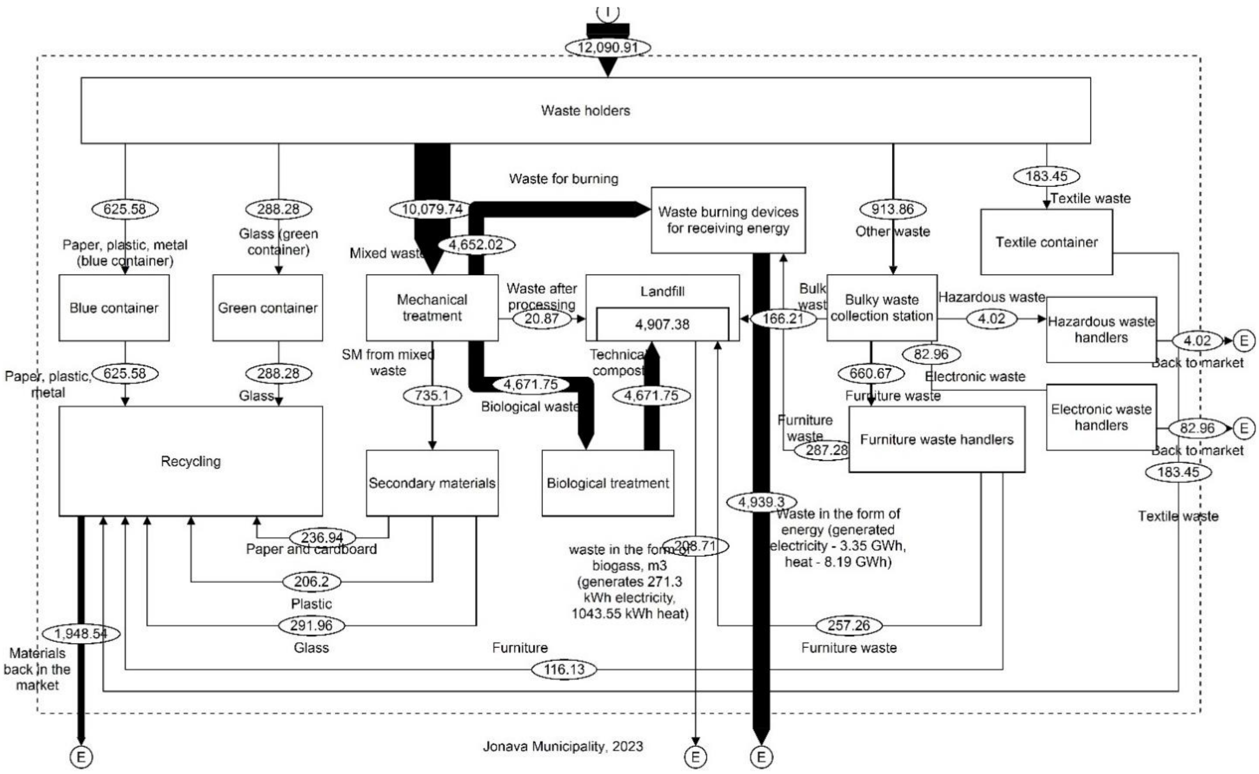

Fig. 10. MFA of Jonava municipality waste management system, 2023

3.2. Budget distribution across distinguished sectors

The overall budget of each organisation was distributed according to their expenses for all bought products, fuel, energy, water, waste, and wastewater treatment for the year 2023 (Fig. 11), and the largest share of the overall budget was distributed to the "Products", "Energy", and "Fuel" categories. The Education sector had the largest budget, with 20 organisations out of the 39 analysed, and around 2 000 000 euros are distributed to the products category in the Education sector, then the second largest share of the budget is for the energy (heating and electricity), and in third place it is the fuel.

In second place regarding the budget, it is the Municipal services sector, as the highest share of the budget for Municipal services is due to energy and fuel, because in this sector, there are public organisations that strongly rely on fuel due to their job descriptions, for example, Jonava buses and Jonava services. The strong reliance on energy is due to companies such as Jonava heating networks and Jonava waters.

In the third place, it is the Sports sector, where a large portion of the budget is distributed to the energy consumption, due to the companies as Jonava swimming pool. The second largest share is for the purchased products, and other categories are not very relevant in terms of budget.

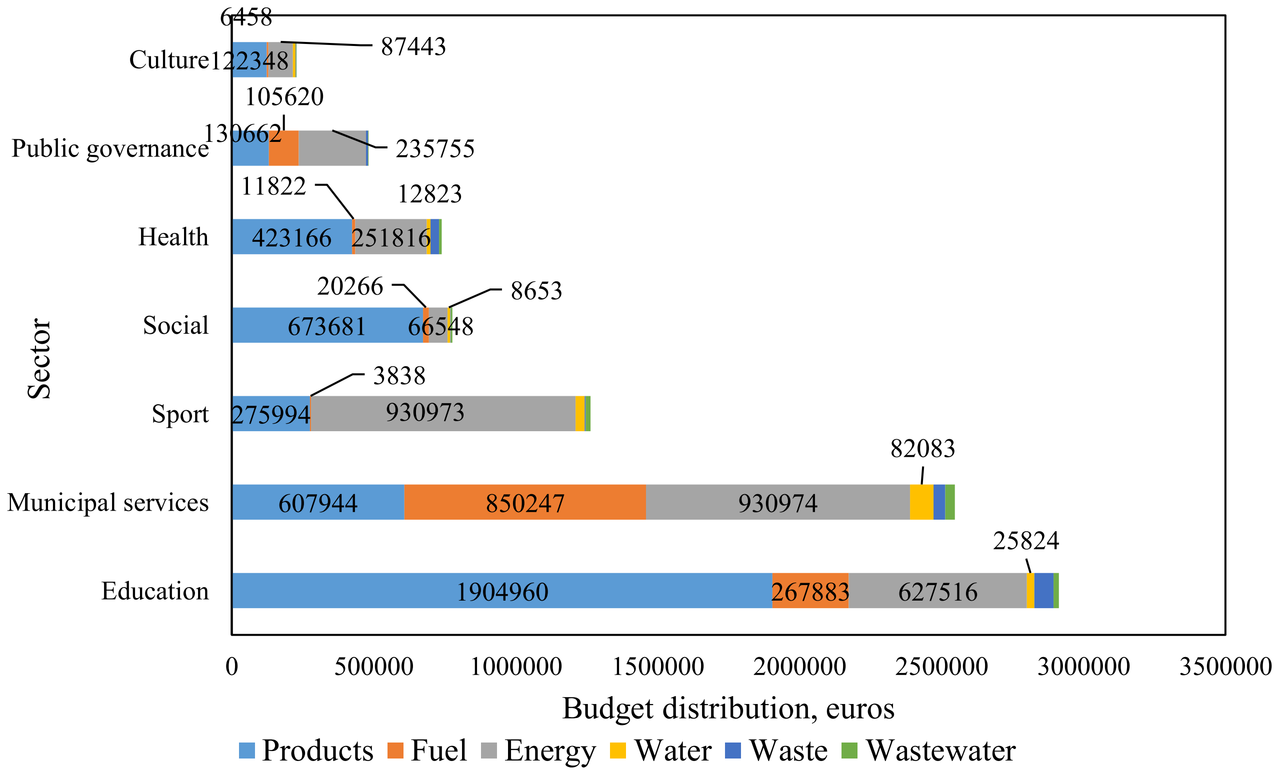

Fig. 11. Budget distribution across sectors in euros

For a better understanding of how the budget is distributed not only through different sectors but also through a single sector. It is seen that even 4 of the sectors (Fig. 12) use over half of their budget for the buying of products. The largest share of products is for the Social sector, as even 87% of the budget is used for this purpose, and the second largest distribution is for Education with 65%, and the two sectors with the most fuel distributed are the Municipal services, which had over 33% of their budget used for this purpose as it is one of neceseary elements in their jobs, and the Public governance, with over 22% of its budget. For the budget part that is used for energy, the highest distributor within a sector is Sport due to the Jonava swimming pool, and the Culture sector uses 30% of its budget; however, the Culture sector does not have huge other costs, therefore, the value for energy seems large. This information depicts that the overall budget is oriented toward the purchasing of products and consumption of energy, and the smallest amounts are for waste treatment, and water consumption.

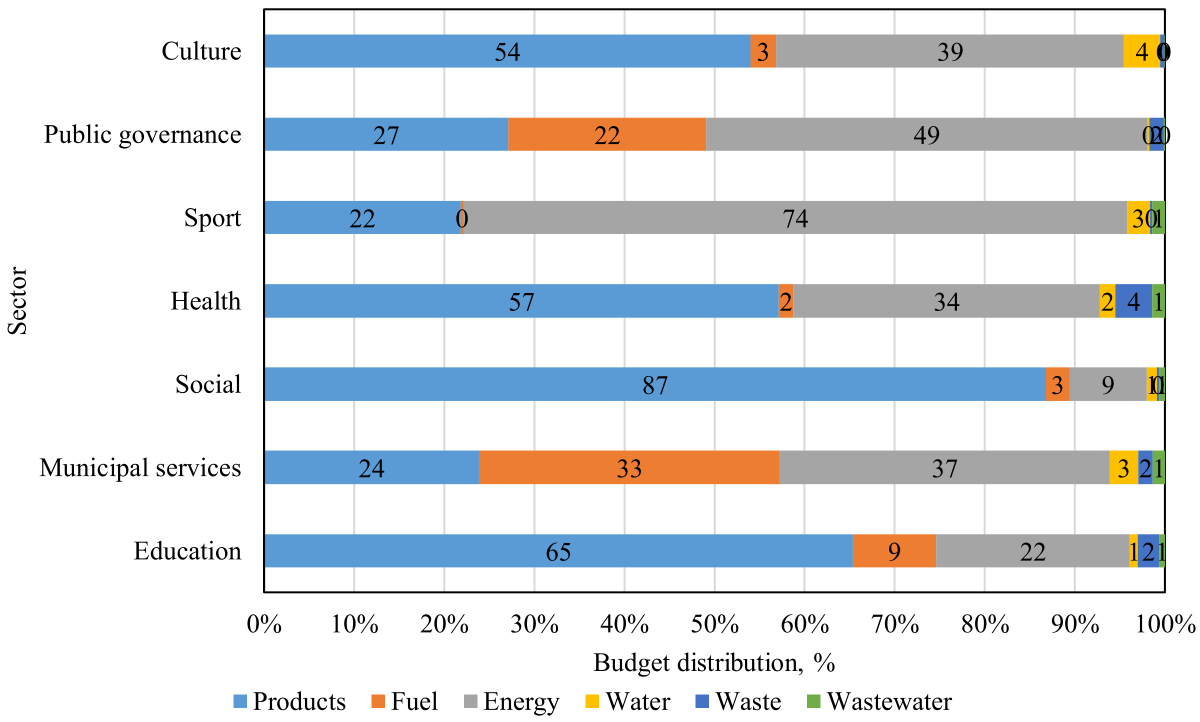

Fig. 12. Budget distribution across sectors, %

When not only new items are considered but the repairing category as well (Fig. 13), the Education sector takes more than half of the overall budget, and other sectors do not change their position by adding the budget for the repair category to the purchasing of items. The smallest amount that was given for repairs was for the Culture sector, which was 0.31% of the overall budget, and the Health sector did not reach 1% of its overall budget for repairs. The largest part of the budget for repairs was used for interior renovation, as all the sectors had a part used for interior renovation, except for the Culture sector, and the second highest amount is for the outdoor work category, which is the only sector that had such repairs was Education. This information shows that public organisations are not only purchasing new items, but are also interested in repairing what they already have, with the exceptionally high value for repairs in the Education sector.

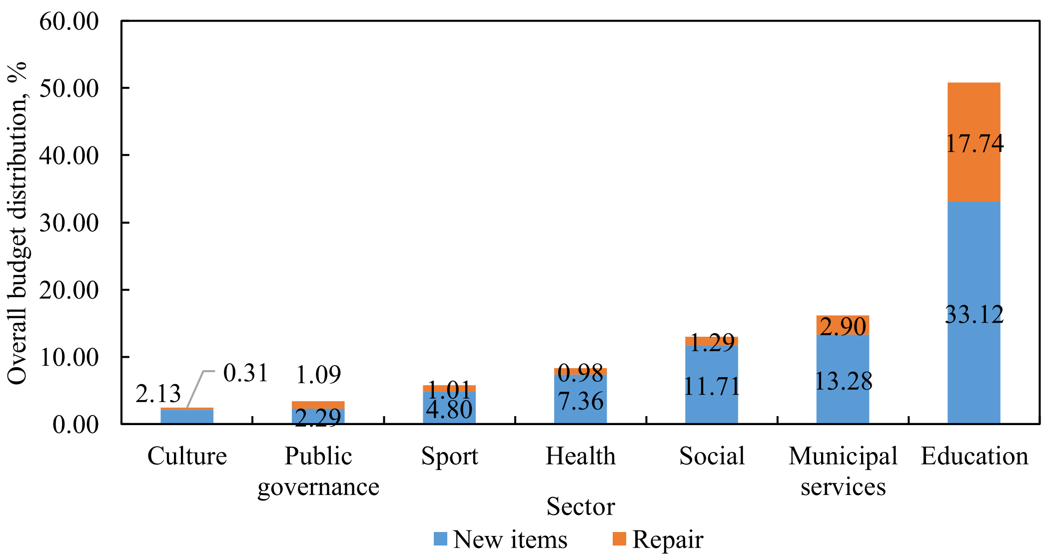

Fig. 13. Overall budget including repairs of Jonava municipality's public organisations sectors (%)

3.3. Life Cycle Assessment of Jonava municipality's public organisations

During the life cycle assessment of Jonava municipality, 39 public organisations' public procurement data are analysed to understand the sectors and categories in which the highest impact can be found, and recommendations for the most problematic areas are given to the municipality.

3.3.1. Goal and scope definition

The goal of this work is to analyse the environmental impact of Jonava municipality's public organisations and find the areas that can be modified to reduce the environmental impact. Identifying the major problematic areas is one of the first steps to obtaining a 100% waste-free municipality. To analyse the situation with LCA methodology, a functional unit must be defined. In this work, the functional unit is 1 sector's activity for the year 2023, and the system boundaries are cradle-to-gate.

3.3.2. Inventory analysis

The inventory consists of electricity, water, wastewater, heating, fuel, waste, and products bought in 2023 by each company; the data is collected through public procurement data provided by the public organisations.

Each of the sectors had different consumption of electricity, water, and heating in 2023, which drastically varied across the different analysed sectors. The environmental impact is calculated using the CCaLC2 program, and the values of environmental impact are chosen from the CCaLC2 database. For electricity, the data is set as low-voltage electricity from the Lithuanian grid, and heating as CHP-1 (combined heating and power), and for water the Econinvent database is used to identify the impact of tap water in Europe and for the wastewater treatment the Ecoinvent dataset for treatment of wastewater from sewage to the treatment of wastewater is chosen. The values of consumption of energy and water are shown in Table 7:

Table 7. Energy and water used in each sector, 2023

Sector	Heating, kWh	Electricity, kWh	Water, m^3	Wastewater, m^3
Public governance	580 032	952 565	1 176	1 176
Education	6 091 709	761 815	25 318	33 278
Health	1 697 560	597 036	12 572	18 597
Social services	426 151	166 547	8 483	9 134
Sport	2 702 693	3 772 339	31597	31538
Municipal services	717 942	4 374 873	80 474	60 837
Culture	778 230	133 710	8 980	232

The companies used different fuels as well, such as diesel, gasoline, biogas, and electricity, and for gasoline and diesel, the CCaLC2 dataset was used to identify the environmental impacts, and the LPG dataset was added from literature sources [39]. In the inventory provided by the public organisations, the units are in liters or m^3, and to have these weights in kilograms, the equivalents are chosen to calculate the environmental impact [40]:

- Gasoline, diesel: 1 litre = 0.84 kilogram;
- LPG: 1 m^3 = 0.70 kilogram;
- Electricity is added to the overall electricity consumption.

Amounts of fuel used are described below for each of the sectors (Table 8):

Table 8. Amount of fuel used in each sector, 2023

Sector	Diesel, l	Gasoline, l	LPG, m^3	Electricity, kWh
Public governance	17 980	50 021	-	-
Education	36 603	1 292	8 190	27 646
Health	3 380	4 885	-	-
Social services	6 302	7 762	1 660	-
Sport	1 197	1 466	-	8 291
Municipal services	581 156	27 310	-	246 000
Culture	2 499	821	-	-

Waste, when possible, was separated by different sources, for example, paper, electronics, and plastics, and the dataset source is Econinvent data V2.2 (2010), which was provided by the CCaLC2 program. The considered assumptions are that municipal waste was disposed of in the incinerator, and other sorted waste was recycled or shredded (in electronic waste), and another assumption is that if the value of waste was provided by the public organisation in m^3 and not kilograms, it was considered that 1 m^3 of municipal solid waste weighs 200 kg, of paper waste 300 kg, of food waste 350 kg, of electronic waste 170 kg, and plastic waste 21 kg [41]. The amounts of waste by different sectors are provided in Table 9:

Table 9. Waste formation by sectors in 2023

Sector	Municipal solid waste, kg	Paper waste, kg	Electronic waste, kg	Food waste, kg	Medical waste, kg	Plastic waste, kg
Public governance	28 992	19 440	1 040	-	-	-
Education	401 341	60 813	3 105	1 806		554
Health	97 118	-	-	347	13 542	-
Social services	20 994	4 360	452	19	232	-
Sport	55 526	-	-	-	-	-
Municipal services	74 457	8 359	365	-	-	-
Culture	11 616	-	-	-	-	-

Lastly, public organisations have provided information regarding all the products that were bought in the year 2023. The provided information is for the categories of food items, paper products, electronic devices, cleaning supplies, automotive, furniture items, stationary supplies, and other items that do not qualify for the other categories but the organisations believe to be important. Some of the products were excluded, as they hold little environmental impact compared to other products; therefore, they were not analysed in this work.

The following assumptions were made for each of the categories when calculating the amounts of products in kilograms when information was provided by the researched organisations in pieces instead of weight, or there was a lack of data in the CCaLC2 program (Table 10):

Table 10. Assumptions for calculations of kilograms in different categories

Category	Assumptions
Food and Beverages	- "Fruits and Vegetables" were provided as a sum; therefore, due to healthy eating proportions, it is assumed that the ratio is 1:4 for fruits and vegetables, respectively, data from CCaLC2; - "Natural water" is considered as bottled water, not tap water, according to data from CCaLC2; - "Meat Products" environmental impacts are assessed from a literature report [42]; - "Bread and Bread Products" environmental impacts are assessed according to a literature source [43]; - Other products and their environmental impacts are from the CCaLC2 program dataset.
Electronics	- "Air conditioner" is evaluated for 1 kWh of cold generated, and it is considered that it is used for 4 months in a year [44]; - "Smartphone" environmental impacts are used from a literature source, and the smartphone weight is considered as 227.73 g [45]; - "Electrical cable" information regarding environmental impacts is found in literature, 1 km of cable is considered to weigh 90 kg [46]; - "Tablet" is considered to weigh 0.946 kg, and information regarding environmental impacts is found in literature [47]; - "Lighting devices", the environmental impact of a lamp is found in literature, the weight of one item is 176 g [48]; - "Desktop monitor", the environmental impact can be found in the literature. The weight of the monitor is 3 kg [49]; - "Powerbank" environmental impact information from literature [50]; - Other device environmental impact is acknowledged from the CCaLC2 dataset.
Cleaning and Maintenance	- "Cleaners" are considered all liquid cleaning supplies in the public organisations given data, except for soap [51]; - "Gloves" are made from polyvinylchloride from the CCaLC2 dataset and a single glove weights 0.005 kg; - "Garbage bags" are made from polyethylene from the CCaLC2 dataset, and a pack of garbage bags weighs 300 g; - "Face mask" environmental impacts analysed from literature sources; the weight of a single mask is 45 g [52]; - "Single-use dishes" information regarding environmental impacts is described in a study report [53]; - "Sponges" are made from polyurethane and are 1-piece, weighing 20 g. - "Dishes" information regarding environmental impacts is described in the literature [54]; - Other products and their environmental impacts are chosen from the CCaLC2 program.
Paper	- "Toilet and tissue paper" – hygienic paper combined in one category, the environmental impact described in literature, the weight of paper towels 0.4 kg, toilet paper roll 0.2 kg, and tissue paper 0.002 kg; - "Paper" environmental impact is used from the CCaLC2 dataset, the weight of a single sheet is 4.7 g, consideration is given not only for printing paper, but for books as well (average book 200 sheets).
Automotive and Transportation	- "Passenger car", the environmental impact is described in literature, the weight of one passenger car is 1415 kg [55].
Furniture	- "Cabinets" environmental impact information can be found in the literature [56]; - "Soft furniture" environmental impact found in literature; weight is 62 kg [57];

Category	Assumptions
	- "Bedding" environmental impact information is found in literature, considered to be made from cotton, and the weight of one piece is 1.6 kg [58]; - "Mattress" weight is 30 kg for one piece, and the environmental impacts found in the literature [59]; - "Carpet" weight is 27 kg for one piece, and environmental impacts found in the literature for woven fabrics [60]; - "Armchair" environmental impacts found in literature [61]; - "Chair" weight is 4 kg, and environmental impact values from the literature [62]; - Other environmental impacts found in the CCaLC2 dataset.
Stationary	- "Pencil" one-piece weights 4.5 g, environmental impact from literature [63] - "Laminating sheets" are made from polyethylene terephthalate, and a single sheet weighs 0.02 kg, information regarding environmental in CCaLC2 dataset; - Other environmental impacts for the category are from the CCaLC2 dataset.
Other	- "Adult diapers" environmental impact found in literature [64]; - "Face masks" weight of one mask is 45 g, environmental impact from the literature [65]; - "Medical robe" weight of one piece 475 g, environmental impact from literature [66]; - "Lawnmower" environmental impacts from literature [67]; - "Work clothes" 1-piece weighs 0.75 kg. environmental impacts from the literature [68]; - "Footwear" weight is 1 kg for a pair of shoes, environmental impacts from literature [69]; - "Toys" 200 g for a single toy, environmental impacts from the literature [70]; - Other environmental impacts taken from the CCaLC2 dataset.

3.3.3. Life cycle impact assessment

Life cycle impact assessment assesses the environmental impacts based on the results of the life cycle inventory, and the research measures the environmental impacts of the products, which were bought in 2023, for each public organisation. The assessment is made for the fuel, electricity, heating, and water consumption. The waste of public organisations is identified, and impacts are calculated for the waste disposal and wastewater treatment.

3.3.4. Environmental impacts

The environmental impacts are assessed for each of the 7 sectors, and the analysed scenario is for the environmental impact of products, water, waste, electricity, heating, and wastewater treatment. The analysed environmental impacts are carbon footprint, acidification potential, eutrophication potential, photochemical smog potential, and human toxicity potential.

3.3.4.1. Carbon footprint

The carbon footprint graph (Fig. 14) displays values in t CO_2 eq. reveals that the Municipal services sector is responsible for the highest emissions, primarily due to its electricity usage (4 374 873 kWh). From a product standpoint, the significant impact in this category stems from diesel purchases (581 156 litres) and the acquisition of passenger cars (6 vehicles were bought). The Sports sector ranks second, largely due to water consumption at the Jonava swimming pool and the treatment of 31 600 m^3 of wastewater. Additionally, the Sport sector significantly contributes to environmental impact through heating (2 700 000 kWh), and electricity use (3 772 000 kWh), making it the second highest in energy consumption among the sectors. The Education sector ranks as the third-largest contributor to the carbon footprint, generating 2 501 t CO_2 eq. The notable environmental effects in this sector are mainly due to heating (6 091 700 kWh) required for 20 school and kindergarten buildings. In terms of product impacts within the Education sector, the highest values are associated with "Food and Beverages," particularly for dairy products (over 45 000 kg), and vegetables (over 60 000 kg).

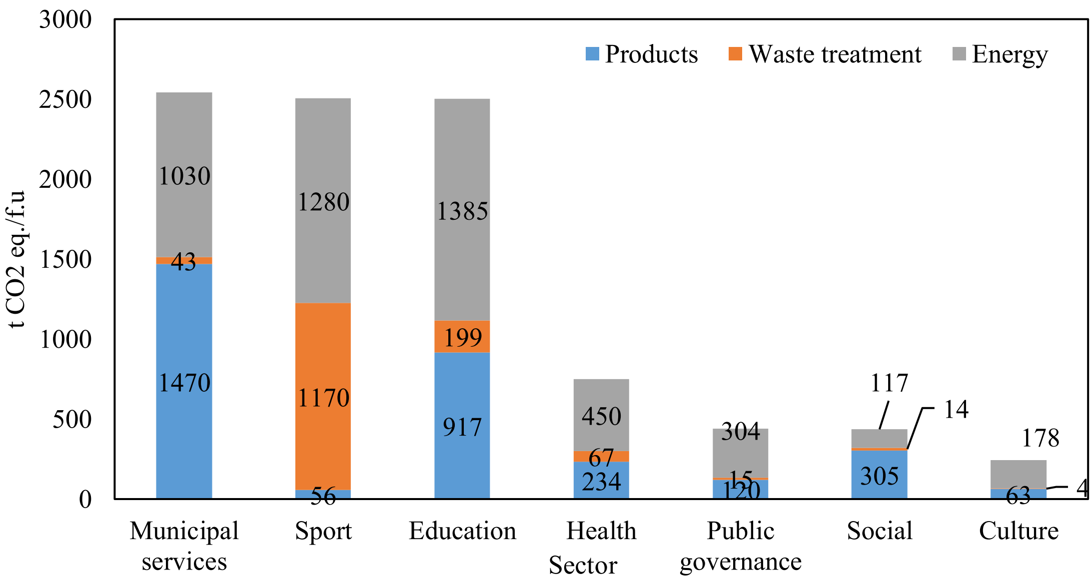

Fig. 14. Environmental impact in the carbon footprint category of Jonava municipality's public organisations

The highest contribution to the carbon footprint by products is Municipal services, as the sector accumulated over 1 470 tons of t CO_2 eq./f.u. in the products category, and most of this number is due to diesel, as shown in Fig. 15 (190 t CO_2 eq./f.u.), and because of new vehicles (180 t CO_2 eq./f.u.). Diesel, gasoline and passenger cars are disregarded in the figure (Fig. 16) of the carbon footprint of products, as diesel has too much of a carbon footprint that the footprint of another product could not be identified, and passenger cars are not a 1-year product, therefore, it has a large environmental impact. The fourth highest carbon footprint is for the work clothes; it has a big impact, even though the amount of product bought is comparatively small, however, textile is known to cause big environmental impacts. The most purchased products are paper products, and the carbon footprint is in 5^{th} place. The information regarding the Municipal services sector shows that the highest carbon footprint in general is due to the energy consumption, and from the products category, it is due to transportation (passenger cars and diesel).

It can also be identified that from the cost perspective, in the Municipal services sector, the largest costs are for diesel and the purchased passenger cars, and other costs are significantly lower, therefore, the costs and environmental impacts correlate in this case (Fig. 15).

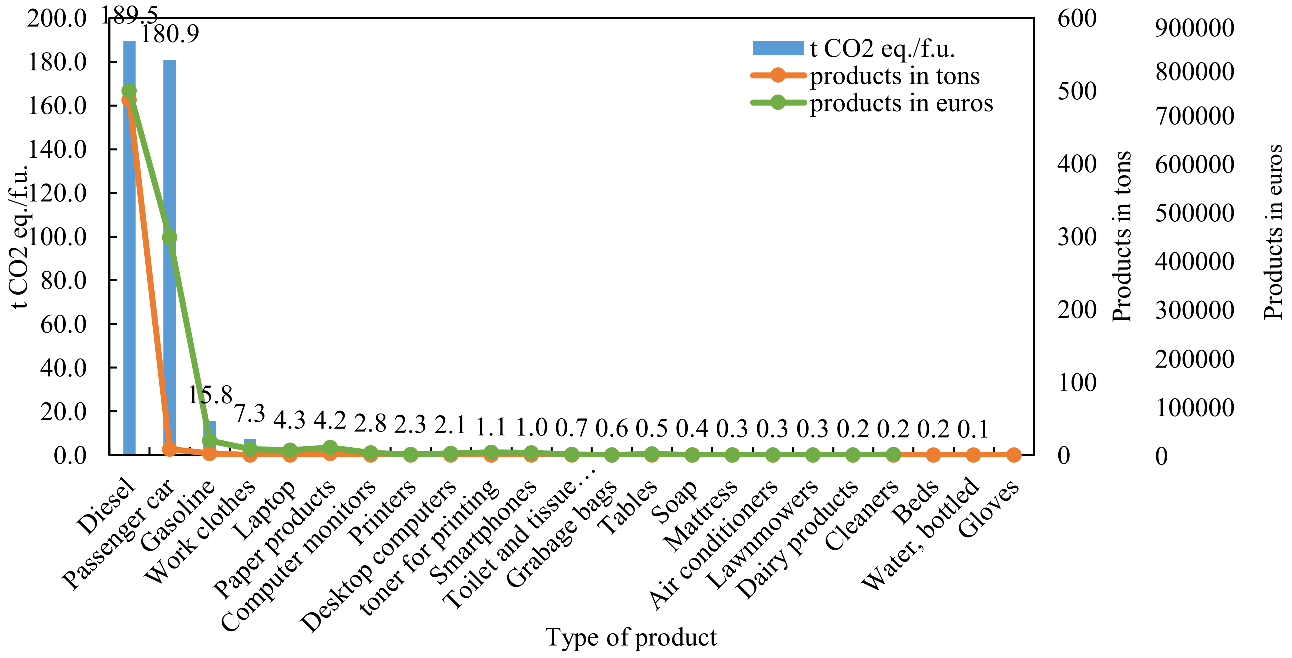

Fig. 15. Environmental impacts in the carbon footprint category of the Municipal services sector

It is also apparent that, from a cost standpoint, the highest expenses in the Municipal services sector (excluding diesel and passenger vehicles) are associated with paper products (Fig. 16), totaling approximately 16 000 euros in 2023. The carbon footprint is significantly impacted by electronics as well; however, the costs of most of these items, such as printers and computers, are relatively lower. In general, the most significant disruption concerning cost, quantity, and the carbon footprint ratio pertains to paper products, which could be reduced through the implementation of suitable measures.

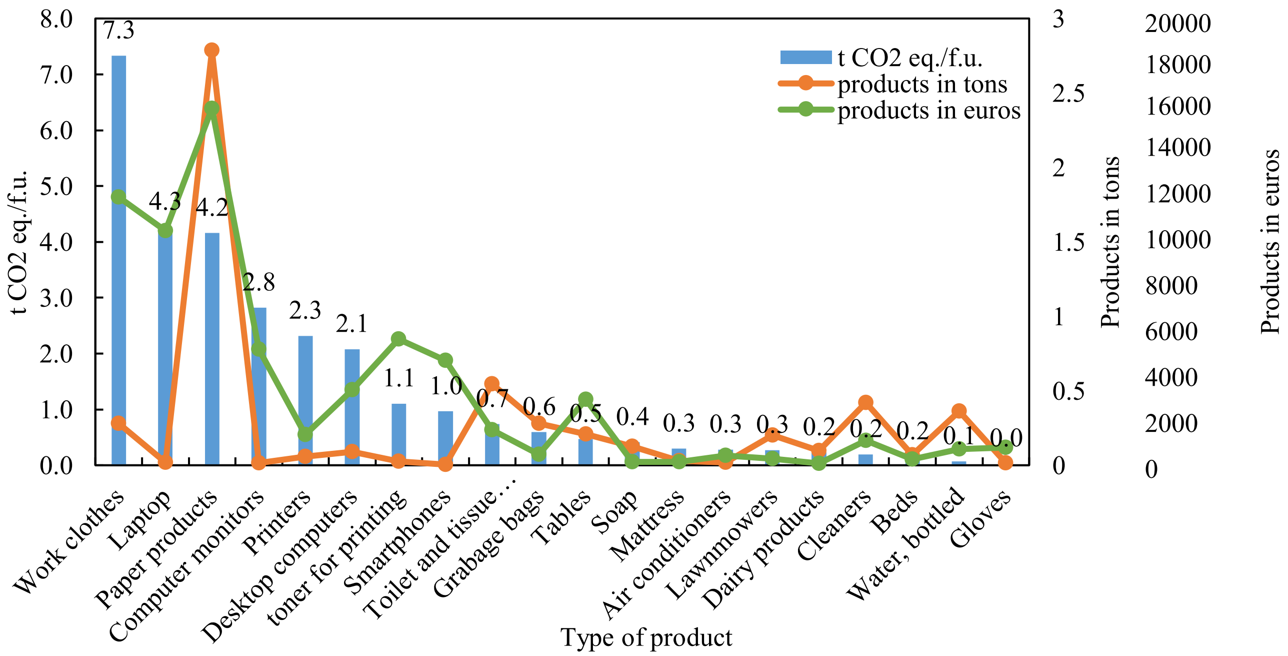

Fig. 16. Environmental impacts in the carbon footprint category of the Municipal services sector (excluding diesel, passenger cars)

In terms of purchased products, the Education sector has the second highest impact (Fig. 17) due to vegetable purchases exceeding 60 tons, resulting in a total of 199 t CO_2 eq./f.u. Dairy products rank second, with nearly half the carbon footprint of the vegetables. The graph below (Fig. 17) illustrates 20 of the most significant contributors to carbon footprints, and some items, like electronics, have a substantial impact but are purchased in low quantities, whereas others, such as wheat and paper products, are bought in larger amounts but have a smaller carbon footprint. Data about the Education sector indicates that the primary overall impact stems from energy use, while the product category's major contributors to carbon footprint are food items (vegetables, dairy, and meat), diesel, and electronic devices (smart boards, desktop computers, laptops, etc.). The relationship between purchased items and carbon footprints is observed in most products, though there are notable variations in electronics, such as smart interactive boards, which are minimal in weight but have a high carbon footprint.

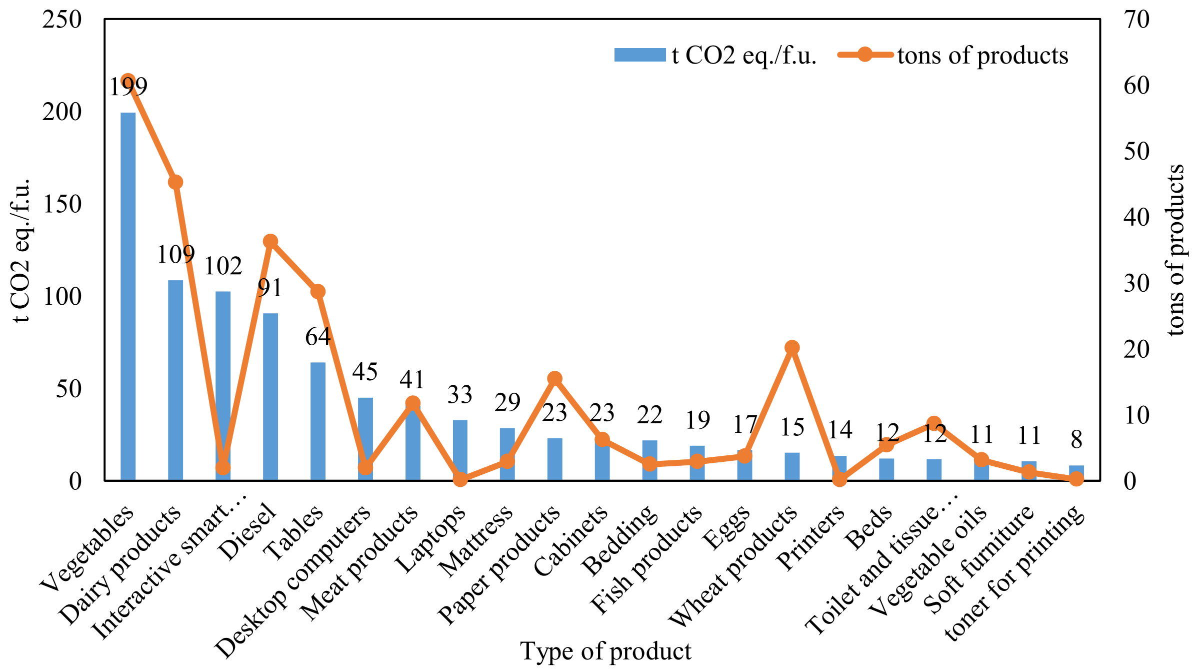

Fig. 17. Environmental impacts in the carbon footprint category of Jonava municipality, Education sector, regarding products

The third sector with the most carbon footprint due to products is the Social services sector (Fig. 18) with 305 t CO_2 eq./f.u., and food items have the biggest contribution to this sector's footprint. From the overall carbon footprint, meat products have the highest impact, and it is also the largest product category by amount. The same principles apply to vegetables and dairy products as well. Other products have a significantly smaller carbon footprint and consist mainly of electronics, furniture items, fuel, and paper. This indicates that the Social sector has its largest carbon footprint due to the purchasing of food.

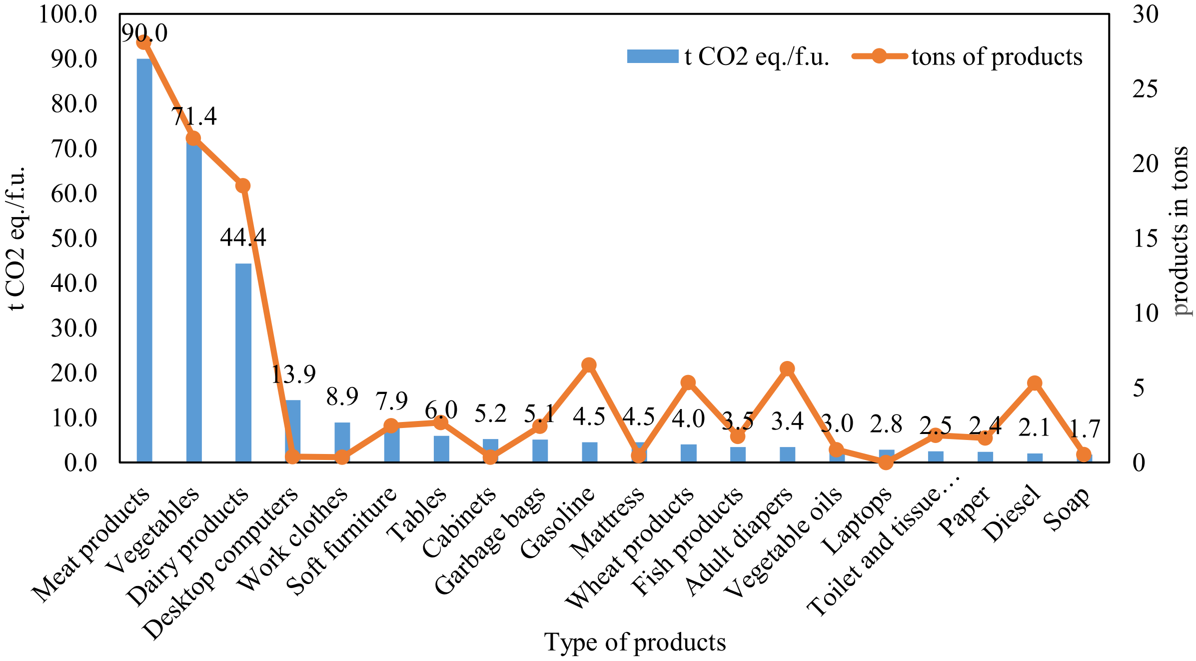

Fig. 18. Environmental impact in the carbon footprint category of Jonava municipality, Social sector

Overall, the carbon footprint is highest in the Municipal services sector, due to energy consumption, fuel, and the purchasing of passenger cars, and he Sports sector is in second place due to energy consumption and wastewater treatment, and a close third is the Education sector, with the highest contributions to the heating of buildings and purchasing of products, such as food items, and electronics. Most sectors had the largest carbon footprint due to energy consumption, and the lowest because of waste handling (except for the Sport sector, which had a lot of wastewater).

3.3.4.2. Acidification potential

The Sports sector exhibits the highest acidification potential, amounting to 5 559 kg SO_2 eq./f.u., attributed mainly to electricity usage and the treatment of 31 600 m^3 of wastewater (Fig. 19). Among the products, meat items have the most significant impact at 29 kg SO_2 eq./f.u., followed by electronic devices like printers and laptops, which contribute 7 kg SO_2 eq./f.u. and 13 kg SO_2 eq./f.u. respectively. While certain products lead to increased acidification potential, the major contributors are wastewater (2 757 kg SO_2 eq./f.u.) and electricity (2 675 kg SO_2 eq./f.u.). The Municipal services sector ranks second in terms of acidification potential, primarily due to electricity consumption (3 103 kg SO_2 eq./f.u.) and significant contributions from diesel (1 167 kg SO_2 eq./f.u.) among the products. In the third position, the Education sector's impact stems mainly from the electronics purchased, including interactive smart boards, desktop computers, laptops, printers, and meat products, which collectively contributed around 700 kg SO_2 eq./f.u. out of over 12 000 kg bought.

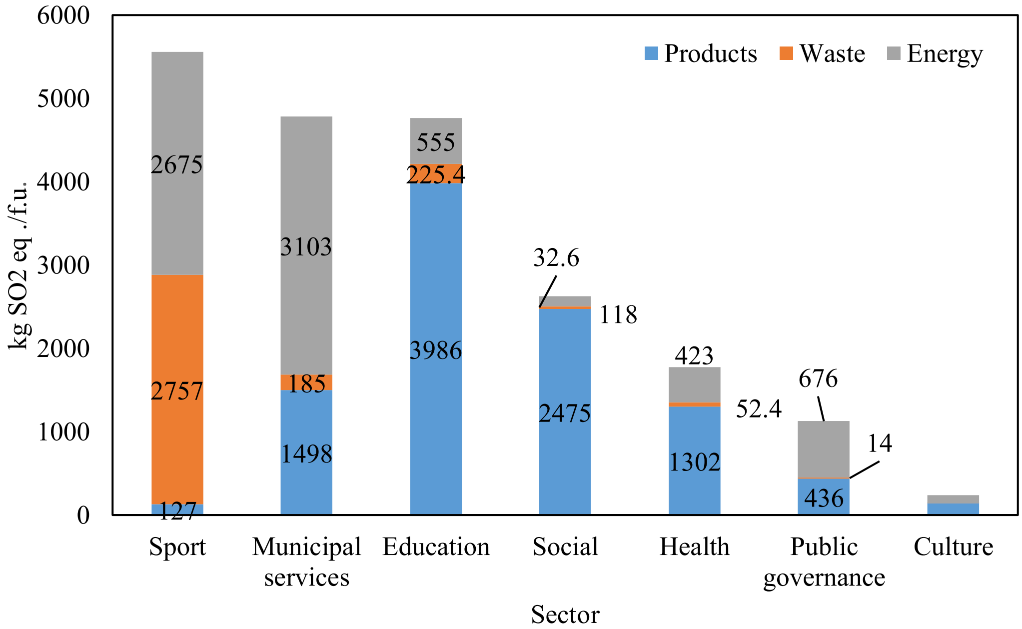

Fig. 19. Environmental impact in the acidification potential category of Jonava municipality public sector organisations

Even though the Education sector has the third-highest acidification potential, it is the highest in the products category across all sectors (Fig. 20). The largest share of acidification potential is for vegetables (as 60 tons were purchased), and it made 1 211 kg SO_2 eq./f.u., other significant contributors are also from the food sector and include dairy and meat products. It can also be seen that some of the largest amounts of products contribute less than those having small amounts, for example, printing paper and diesel.

When considering costs, toilet paper and tissue paper emerge as notable items due to their substantial expenses, even though their potential for acidification is relatively low. Significant differences are also observed with printing paper and diesel, as they entail considerable purchases, yet their overall impact is not as pronounced as that of products in the food category. On the other hand, food items demonstrate the contrary trend, where their costs are not the highest, but their environmental impact is significantly greater than other categories, and this illustrates that not every product that incurs high spending or large quantities is a major driver of environmental effects.

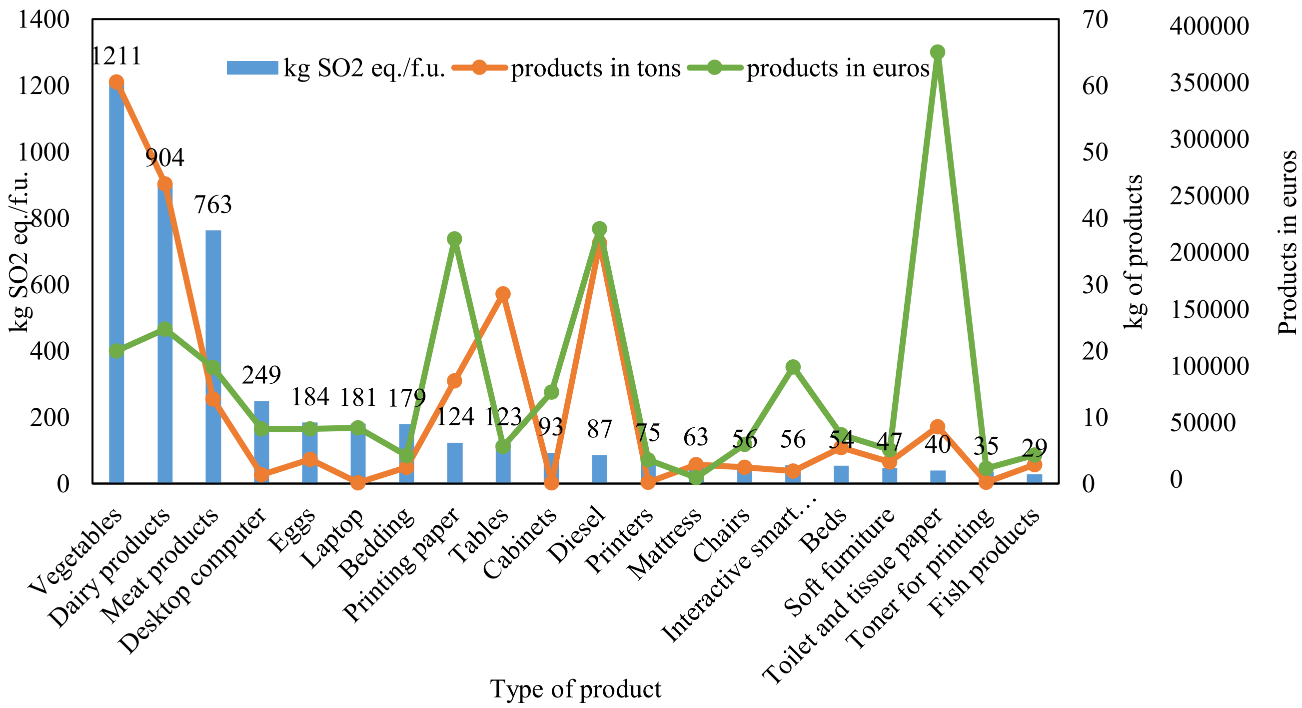

Fig. 20. Environmental impact in the acidification potential category of Jonava municipality, Education sector

The second largest contributor to the acidification potential category of products is the Social services sector, as it has the highest impact is for the meat products (Fig. 21), and it was also the largest bought product considering weight, as around 27 000 kg were purchased. In the second place, it is dairy products, which are also from the food category and accumulated to around 1 100 SO_2 eq/f.u. as it is shown in the graph (Fig. 21), these are the two main contributors to acidification potential. In order to analyse more in-depth, the meat and dairy products are excluded, to see what other products cause an impact, and the results are shown below (Fig. 21).

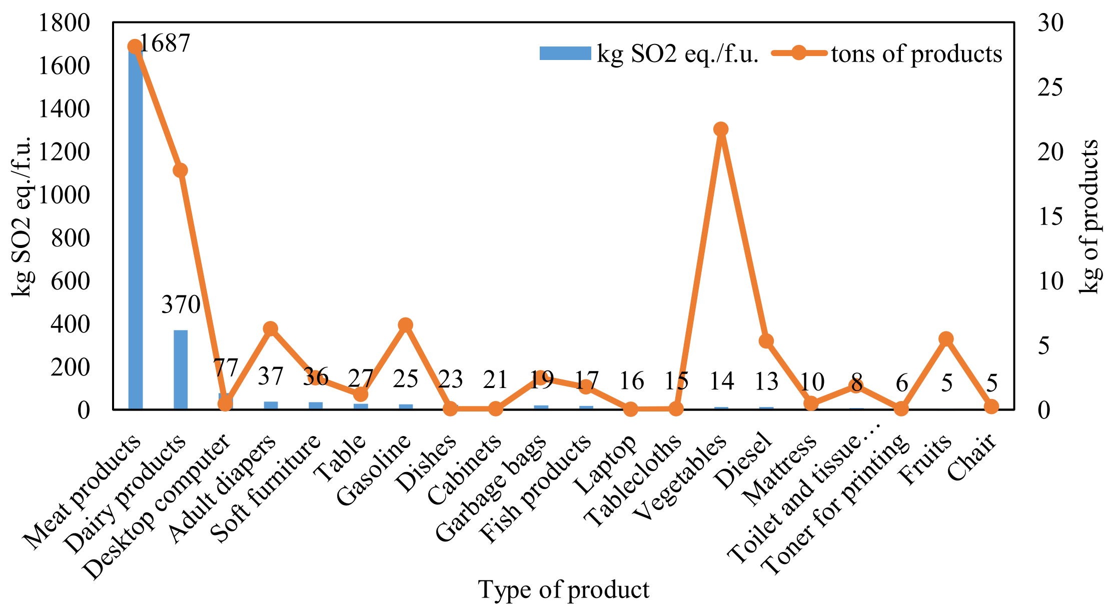

Fig. 21. Environmental impact in the acidification potential category of Jonava municipality, Social sector

When meat and dairy are not included, desktop computers rank highest with an impact of 77 kg SO_2 eq./f.u. Among the purchases, vegetables are notable, as more than 20 tons were acquired, yet their environmental impact is significantly less than that of other goods, and the leading items in terms of acidification potential are furniture, fuel, and electronics. However, their impact is significantly lower than it is for meat and dairy products.

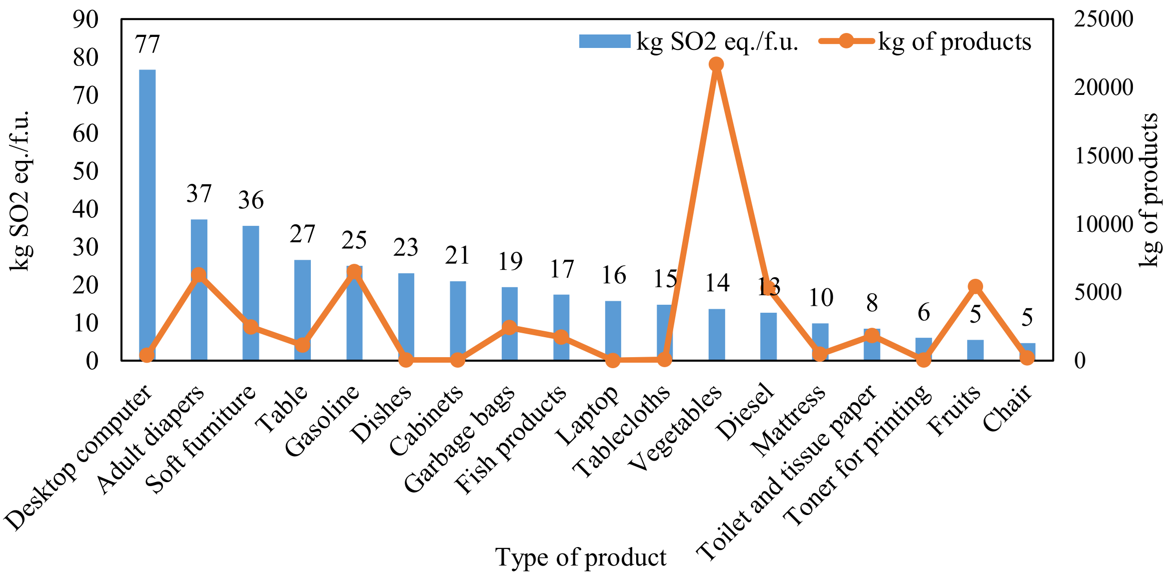

Fig. 22. Environmental impact in the acidification potential category of Jonava municipality, Social sector (excluding meat and dairy products)

In third place for the acidification potential is the Municipal services sector with the impact regarding products making 1 498 SO_2 eq./f.u., of which the largest amount is due to the fuel consumption (Fig. 23). Diesel consumption made over 1 167 SO_2 eq./f.u., and gasoline 88 SO_2 eq./f.u., which were the two largest contributors, as over 580 000 litres of diesel and over 27 000 litres of gasoline were consumed.

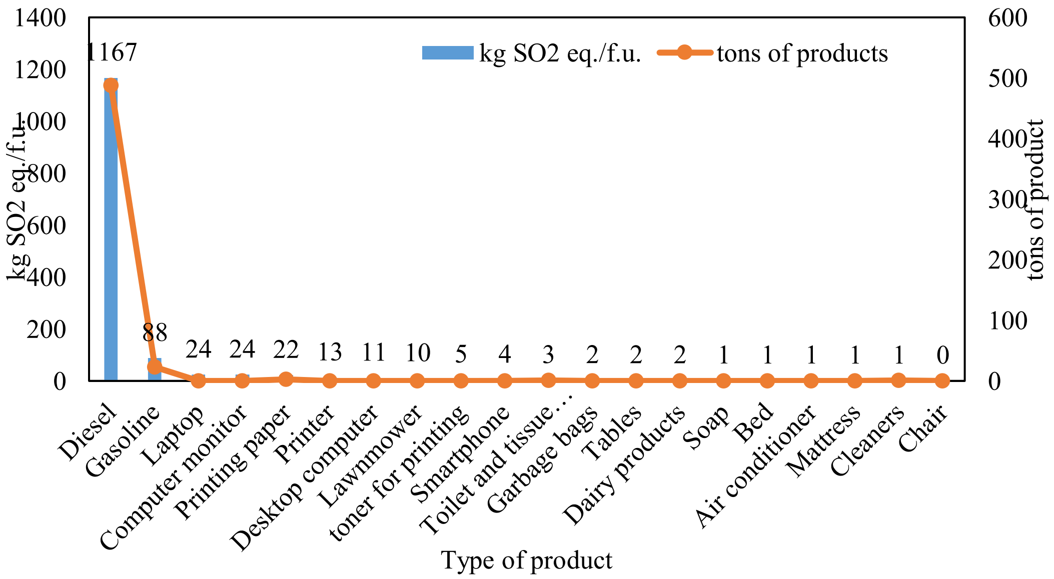

Fig. 23. Environmental impact in the acidification potential of Jonava municipality, Municipal services sector

As diesel and gasoline are the largest contributors to the acidification potential, solutions to lower the impact should be implemented. To see other products causing an environmental impact, diesel and gasoline were excluded (Fig. 24), and from the results, the highest impact is due to the electronics (for example, laptops, computer monitors, printers, and desktop computers) and printing paper, which is due to the large amount of paper purchased (over 2 500 kg).

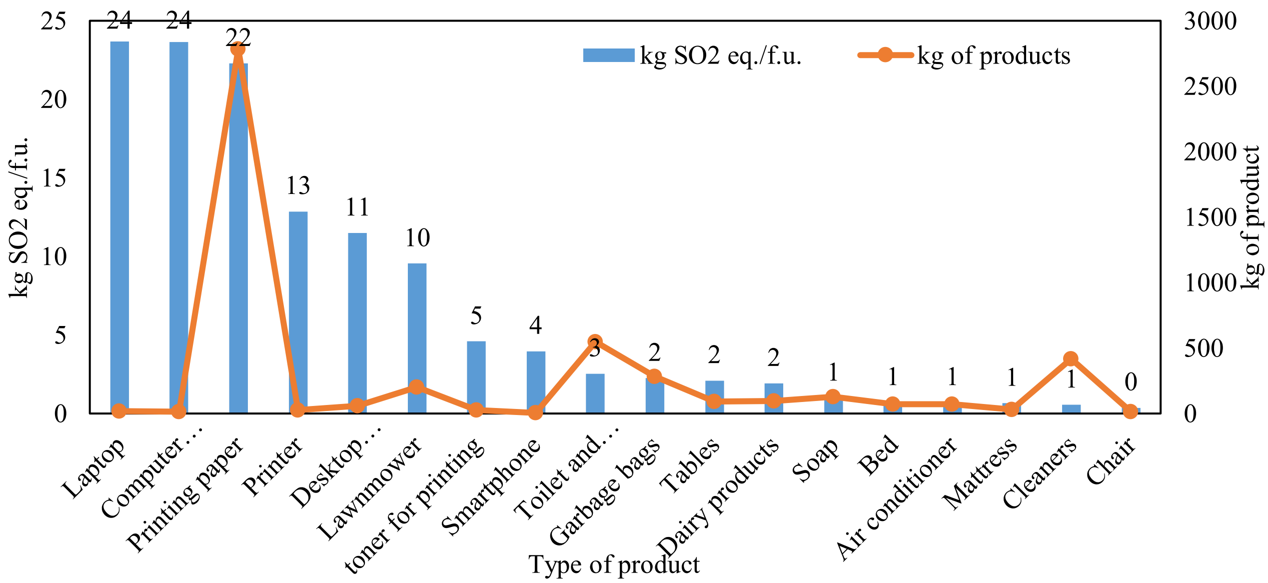

Fig. 24. Environmental impact in the acidification potential of Jonava municipality, Municipal services sector (excluding fuel)

3.3.4.3. Eutrophication potential

The Education sector ranks first in the eutrophication potential category (Fig. 25), primarily due to the impact of products (2 354 kg PO_4 eq./f.u.) and especially from the food category (eggs, dairy products, fish products, and vegetables). In second place is the Social services sector as well because of the food products (1 473 kg PO_4 eq./f.u.) and especially meat and dairy products. For the Municipal services and Sport sectors, the highest eutrophication potential is due to the waste treatment, where a lot of wastewater is formed that needs to be treated. The smallest potential is for the energy, which is the highest in Municipal services (282 kg PO_4 eq./f.u.) and Sport sectors (243 kg PO_4 eq./f.u.).

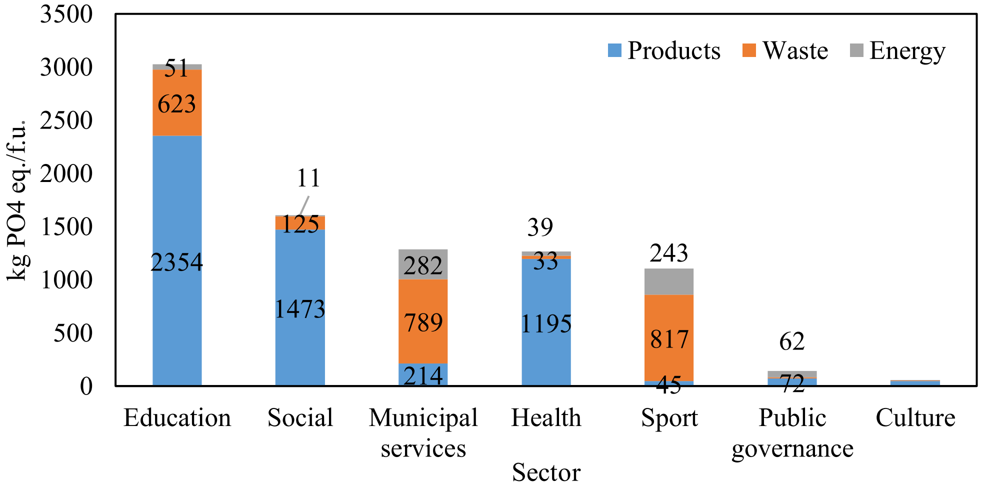

Fig. 25. Environmental impact in the eutrophication potential category of Jonava municipality public sector organisations

From the purchased products, the largest impact is the Education sector, and it is due to the purchased food (Fig. 26), and the highest cost is for the printing paper, as it is over 250 000 euros; however, it has a much smaller eutrophication potential than the food products. From the quantity perspective, the highest values are for the vegetables (60 tons), and dairy products (45 tons), and this reason contributes to the fact that they have a higher environmental impact than those items with much smaller amounts.

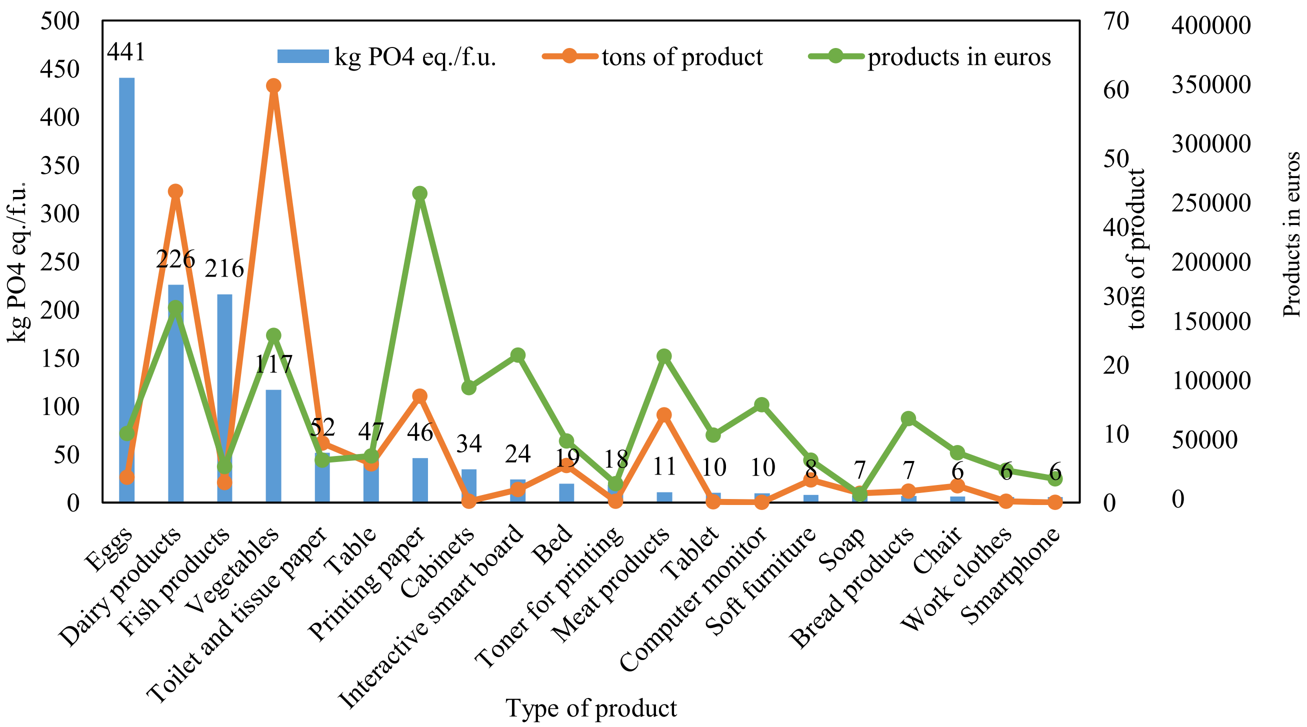

Fig. 26. Environmental impact in the eutrophication category of Jonava municipality, Education sector

The second highest eutrophication potential in products is for the Social services sector (Fig. 27). The most significant contributors are the dairy products with 925 kg PO_4 eq./f.u., and one of the highest quantities overall (around 17 tons). The other influential products are from the food category, such as vegetables, fish products, and meat products, as can be seen, other products do not have a large impact.

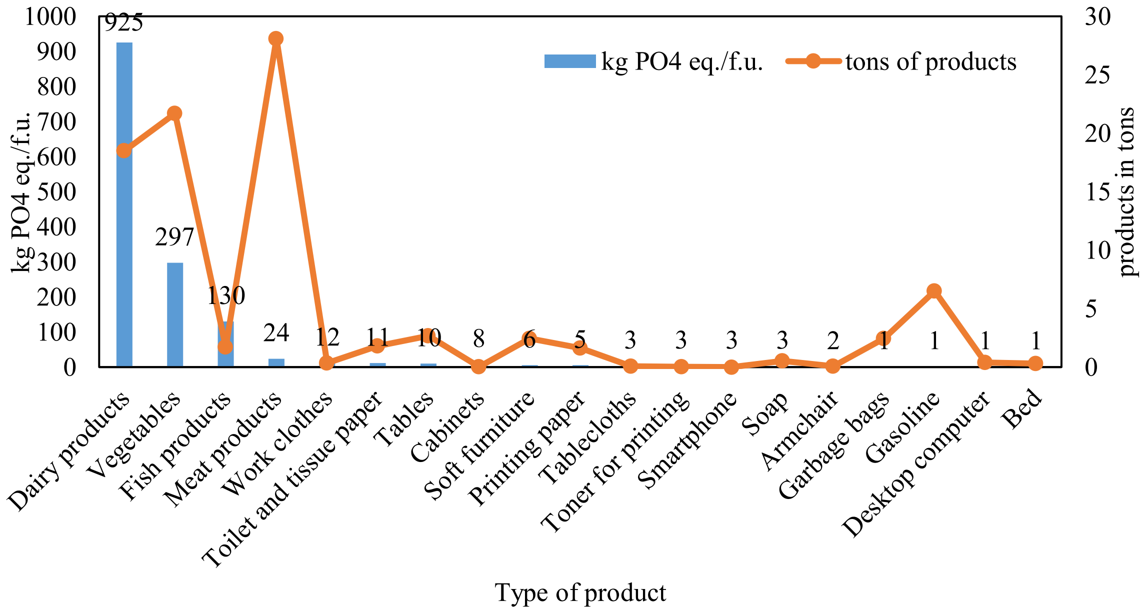

Fig. 27. Environmental impact in the eutrophication category of Jonava municipality, Social sector

In third place according to the eutrophication potential of products is the Health sector (Fig. 28), and like in the other two analysed sectors, the highest impact is due to the food items. In this case, the largest impact is for the dairy products, and then in second place are eggs, which have a third of the impact of dairy products. For vegetables, the eutrophication potential is 218 kg PO_4 eq./f.u., and it is due to the 16 tons of vegetables purchased. Other items do not have a very high eutrophication potential. However, some of the items have a smaller impact but are larger in quantity, like fruits, diesel, cleaners, and gasoline.

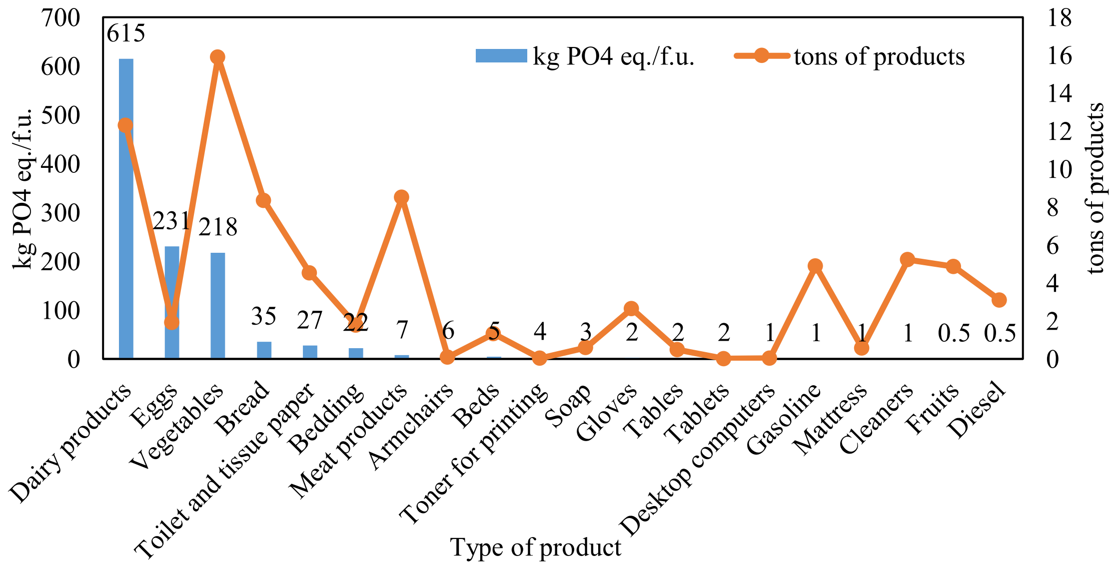

Fig. 28. Environmental impact in the eutrophication potential category of Jonava municipality, Health sector

3.3.4.4. Photochemical smog potential

For the photochemical smog potential, the largest values for Municipal services and Sport sectors are due to the energy consumption (Fig. 29). A large contributor for Municipal services is the products bought as well (195 kg C_2H_4 eq./f.u.), and it is the second highest value after the Education sector in photochemical smog potential for products, and the Education sector is in third place overall in the potential impact. From the overall results, the biggest concern areas are the energy and the products categories, as they show the highest photochemical smog potential.

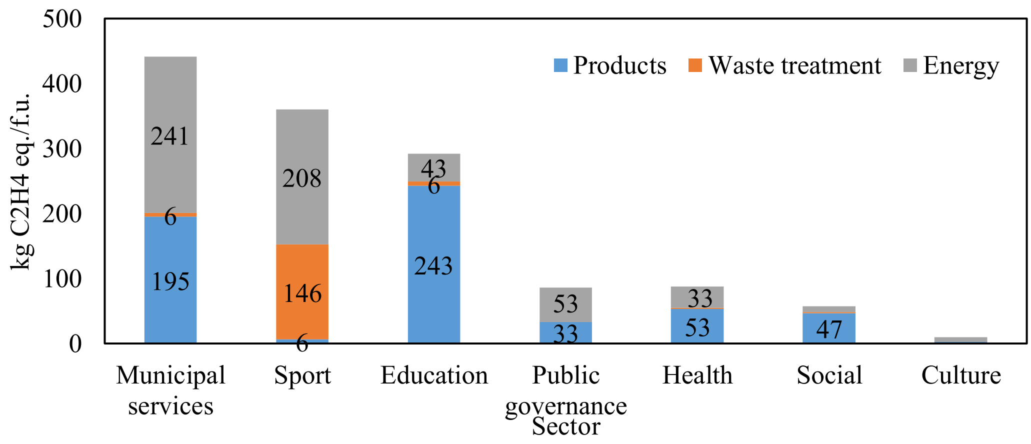

Fig. 29. Environmental impact in the photochemical smog potential category of Jonava municipality public sector organisations

The highest photochemical smog potential because of the products is in the Education sector, as from the figure below (Fig. 30), it can be seen a correlation between the amounts of products bought, their cost, and the environmental impact they cause in the category of photochemical smog potential. The food items cause the biggest impact, as dairy products and eggs are at the top. The dairy products cause the biggest photochemical smog potential; however, it is one of the cheaper products, which shows that even simple products can have the biggest impact. The largest price is for the toilet and tissue paper, but its impact is not as significant as a lot of the other products.

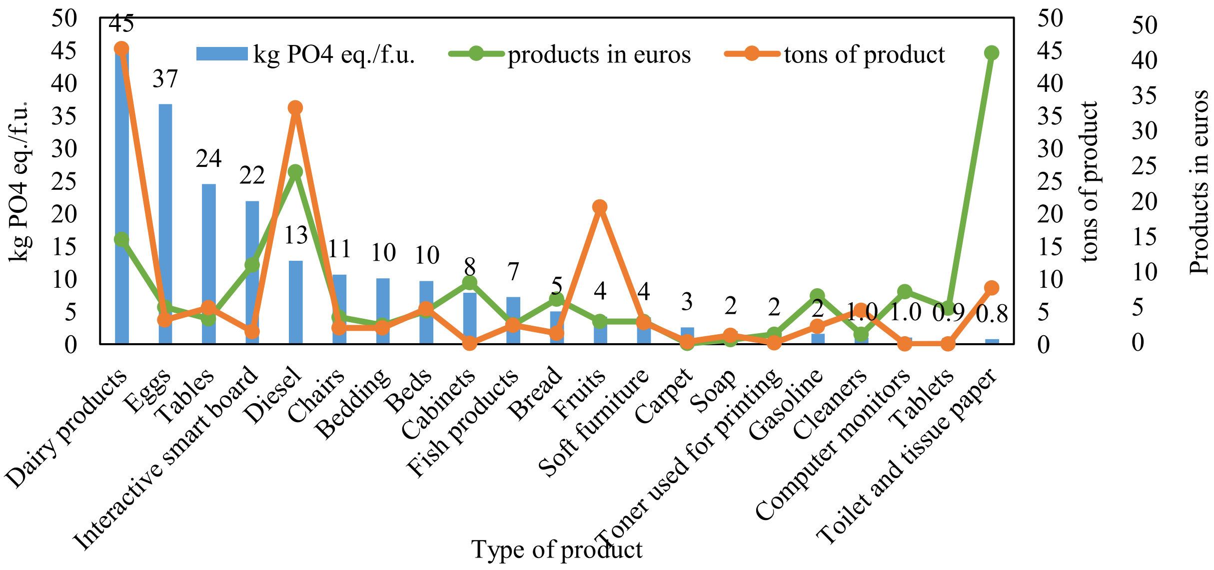

Fig. 30. Environmental impact in the photochemical smog potential category of Jonava municipality, Education sector

In second place for products, it is the Municipal services sector, with the most significant contributor being diesel with 172 kg C_2H_4 eq./f.u. (Fig. 31), and another product that can be seen as well is gasoline with 13 kg C_2H_4 eq./f.u. Other products do not have such a significant impact as those from the fuel category, as this shows that the Municipal services have a strong influence to environmental impacts due to the consumption of fuel.

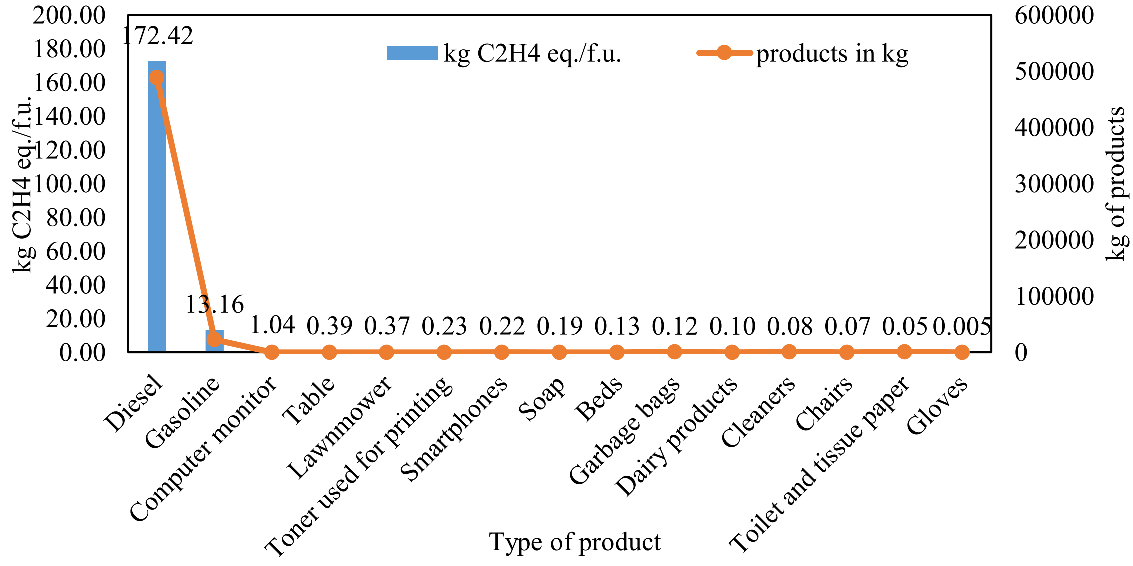

Fig. 31. Environmental impact in the photochemical smog potential category of Jonava municipality, Municipal services sector

In third place, by products, it is the Health sector, which has a lot smaller impact than the first two sectors analysed at 53 kg C_2H_4 eq./f.u. and the top categories are shown in Fig. 32. It can be seen that the dominating items are from the food category (eggs and dairy products), and other items having a photochemical smog potential include furniture items, fuel, and cleaning supplies.

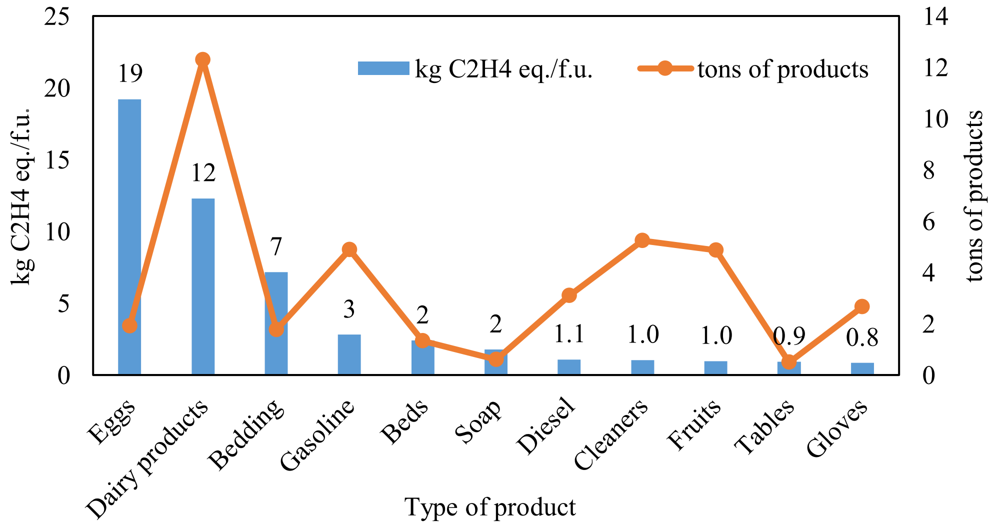

Fig. 32. Environmental impact in the photochemical smog potential category of Jonava municipality, Health sector

3.3.4.5. Human toxicity potential

From the human toxicity potential, the highest value is for the Education sector (Fig. 33) due to the waste treatment, for the other two top categories, the largest contributor is the energy consumed. Products make a much smaller impact than waste treatment and energy, however, as products are the largest area by budget, it is important to analyse the potential in a way to understand if the largest impacts are in areas with the highest costs and quantities.

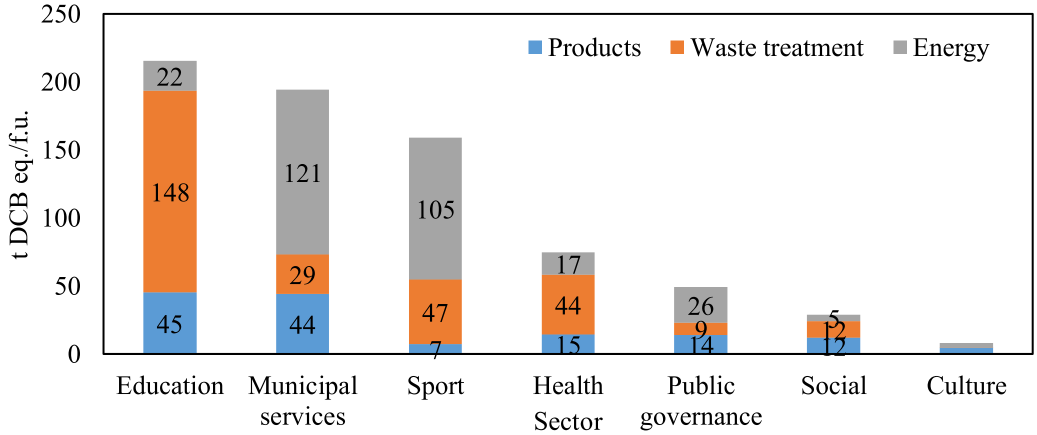

Fig. 33. Environmental impact in the human toxicity potential category of Jonava municipality's public organisation sectors

The highest human toxicity potential for products is in the Education sector. In the figure below (Fig. 34), where the largest distribution of cost and quantities is, those products do not have the highest human toxicity potential. The highest impact in the category is for the toner for printers, as it has very hazardous chemicals to health, and then there are electronic devices like desktop computers, and laptops. Items such as toilet paper and tissue paper, or dairy products, are bought in large quantities, and costs do not have such a large impact, and the received results show that it is not always the case that costs and environmental impact correlate.

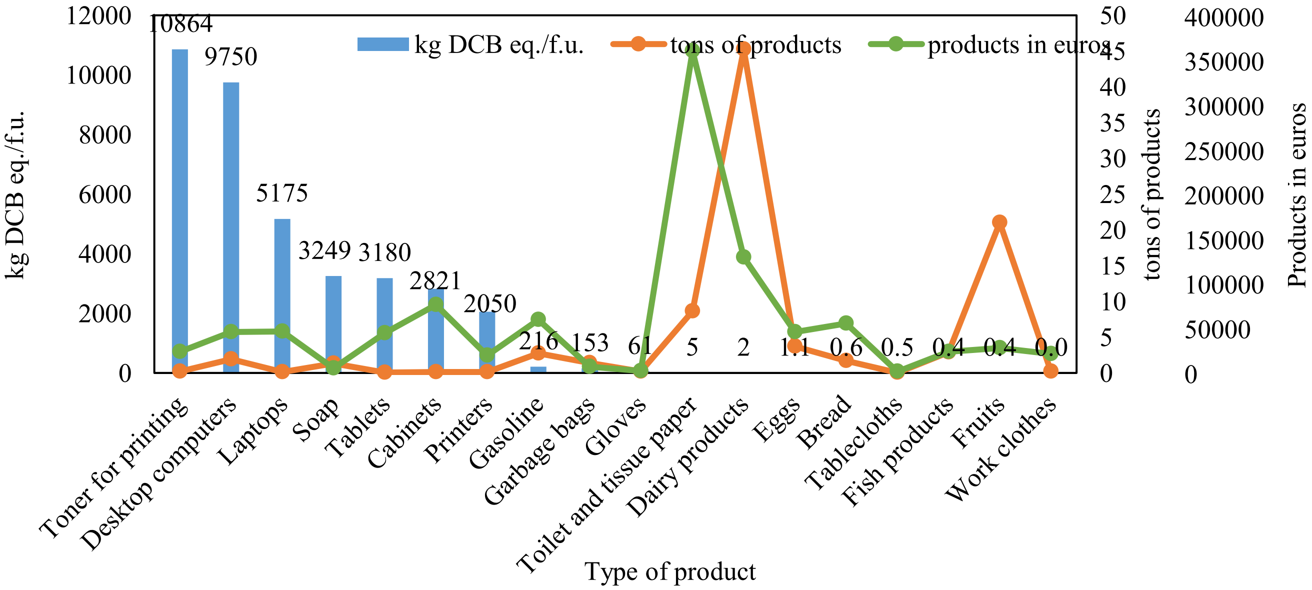

Fig. 34. Environmental impact in the human toxicity potential category in Jonava municipality, Education sector

The second largest contributor to the human toxicity potential is the Municipal services sector (Fig. 35), and as in the Education sector's case, in the Municipal services sector, the largest contributor is the toner for printing, and then the electronic devices (laptops, smartphones, desktop computers, and printers). The largest quantities are for items that do not cause the largest impact, such as toilet paper, tissue paper, and work clothes.

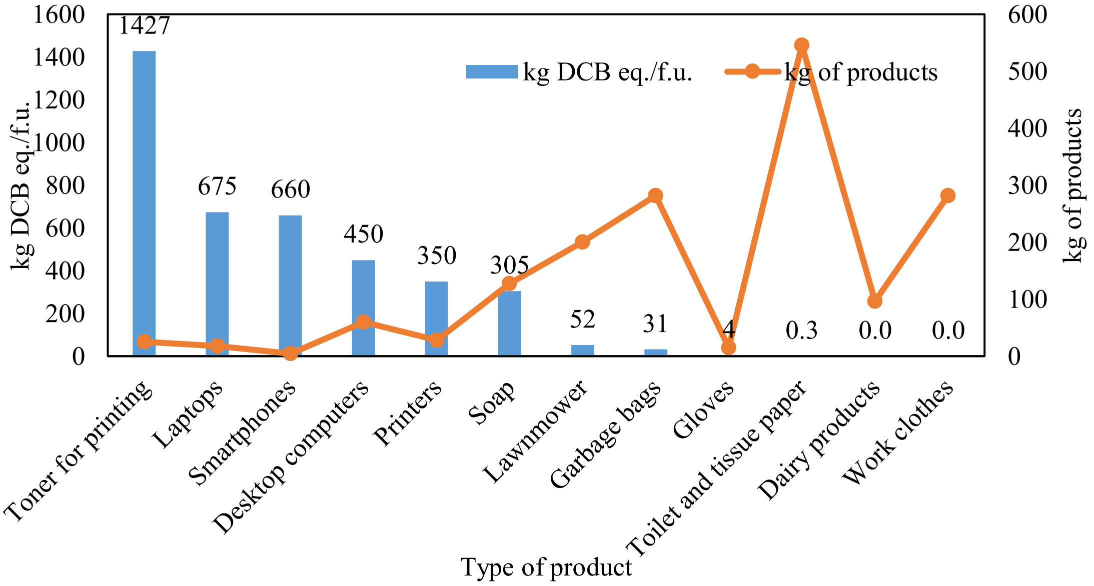

Fig. 35. Environmental impact in the human toxicity potential category in Jonava municipality, Municipal services sector

In third place is the Health sector's products in the human toxicity potential category (Fig. 36). The largest contributors are electronic devices such as desktop computers, laptops, and tablets. Toner for printing, which dominated in other sectors for human toxicity potential, in the Health sector is in third place. Food items like dairy products, eggs, and fruits have higher quantities, but their impact is considered very small compared to the dominating items.

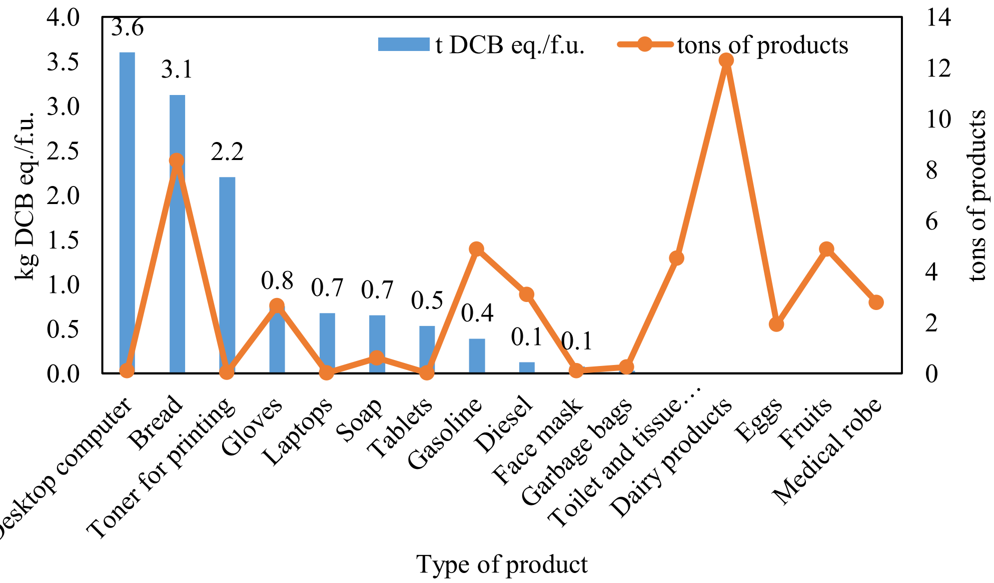

Fig. 36. Environmental impact in the human toxicity potential category in Jonava municipality, Health sector

Overall, it can be seen that the largest contributors to the environmental impacts are energy, purchased products, and, for some of the sectors, fuel. The largest share of environmental impacts in the products category is for the food items (such as dairy, meat products, and vegetables), for fuel (especially diesel), and electronics. Most of the products with the highest impact due to products show that it is not necessary the case, that they have to be the most expensive products.

3.4. Discussion and feedback method results from Jonava municipality public organisations

The results are collected through a discussion with the representatives of the analysed public organisations, and the results show that public organisations are trying to implement circular activities, such as, waste reduction by composting and reuse. Some of the organisations expand beyond the products and are trying to integrate energy and water efficiency technologies. As transportation is also a huge concern for some of the organisations, they try promoting sustainable transportation methods. Regarding the challenges that the organisations face, these include the lack of funding, the lack of management contribution, and inadequate awareness about circularity. Besides that, institutions lack the knowledge and clarity how to precisely do green public procurement documents. However, from the discussion, it is seen that the public organisations are willing to change their habits and implement circular activities, which would also bring them a financial gain, such as optimisation of water and energy consumption efficiency. Also, companies are willing to implement educational events for the employees, students, and the public to raise the awareness about the methods how to contribute to the positive environmental change.

The results of the discussion show that there is a large possibility of implementing circular activities, as companies are already trying to become environmentally friendly. However, for companies to implement more focused solutions, a plan of where to start should be done.

3.5. Recommendations for Jonava municipality

Recommendations for Jonava municipality are that one of the largest impact areas is the energy consumption, waste formation and treatment, and the large environmental impact of products. The recommendations are of a broader type, as a Living Lab is a method of continuous improvement, and if a concrete solution is given, it can turn into a one-time project, which, when implemented, is stopped. The recommended solutions are described in this section.

3.5.1. Recommendations regarding saving energy for Jonava municipality

As Jonava municipality uses a lot of energy for its buildings, especially high consumption of heating is for the Education sector, therefore, it is recommended to invest in the renovations of the buildings of schools and kindergartens using high-quality insulating materials. It is also recommended to invest in energy-saving devices for the Municipal services sector, as it has consumed over 4 000 000 kWh of electricity. Examples could be motion-detecting devices for lighting in administrative departments. Modernising the equipment, which has a smaller energy consumption, would also benefit the organisations that use enormous amounts of electricity. To maximise the use of natural lighting would also lower the consumption of electricity, as a lot of the organisations have large windows that could be used for this purpose.

Another beneficial recommendation would be to monitor progress and continuously improve within the company. To do so, an energy management software can be used to identify usage patterns, which helps to review performance data to identify new improvement opportunities. The goals which need to be achieved within a certain timeframe can be set, and the results of the goals published to keep the motivation moving forward going. This should be implemented in organisations with the highest energy consumption. A consideration would also be to have a voluntary international standard for energy management systems ISO 50001, especially in energy intensive sectors, such as Municipal services, or Sports.

3.5.2. Recommendations regarding waste management for Jonava municipality

From the results of the environmental impact assessment and discussion results, changes need to be made regarding the food waste in the Education sector, as children refuse to eat certain food or eat less than what their given. For this reason, a buffet-style cafeteria can be implemented in facilities where it is appropriate (for example, for older children), by doing so, less food waste can be formed. Besides that, meal planners can be implemented where the staff tracks which products the students do not like, and which they love to eat, and even survey-type actions can be one where students evaluate if they liked the food or not. The leftovers can be donated to the staff, or the people in need.

Another common waste is paper, as many sectors buy it in very large quantities. It is recommended to form habits of saving files in electronic form instead of printing. This can be done by making a comfortable system for saving documents on the computer, and employees would not feel lost among the saved documents. It is also recommended not to have printers in every office of employees. When printers are in their dedicated place in the organisation, employees may want to change their habits as they will need to think before going to the printers if they really need it. This would also lower the toner for printers' consumption, which had the highest value for the human toxicity potential. For the reduction of paper waste, paper bins should be close by as employees would then be more likely to sort the formed waste

Awareness regarding sorting waste needs to be implemented in almost every organisation analysed. From the results, most sectors do not sort their waste, and therefore, huge amounts of municipal solid waste are being thrown out. Educational events could be implemented for people to understand the value of sorting and how to do it properly. This could be implemented through the whole municipality, including inhabitants, as it can be seen from the MFA of the waste management system, that only 2 thousand tons were collected from sorting out of 12 thousand tons of municipal solid waste collected.

Some of the organisations may help those in need as well, by lowering the impact of textile products' waste. Educational institutions can incorporate the parents of the children in events to trade or give away clothing items or toys that their children no longer need. This type of event can help not only the environment but also unite the community.

To lower the waste of public organisations, a trade system of furniture, electronics, and other tradeable items can be implemented. It would lower the waste, as something that is no longer needed can be sold, borrowed, or given to another organisation, instead of being thrown out. The trade system would benefit all the organisations, as it would make the inventory trackable, as the current system disregards the benefits of trading items between organisations.

The wastewater treatment is of highest concern in the Sports sector, however, all of public organisations may implement simple water saving technologies, as installing water-efficient fixtures (low-flow toilets, faucets), or checking for leaks regularly. A wastewater management plan should be developed for the highest water-consuming organisations, where goals to reduce the impact should be described.

3.5.3. Recommendations regarding products for Jonava municipality

One of the products that is large for the amount, cost, and environmental impact is the fuel consumption (especially for diesel in the Municipal services sector). It is recommended to transition to more sustainable transportation. Another suggestion is to analyse which vehicles are causing these impacts and consider purchasing new vehicles. Tracking systems could also benefit in order to see the movement of transportation and finding shorter routes to destinations that save fuel. Another method would be to train drivers about efficient driving techniques and to avoid driving in urban areas during peak hours whenever possible.

Food products are also of high concern due to the large quantities that are being bought by the organisations that provide catering. Regulatory changes need to be made regarding the obligatory portion sizes, as each institution knows how much food is needed to cater to schools, social homes, or hospitals. Food could be made for the demand that is needed, with the products that the institutions know will be eaten, instead of having a general portion size. As vegetables are responsible for a large part of environmental impact, and it Is known that it forms a lot of food aste, schools can start vegetable gardens, where it would teach children about gardening and nutrition, it also shows them first hand the amount of effort and enerfy that is needed to gor vegetales. This initiative can help reduce the wasting of food, as students directly see the work that is needed to produce it.

Paper waste is also of high concern, as it can be seen from the environmental impact assessment, it is among the top 20 largest contributors to impacts, however, a bigger concern for the organisations should be that it is a large contributor to the costs. Therefore, reusable tablecloths can be used (some organisations are transitioning to reusable tablecloths and lowering their paper consumption because of it). Besides, environmental awareness should be introduced, as employees are used to consuming a lot of tissue, or paper hand towels, due to habit rather than need.

Other products that cause problems, are cleaning supplies, such as soap. During the discussion companies ackwoldeged that some of them are using eco-friendly cleaning supplies; other companies should follow their lead as well, as tons of cleaning supplies are being consumed by the sectors.

Overall, to save energy, it is recommended to renovate buildings and use energy-saving techniques (starting in the Education and Municipal services sectors). Food waste is another large problem, especially in the Education sector, due to a self-catering system could be implemented, or initiatives to educate the students and staff about food waste. To reduce the consumption of fuel (especially in the Municipal services sector) a review of routes and the driving habits of drivers needs to be conducted, also new vehicles can be purchased, which have a lower fuel consumption. The recommendations provided are done in such a way that the organisations will need to think how to implement them, as it will make them think about implementing circular activities in the future as well. If the recommendations were given precisely, then it would turn into a one-time project, instead of a Living lab, which has a criterion that it needs continuous improvement.

Conclusions

1. According to the legal requirements, in the Waste Handling Law, municipalities are responsible for developing their municipal waste management systems and ensuring their effectiveness. Furthermore, from the Pact of Amsterdam, urban challenges need to be solved by three components: member states, municipalities, and stakeholders, which connect the different entities to work together.
2. Cities seeking urban circularity and best examples among analysed include Amsterdam, which focuses on broad categories and implements projects to eliminate all waste, promote new business models, and regenerate ecosystems. Paris forms initiatives for the reuse of construction materials and food waste management, which can bring fees to businesses when not complying. Osaka has an 83% sorting rate, as residents separate 27 different types of waste, making it one of the most effective systems.
3. After analysing the material flow of the waste management system in Jonava municipality, which belongs to the Kaunas region waste treatment center, only 2 thousand tons, out of 12 thousand tons of municipal solid waste, are being collected through sorting. This shows the potential of implementing better sorting initiatives. Additional data should be collected by the Jonava municipality to understand where their waste flows are going and how much of the materials are brought back to the market.
4. After analysing the environmental impacts of sectors, it is not always the case that environmental impacts correlate with the costs and quantities. The largest potential to lower the impact is for the food, paper, and fuel items in the products. Another large potential is for the reduction of heating and electricity consumption, especially in the Education and Municipal services sectors. The largest three contributing sectors are Education, due to the purchasing of items (especially food items), the Municipal services sector (due to fuel and energy consumption), and the Sports sector (due to energy and wastewater treatment). The highest carbon footprint is for Municipal services (2 543 CO_2 eq./f.u.), the highest acidification potential for the Sports sector (5 559 SO_2 eq./f.u.), highest eutrophication potential for the Education sector (3 028 PO_4 eq./f.u.).
5. From the discussion results, it is seen that organisations face challenges in purchasing through green procurement due to a lack of knowledge and clarity. The main barriers for implementing circular activities are lack of knowledge, funding, and over-regulation. However, there is potential to implement activities for saving electricity, heating, and water. Also, through collaboration and communication, organisations can work together to reach circularity in the Jonava municipality public sector.
6. Recommendations (based on results of conducted research) for Jonva municipality would be to renovate buildings and implement energy-saving devices in the Education and Municipal services sectors first. Also, to reduce food waste by self-catering systems, and educational events for students and staff, especially in the Education sector. Reducing fuel consumption by reviewing routes and times in urban areas, especially for the Municipal services sector. Paper consumption can be reduced by lowering the number of printers in offices and having a clear system for holding documents in electronic form.

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Appendices

Appendix 1. Public governance sector inventory

Table 11. Public governance sectors product inventory

Products	Amount (kg)	Category	Database
Cabinets	140	Furniture	User defined
Chairs	44	Furniture	User defined
Cleaners	417	Cleaning and Maintenance	User defined
Coffee, tea, and cocoa	2	Food and Beverages	CCalC database
Dairy products	80	Food and Beverages	User defined
Desktop computers	40	Electronics	User defined
Diesel	15100	Fuel	CCaLC database
Gasoline	42000	Fuel	CCaLC database
Garbage bags	2220	Cleaning and Maintenance	Ecoinvent database
Gloves	16	Cleaning and Maintenance	Ecoinvent database
Laptops	68	Electronics	User defined
Pencils	3.15	Stationary	User defined
Printers	110	Electronics	User defined
Printing paper	6624	Paper	CCaLC database
Single-use dishes	13.5	Other	User defined
Smartphones	3.4	Electronics	User defined
Soap	110	Cleaning and Maintenance	Ecoinvent database
Tablecloths	28	Cleaning and Maintenance	CCaLC database
Tables	490	Furniture	User defined
Tablets	11.4	Electronics	User defined
Tap water	1176	Water	Ecoinvent database
Toilet and tissue paper	1713	Paper	User defined
Toner for printers	84.3	Stationary	Ecoinvent database
Water, bottled	6600	Food and Beverages	CCaLC database
Work clothes	153	Other	User defined

Table 12. Public governance sector energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	952565	CCaLC database	190513
Heating	580032	CCaLC database	45242

Table 13. Public governance sectors waste inventory

Waste	Amount (kg, m^3)	Database	Costs (euros)
Disposal, mixed municipal waste	29000	Ecoinvent database	4978
Disposal, paper waste	19400	Ecoinvent database	2567
Disposal, electronic waste	1040	Ecoinvent database	104
Wastewater treatment	1176	Ecoinvent database	659

Appendix 2. Culture sector inventory

Table 14. Culture sectors product inventory

Products	Amount (kg)	Database	Category
Biscuits and crackers	3.95	CCaLC database	Food and Beverages
Chairs	16	User defined	Furniture
Chocolate and sweets	4	CCaLC database	Food and Beverages
Cleaners	271	User defined	Cleaning and Maintenance
Coffee, tea, and cocoa	53.7	CCaLC database	Food and Beverages
Computer keyboards	3	User defined	Electronics
Computer mouses	1.6	User defined	Electronics
Dairy products	19	User defined	Food and Beverages
Desktop computers	10	User defined	Electronics
Diesel	2499	CCaLC database	Fuel
Wheat products	6	CCaLC database	Food and Beverages
Fruits	4.45	User defined	Food and Beverages
Gasoline	821	CCaLC database	Fuel
Shelfs	550	Ecoinvent database	Furniture
Laptops	18	User defined	Electronics
Passenger cars	1416	User defined	Vehicles
Pencils	12.2	User defined	Stationary
Garbage bags	174	Ecoinvent database	Cleaning and Maintenance
Gloves	4	Ecoinvent database	Cleaning and Maintenance
Printers	60	User defined	Electronics
Printing paper	8982	User defined	Paper
Single-use dishes	230	User defined	Cleaning and Maintenance
Smartphones	0.6	User defined	Electronics
Soap	10.4	Ecoinvent database	Cleaning and Maintenance
Sugar	14	CCaLC database	Food and Beverages
Tables	90	User defined	Furniture
Tap water	8980	Ecoinvent database	Water
Toilet and tissue paper	909	User defined	Paper
Toner used for printing	23.7	Ecoinvent database	Stationary
Vegetable oils	8.59	CCaLC database	Food and Beverages
Vegetables	17.8	User defined	Food and Beverages
Water, bottled	1142	CCaLC database	Food and Beverages
Work clothes	10.5	User defined	Other

Table 15. Culture sectors energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	133710	CCaLC database	26742
Heating	778230	CCaLC database	60701

Table 16. Culture sectors waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, mixed municipal waste	11616	Ecoinvent database	4978
Treatment of wastewater	232	Ecoinvent database	130

Appendix 3. Health sectors inventory

Table 17. Health sectors product inventory

Products	Amount (kg, m^3)	Category	Database
Armchairs	400	Furniture	User defined
Beds	1330	Furniture	User defined
Bedding	1765	Other	User defined
Bread products	8356	Food and Beverages	User defined
Chairs	84	Furniture	User defined
Cleaners	5239	Cleaning and Maintenance	User defined
Coffee, tea, and cocoa	88	Food and Beverages	CCaLC database
Computer keyboards	15	Electronics	User defined
Computer mouses	8.6	Electronics	User defined
Dairy products	12300	Food and Beverages	User defined
Desktop computers	240	Electronics	User defined
Diesel	3092	Fuel	User defined
Eggs	1921	Food and Beverages	User defined
Face masks	101	Other	User defined
Gasoline	4885	Fuel	CCaLC database
Shelfs	5650	Furniture	Ecoinvent database
Laptops	18	Electronics	User defined
Mattress	570	Furniture	User defined
Meat products	8511	Food and Beverages	User defined
Medical robes	2774	Other	User defined
Pencils	8.85	Stationary	User defined
Garbage bags	245	Cleaning and Maintenance	Ecoinvent database
Gloves	2657	Cleaning and Maintenance	Ecoinvent database
Printing paper	12000	Paper	User defined
Soap	603	Cleaning and Maintenance	Ecoinvent database
Spices and salt	407	Food and Beverages	CCaLC database
Sugar	390	Food and Beverages	CCaLC database
Tables	490	Furniture	User defined
Tablets	13.3	Electronics	User defined
Tap water	12572	Water	Ecoinvent database
Toilet and tissue paper	4526	Paper	User defined
Toner used for printing	38.4	Stationary	Ecoinvent database
Vegetables oils	525	Food and Beverages	CCaLC database
Vegetables	15900	Food and Beverages	User defined
Water, bottled	6703	Food and Beverages	CCaLC database
Wheat products	4002	Food and Beverages	CCaLC database

Table 18. Health sectors energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	597036	CCaLC database	119407
Heating	1697560	CCaLC database	132409

Table 19. Health sectors waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, mixed municipal waste	97118	Ecoinvent database	4978
Disposal, biodegradable waste	347	CCaLC database	85
Treatment of wastewater (m^3)	18597	Ecoinvent database	10414
Disposal, medical waste	13542	Ecoinvent database	21802

Appendix 4. Kindergarten (part of Education sector) inventory

Table 20. Kindergarten (part of Education sector) product inventory

Products	Amount (kg, m^3)	Category	Database
Air conditioner	5600	Electronics	User defined
Beds	5390	Furniture	User defined
Bedding	2291	Other	User defined
Berries	732	Food and Beverages	CCaLC database
Paint	33.6	Other	CCaLC database
Bread products	1353	Food and Beverages	User defined
Cabinets	760	Furniture	User defined
Carpet	405	Other	User defined
Chairs	500	Furniture	User defined
Cleaners	2042	Cleaning and Maintenance	User defined
Computer keyboards	1	Electronics	User defined
Dairy products	44400	Food and Beverages	User defined
Desktop computers	60	Electronics	User defined
Eggs	1573	Food and Beverages	User defined
Fish products	2634	Food and Beverages	User defined
Fruits	19300	Food and Beverages	User defined
Gasoline	1775	Fuel	CCaLC database
Laptop	34	Electronics	User defined
LPG	15000	Fuel	User defined
Mattress	2880	Furniture	User defined
Meat products	11600	Food and Beverages	User defined
Pencils	4.27	Stationary	User defined
Laminating film	25	Stationary	CCaLC database
Garbage bags	562	Cleaning and Maintenance	Ecoinvent database
Gloves	85.1	Cleaning and Maintenance	Ecoinvent database
Printers	140	Electronics	User defined
Printing paper	1348	Paper	User defined
Single-use dishes	17.5	Other	User defined
Soap	485	Cleaning and Maintenance	Ecoinvent database
Soft furniture	377	Furniture	User defined
Tables	1330	Furniture	User defined
Tablets	8.51	Electronics	User defined
Tap water	11500	Water	Ecoinvent database
Toilet and Tissue paper	1863	Paper	User defined
Toner for printing	61.8	Stationary	Ecoinvent database
Toys	274	Other	User defined
Vegetable oils	2967	Food and Beverages	CCaLC database
Vegetables	57800	Food and Beverages	User defined
Water, bottled	22800	Food and Beverages	CCaLC database
Wheat products	19800	Food and Beverages	CCaLC database
Work clothes	39	Other	User defined

Table 21. Kindergarten (part of Education sector) energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	207000	CCaLC database	41400
Heating	1230000	CCaLC database	95940

Appendix 4 continued

Table 22. Kindergarten (part of Education sector) waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, mixed municipal waste	141000	Ecoinvent database	11280
Disposal, biodegradable waste	1300	CCaLC database	340
Treatment of wastewater (m^3)	14300	Ecoinvent database	8008
Disposal, paper waste	59.5	Ecoinvent database	10
Disposal, electronic waste	268	Ecoinvent database	27

Appendix 5. Schools (part of Education sector) inventory

Table 23. Schools (part of Education sector) product inventory

Products	Amount (kg, m^3)	Category	Database
Bedding	200	Other	User defined
Bread products	307	Food and Beverages	User defined
Cabinets	2340	Furniture	User defined
Chairs	1956	Furniture	User defined
Cleaners	3161	Cleaning and Maintenance	User defined
Coffee, tea, and cocoa	13.2	Food and Beverages	CCaLC database
Computer keyboards	1	Electronics	User defined
Computer monitors	70	Electronics	User defined
Computer mouse	0.4	Electronics	User defined
Dairy products	809	Food and Beverages	User defined
Desktop computers	1240	Electronics	User defined
Diesel	36200	Fuel	CCaLC database
Eggs	2100	Food and Beverages	User defined
Electrical cables	18.1	Electronics	User defined
Fish products	249	Food and Beverages	User defined
Footwear	9	Other	User defined
Fruits	1728	Food and Beverages	CCaLC database
Gasoline	936	Fuel	CCaLC database
Interactive smart boards	1892	Electronics	User defined
Laptops	104	Electronics	User defined
Lawnmower	200	Electronics	User defined
Meat products	1114	Food and Beverages	User defined
Pencils	19.3	Stationary	User defined
Laminating sheets	2.38	Stationary	CCaLC database
Garbage bags	824	Cleaning and Maintenance	Ecoinvent database
Sponges	4.22	Cleaning and Maintenance	CCaLC database
Gloves	128	Cleaning and Maintenance	Ecoinvent database
Printers	170	Electronics	User defined
Printing paper	14100	Paper	User defined
Sand	500	Other	CCaLC database
Single-use dishes	1.3	Other	User defined
Smartphones	5.2	Electronics	User defined
Soap	867	Cleaning and Maintenance	Ecoinvent database
Soft furniture	2889	Furniture	User defined
Spices and salt	40	Food and Beverages	CCaLC database
Sugar	29	Food and Beverages	Ecoinvent database
Tables	11700	Furniture	User defined
Tablets	71	Electronics	User defined
Tap water	13800	Water	Ecoinvent database
Toilet and tissue paper	6734	Paper	User defined
Toner for printing	128	Stationary	Ecoinvent database
Vegetable oils	173	Food and Beverages	CCaLC database
Vegetables	2750	Food and Beverages	User defined
Water, bottled	140	Food and Beverages	CCaLC database
Wheat products	309	Food and Beverages	CCaLC database
Work clothes	138	Other	User defined

Appendix 5 continued

Table 24. Schools (part of Education sector) energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	554815	CCaLC database	110963
Heating	4861709	CCaLC database	379213

Table 25. Schools (part of Education sector) waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, mixed municipal waste	260341	Ecoinvent database	35537
Disposal, biodegradable waste	506	CCaLC database	310
Treatment of wastewater (m^3)	18978	Ecoinvent database	10628
Disposal, paper waste	60753	Ecoinvent database	2430
Disposal, electronic waste	2840	Ecoinvent database	284

Appendix 6. Municipal services sector inventory data

Table 26. Municipal services sectors product inventory

Products	Amount (kg, m^3)	Category	Database
Air conditioner	50	Electronics	User defined
Beds	70	Furniture	User defined
Chairs	16	Furniture	User defined
Cleaners	419	Cleaning and Maintenance	User defined
Computer monitors	14	Electronics	User defined
Dairy products	96	Food and Beverages	User defined
Desktop computers	30	Electronics	User defined
Diesel	581156	Fuel	CCaLC database
Gasoline	27310	Fuel	CCaLC database
Shelfs	250	Furniture	Ecoinvent database
Laptops	18	Electronics	User defined
Lawnmowers	200	Other	User defined
Mattress	30	Furniture	User defined
Passenger cars	8494	Vehicles	User defined
Pencils	1.17	Stationary	User defined
Garbage bags	282	Cleaning and Maintenance	Ecoinvent database
Gloves	15	Cleaning and Maintenance	Ecoinvent database
Printers	35	Electronics	User defined
Printing paper	2785	Paper	User defined
Smartphones	4.4	Electronics	User defined
Soap	127	Cleaning and Maintenance	Ecoinvent database
Tables	210	Furniture	User defined
Tap water	80474	Water	Ecoinvent database
Toilet and tissue paper	546	Paper	User defined
Toner for printing	24.9	Stationary	Ecoinvent database
Water, bottled	362	Water	CCaLC database
Work clothes	282	Other	User defined

Table 27. Municipal services sectors energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	4374873	CCaLC database	874975
Heating	717942	CCaLC database	55999

Table 28. Municipal services sectors waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, mixed municipal waste	74457	Ecoinvent database	6593
Treatment of wastewater (m^3)	60837	Ecoinvent database	34068
Disposal, paper waste	8359	Ecoinvent database	334
Disposal, electronic waste	365	Ecoinvent database	37

Appendix 7. Social services sectors inventory data

Table 29. Social services sectors products inventory

Products	Amount (kg, m^3)	Category	Database
Adult diapers	1878	Other	User defined
Air conditioner	300	Electronics	User defined
Armchair	100	Furniture	User defined
Beds	280	Furniture	User defined
Biscuits and crackers	316	Food and Beverages	CCaLC database
Cabinets	525	Furniture	User defined
Carpet	216	Other	User defined
Chairs	200	Furniture	User defined
Cleaners	1166	Cleaning and Maintenance	User defined
Dairy products	18500	Food and Beverages	User defined
Desktop computers	400	Electronics	User defined
Diesel	5294	Fuel	CCaLC database
Fish products	52	Food and Beverages	User defined
Footwear	1734	Other	User defined
Fruits	112	Food and Beverages	User defined
Gasoline	5436	Fuel	CCaLC database
Laptops	6520	Electronics	User defined
Mattress	450	Furniture	User defined
Meat products	28100	Food and Beverages	User defined
Medical drugs	6	Other	User defined
Pencils	15	Stationary	User defined
Lamps	150	Furniture	CCaLC database
Garbage bags	2432	Cleaning and Maintenance	Ecoinvent database
Sponges	60	Cleaning and Maintenance	CCaLC database
Gloves	633	Cleaning and Maintenance	Ecoinvent database
Power banks	25	Electronics	User defined
Printers	40	Electronics	User defined
Printing paper	1624	Paper	User defined
Single-use dishes	76	Other	User defined
Smartphones	3	Electronics	User defined
Soap	537	Cleaning and Maintenance	Ecoinvent database
Soft furniture	2449	Furniture	User defined
Tables	2660	Furniture	User defined
Tap water	8483	Water	Ecoinvent database
Textile shopping bags	25	Other	User defined
Textile products	58	Other	Ecoinvent database
Toilet and tissue paper	1814	Paper	User defined
Toner for printing	33	Stationary	Ecoinvent database
Vegetable oil	839	Food and Beverages	CCaLC database
Vegetables	21700	Food and Beverages	User defined
Water, bottled	1036	Food and Beverages	CCaLC database
Wheat products	5337	Food and Beverages	CCaLC database
Work clothes	344	Other	User defined

Appendix 7 continued

Table 30. Social services sectors energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	166547	CCaLC database	33309
Heating	426151	CCaLC database	33240

Table 31. Social services sectors waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, lamps	22	Ecoinvent database	0
Disposal, medical waste	232	Ecoinvent database	373
Disposal, municipal mixed waste	20994	Ecoinvent database	1320
Disposal, paper	4360	Ecoinvent database	174
Disposal, biodegradable waste	19	CCaLC database	15
Disposal, electronic waste	452	Ecoinvent database	45
Treatment of wastewater (m^3)	9134	Ecoinvent database	5115

Appendix 8. Sports sectors inventory data

Table 32. Sports sectors products inventory

Products	Amount (kg, m^3)	Category	Database
Cleaners	2641	Cleaning and Maintenance	User defined
Computer keyboards	3	Electronics	User defined
Computer mouses	4	Electronics	User defined
Dairy products	1885	Food and Beverages	User defined
Desktop computers	20	Electronics	User efined
Diesel	1005	Fuel	CCaLC database
Electrical cables	129	Other	User defined
Fruits	1014	Food and Beverages	User defined
Gasoline	1231	Fuel	CCaLC database
Laptops	10	Electronics	User defined
Lighting devices	9	Electronics	User defined
Meat products	485	Food and Beverages	User defined
Printing paper	270	Paper	CCaLC database
Pencils	0.05	Stationary	User defined
Garbage bags	695	Cleaning and Maintenance	Ecoinvent database
Gloves	39	Cleaning and Maintenance	Ecoinvent database
Printers	60	Electronics	User defined
Single-use dishes	1360	Other	User defined
Small metal items	558	Other	User defined
Smartphones	1	Electronics	User defined
Soap	32	Cleaning and Maintenance	Ecoinvent database
Sodium chloride	300	Other	CCaLC database
Soft drinks	6897	Food and Beverages	CCaLC database
Tablets	2	Electronics	User defined
Tap water	31597	Water	Ecoinvent database
Toilet and tissue paper	593	Paper	User defined
Toner for printing	5	Stationary	Ecoinvent database
Vegetable oils	665	Food and Beverages	CCaLC database
Vegetables	4054	Food and Beverages	CCaLC database
Water bottled	6897	Food and Beverages	CCaLC database
Wood	131	Other	CCaLC database
Work clothes	195	Other	User defined

Table 33. Sports sectors energy inventory

Energy	Amount (kWh)	Database	Costs
Electricity	3772339	CCaLC database	754468
Heating	2702693	CCaLC database	210810

Table 34. Sports sectors waste inventory

Waste	Amount (kg)	Database	Costs (euros)
Disposal, municipal mixed waste	55526	Ecoinvent database	3490
Treatment of wastewater (m^3)	31538	Ecoinvent database	17661