RIGA TECHNICAL UNIVERSITY

Rudīte Vesere

WASTE AS AN EFFICIENT RESOURCE ON THE WAY TO A CIRCULAR ECONOMY MODEL

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Electrical and Environmental Engineering
Institute of Energy Systems and Environment

Rudīte Vesere
Doctoral Student of the Study Programme "Environmental Engineering"

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Scientific supervisor
Professor Dr. habil. sc. ing.
DAGNIJA BLUMBERGA

Dr. sc. ing.
SILVIJA NORA KALNIŅŠ

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on November 10, 2022 at 14.00 at the Faculty of Electrical and Environmental Engineering of Riga Technical University, Āzenes iela 12/1, Room 212.

OFFICIAL REVIEWERS

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Pf. D) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Rudīte Vesere ……………………………. (signature)

Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction; 4 Chapters; Conclusion; Recommendation; 39 figures; 14 tables; 10 appendices; the total number of pages is 235, including appendices. The Bibliography contains 125 titles.

CONTENTS

Introduction

As the economy experiences a significant boom, production needs more and more raw materials, and this inevitably has a significant impact on the increase in waste volumes. Irrational consumption of resources is part of the standard business model which is used all over the world in the 20th and 21st centuries and can be defined as a linear economy. The core of the linear economy is the chain "resource extraction – production – use – profit – wasteful business practices at lower costs" which has resulted in short-term consumption products with a significantly low increase in the product's lifetime. As a result of the development of industrialization, population numbers in cities over the period from 1990 to 2015 increased from 14 to 54 %. As a result, the growth of resource consumption/extraction has increased 12 times over the same time period. The amount of CO_2 emissions has also increased accordingly, and 70 % of them are generated in cities. Plastic consumption has increased 20 times since the 1950s. Consumption continues to grow, and correspondingly the amount of waste generated grows as well, some of which is non-recyclable. The natural ecosystem is both a source of raw materials and a destination for the disposal of human-generated waste. The abovementioned made people think of a new economic system that would allow resources to be used as effectively as possible.

The European Union set the transition to a circular economy model as a goal since 2015. On December 11, 2019, however, the European Commission issued The European Green Deal in which it proposed a new growth strategy that aims to transform the European Union into a fair and prosperous society with a modern, resource-efficient and competitive economy, in which economic growth would be decoupled from resources consumption. In accordance with the European Green Deal roadmap (Fig. 1), on March 10, 2020, the EC published the New Circular Economy Action Plan, which defines measures to strengthen the circular economy.

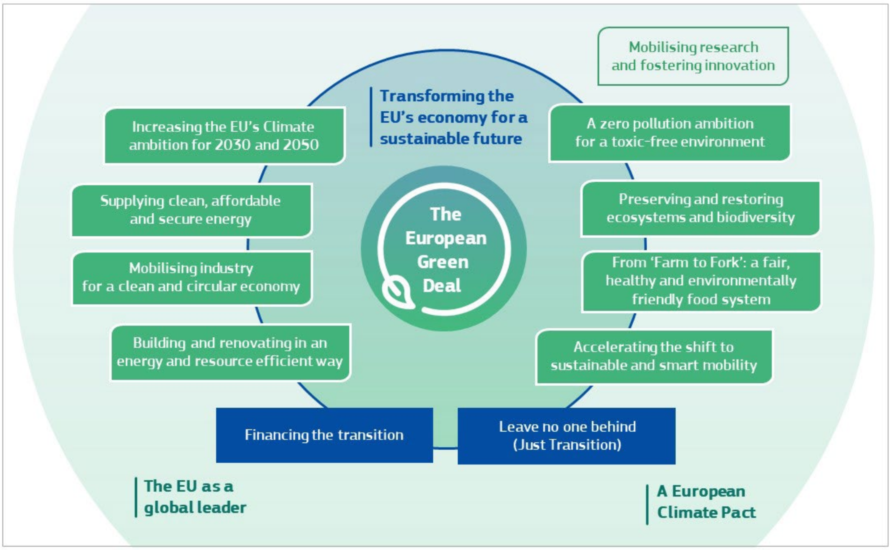

Fig. 1. The European Green Deal roadmap [1].

The Green Deal includes initiatives for the entire product life cycle – from the development and production of a product to its consumption, repair, reuse, recycling and returning resources back into the economy. The measures contained combine the goals of the circular economy and the social economy, creating conditions for the creation of new jobs, supporting green transition and social inclusion [1].

According to one of the leading developers of circular economy principles, the Ellen MacArthur Foundation [2], [3], the circular economy is essentially restorative and regenerative, and within it, society constantly strives to preserve products, components and materials at their highest level of usefulness and value, distinguishing between technological and biological cycles. The circular economy marks the path to a systemic transformation of the national economy and society.

Reducing the volume of waste and thoughtful management is one of the basic elements of the circular economy, and the waste hierarchy is one of the basic principles of waste policy making. There is no longer any doubt that waste can also be a valuable resource. It is essential to recognize that waste is not only an environmental problem, but also a loss for the national economy. In Europe, each resident produces an average of 481 kg of household waste per year. At the same time, more and more of this waste is being recycled and less and less of it ends up in landfills. The task on the way to the circular economy model is to change production and consumption in such a way that there is less and less waste, while the existing waste is used as a resource as much as possible (Fig. 2).

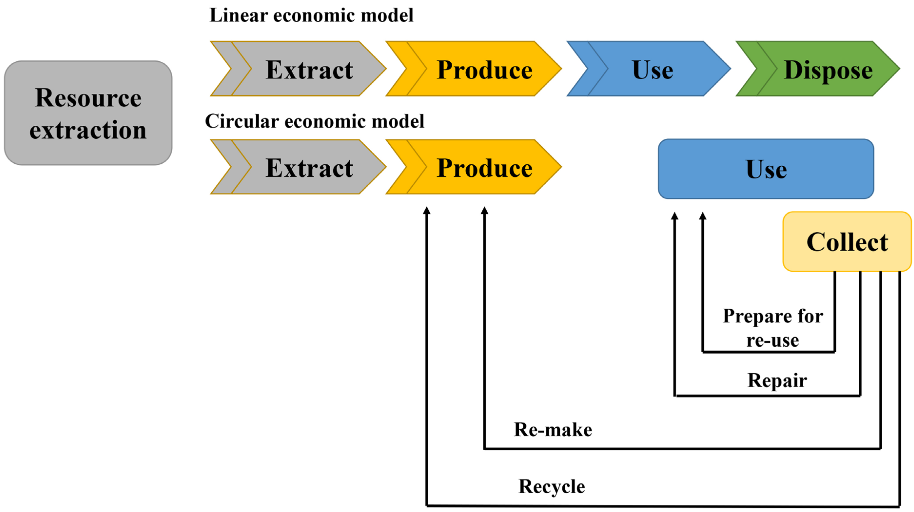

Fig. 2. Comparison of the linear and circular economy models.

The circular economy offers opportunities to increase employment and combat climate change. The main ways to manage generated waste include recycling and reuse, which means thoughtful consumption of resources and long-term benefits. At the same time, it is very important to reduce the amount of generated waste because in this way the consumption of primary resources is reduced and the resources remain in economic circulation for a longer time. This requires changes not only in consumer behaviour, but even more so on the production side, especially in terms of resource extraction and the choice of materials and technologies. In order to achieve the set goals, it is essential to make appropriate choices both when developing the product design and creating the waste management policy, as well as when choosing and developing waste processing technologies for each of the streams and evaluating which of the waste streams and technologies require and allow financial support.

Building a global coalition for action that is both diverse and inclusive brings together businesses, governments, NGOs and scientists to increase capacity to meet the needs of society and to address challenges sustainably (Fig. 3). By closing the loops it is possible to monitor the flow of resources and identify opportunities for recycling or industrial symbiosis [4], [5], [6], [7].

Fig. 3. Measures for transition to a circular economy and for reducing inequality.

Recent challenges include the Covid-19 pandemic, which has accentuated such upheavals to the world's socioeconomic and financial systems as we have not experienced. Therefore, it is important for policy makers, financiers and entrepreneurs who work or want to work in the field of waste management to understand what choices can be made, what assessment methods can be used for decision-making in order to successfully implement the transition to a circular economy model, reduce inequality and make resource use more efficient, bearing in mind that some of the resources available to us are non-renewable and available in limited quantities.

Within the framework of the Doctoral Thesis, certain aspects of the circular economy and the use of research methods for making choices and making decisions in the efficient use of resources, the sustainable development of the waste management system and the reduction of the amount of waste are evaluated, so that in the long term, Latvia can become a country without landfills in which waste is buried, i.e. a country that implements a zero waste strategy.

Relevance of the topic

Already in 2015, the European Commission (EC) issued a statement on the transition to a circular economy. Moreover, in 2018, the EC approved the Circular Economy Package, which resulted in amendments to six directives that provided for ambitious goals in the field of waste management in the period up to 2035. The EC statement "European Green Deal" of December 2019 was released and accordingly on March 10, 2020, the EC published the New Circular Economy Action Plan which defines measures to strengthen the circular economy. The circular economy package implements the EU action plan for transition to a circular economy. An ambitious action program has been created with measures throughout the product cycle: from production and consumption to waste management and the market for secondary raw materials.

According to the Circular Economy Package, EU member states have set qualitative and quantitative goals in the field of waste management, including specific goals for individual waste streams:

1. By 2035 – the proportion of household waste buried in landfills is no more than 10 % of the total amount of household waste generated.
2. By 2035 – the amount of household waste recycling is at least 65 % by mass.
3. By 31 December 2023 – it must be ensured that biological waste which makes up almost 40 % of the volume of household waste is either separated and recycled at the point of origin or collected separately (not mixed with other types of waste).
4. By 1 January 2025 – the establishment of a separate collection system of textile materials.
5. By 31 December 2024 – the establishment of a separate collection system for hazardous household wastes.

Specific goals are also set for waste streams such as construction waste, used packaging, food waste and loss, electrical and electronic equipment waste, batteries, etc.

The indicators which are important in the context of the Thesis are connected in a single causal chain (Fig. 4).

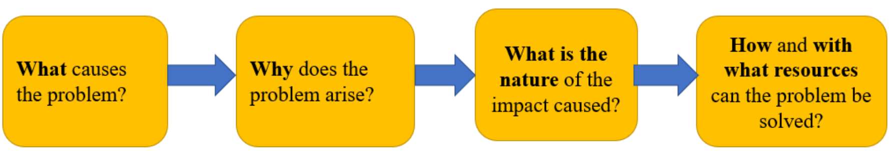

Fig. 4. Single causal chain of indicators.

The indicators must be:

1) credible and scientifically precise;
2) set for a specific timeframe and region;
3) verifiable and comparable;
4) easily perceived and understood;
5) obtained with standardised methodologies and expressed in standardised units of measurement;
6) non-intersecting;
7) useful to the user;
8) sensitive to changes;
9) possible to implement at a reasonable cost.

The need to implement a sustainable development policy, increase resource efficiency and decouple the development of the national economy from the consumption of primary resources, move to a circular economy model and the resulting goals are established in Latvia's national policy planning documents, the main ones in this area being the National

Development Plan 2021–2027, the Action Plan for the Transition to Circular Economy in Latvia 2021–2027 and the State Waste Management Plan 2021–2028 (hereinafter – waste management plan). The policy implemented by the country outlines the new challenges and the way to turn them into opportunities in the field of waste management and efficient use of resources, while also providing for measures to reduce and prevent waste. The waste management plan defines a set of measures to be taken to successfully achieve the goals, calculates the necessary amount of investments required in the development of the waste management system and identifies funding sources. At the same time, there are different ways and methods by which waste can be recycled or regenerated, and it is important to make choices that allow the set goals to be achieved most effectively. The choices are related to the assessment of waste as a potential raw material (usable material that is converted into secondary raw materials from which a new product is produced or energy is obtained that is further used in the national economy) in order to understand which types of waste preparation and use play the most important role in waste management and resource use. The assessment also plays an important role in attracting investments, and in case of limited availability of funding, it allows choosing a more optimal and appropriate method and technology to be financed. This issue is relevant both at the national and at the company level. The process of evaluating the technology of waste management flows is related to the following essential aspects: technological, economic, social, and environmental and climate. Any system can be developed at a maximum level of effectiveness if its development and implementation is based on several cornerstones (pillars):

1. Legal framework from which the general conditions and requirements of the system as a whole and its elements derive.
2. Administrative conditions that, in accordance with the regulatory framework, are imposed on a specific subject in set circumstances, place and environment.
3. Technological solutions and best available techniques.
4. Environmental aspects (the impact on the environment of operations and measures or activities for reducing or eliminating these negative impacts).
5. Impact on climate change of the actions to be taken.
6. Economic instruments that motivate to take thoughtful, sustainable decisions and to make respective choices, including changes in behaviour.
7. Social aspects.
8. Educating society and informing the public.

The legal framework for the implementation and development of the waste management system is defined both at the EU and national level. On the other hand, administrative conditions derive from the regulatory framework. The economic instruments used within the waste management system in different countries are developed according to common principles, they are comparable but not unified. In the case of Latvia, the most important economic tool in waste management is the tax on natural resources, which motivates to make thoughtful and sustainable decisions and to reduce both the amount of waste as such and the amount of waste to be sent to landfill. Green public procurement is used to promote organizations to choose goods made from secondary raw materials.

Climate change policy based on the Sustainable Development Goals (SDGs) is the inspiration for many types of businesses that combine value creation with environmental and social protection. The perceptions and understanding of participants in the economic process affect how much attention they pay to the potential of the proposed circulation business models. In order to prepare participants in innovation for experiments and increase their ability to reflect on their life assumptions, a set of principles is proposed [8], [9].

Companies are looking for ways to develop in a competitive environment with innovative business models while respecting society and avoiding activities that harm the environment and its quality. Directions such as the circular economy, fair trade, shared economy are some of the new business approaches that address this problem, but there is still a gap between theoretical arguments and the level of environmental and social sustainability implemented in practice [10].

A circular economy could be described as a network of smaller circular economies where the main development takes place in local areas, such as cities or regions, with the active involvement of territorial stakeholders. The active role of social entrepreneurs in supporting the transition in the regions highlights the great variety of challenges they face in developing local business models at the technological, social and political levels [11]. Changes at the level of society and the complexity of socio-ecological systems require a holistic approach and foresight in the development of strategies, policies and programs [9]. It is also important to emphasize the role of social entrepreneurship, as it is an integral part of Europe's diverse social market economy. For the promotion of social enterprises, it is especially important to introduce circular economy elements into the daily activities of the social enterprise.

An important section is the use of various financial sources in the development of the waste management system, choosing and implementing recycling and recovery technologies and methods. At the moment, there is no unified approach to the evaluation of options and applicable research methods in Latvia. It should be noted that there is no uniform approach in this aspect of waste management in the EU member states (MS), which is related to the different situations of each MS in terms of the development of management systems, which is related to the country's economic and geographical situation (landscape, availability and diversity of resources, population and density), the development level of the management system, the habits, skills and knowledge of the population.

Purpose and tasks of the RESEARCH

The goal of the Thesis is to evaluate certain aspects of the circular economy in the efficient use of resources, the sustainable development of the waste management system and the reduction of the volume of waste and to develop recommendations for decision-making for policy makers, financiers and entrepreneurs who work or want to work in the field of waste management, so that in the long term, Latvia may become a country without landfills and implement a zero waste strategy (Fig. 5).

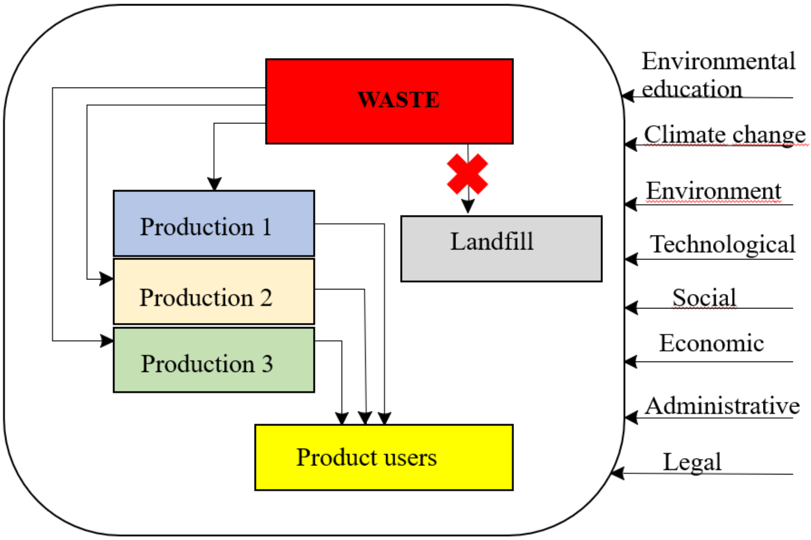

Fig. 5. Development of a sustainable waste management system towards a zero waste strategy.

One of the tasks of the Doctoral Thesis is to evaluate the application of various research methods for the selection of priority technologies in waste management for individual waste streams in Latvia. It is essential to find out whether and which scientific research methods can be used in the evaluation of waste as potential raw materials and technologies, so that, as a result, money givers and money recipients can make well-considered and justified choices. Waste streams for which sufficient data are available and for the management of which development plays a particularly important role for Latvia in achieving EU goals have been selected for the study – paper, beverage packaging, textiles, biological waste and the use of waste for energy production, which are particularly relevant in the context of the energy resource crisis. By increasing the volumes of waste processing and regeneration, the amount of waste to be buried in landfills is correspondingly reduced.

Within the scope of the second task, the application of various research methods for the selection of alternatives and decision-making on the economic and social aspects of waste management on the way to achieving circular economy goals was evaluated, including evaluating the impact of external conditions – the COVID-19 pandemic – on transition to the circular economy.

The third task of the research is related to the role and place assessment of green companies, green workplaces and society's green activities in waste management, respecting the hierarchy of waste management and emphasizing waste volume reduction and prevention.

The Thesis examines social entrepreneurship in the field of textiles, as this is a waste stream that has new specific objectives and therefore needs to be managed in a more sustainable way as so far.

The research refers to Latvia's waste management system and has been carried out in compliance with the requirements of the EU and national policy planning documents and regulatory acts and using the experience of other countries. Research data management, which includes the planning, creation, processing, analysis, storage, sharing and reuse of data, is also an essential aspect.

Scientific novelty

Research innovation is the use of various methods for the selection of technology, criteria, directions of action and measures for the development, improvement and optimization of the waste management system in the transition to the circular economy model, within the framework of several interrelated aspects: political and legal regulation of the sector, economic instruments, social inclusion and environmental and climate impacts for change, as part of the social dimension.

The innovation of the research is the use of several academic methodologies together for the effective development of the waste management system and recommendations for the implementation of the circular economy in Latvian economic sectors at the micro, meso and macro level.

The novelty of the research is underlined by the fact that in Latvia there is no unified approach to the evaluation of options and whether and how to use research methods for attracting and using different financial sources in the development of the waste management system, choosing and implementing recycling and regeneration technologies and methods and making decisions on measures for the transition to a circular economy. It should be noted that neither in Latvia nor in Europe studies and evaluations been carried out on green business, green workplaces, the aspects and approaches that motivate their development, and public initiatives in the field of waste management to reduce resource consumption and the amount of generated waste and to increase the amount of secondary raw materials use in the economy.

A new approach is also the evaluation of green entrepreneurship, green workplaces, the aspects that motivate their development and the public initiatives promoting them in the field of waste management in Latvia in order to reduce the consumption of resources, the amount of generated waste and to increase the use of secondary raw materials in the national economy using scientific research methods.

Hypothesis

The hypothesis of the study is the assumption that usage of scientific research methods in the decision-making and decision-making process supports Latvia to reach the status of a resource-efficient country in the long term, which implements a circular economy model and a zero waste strategy (the amount of generated waste decreases and the amount of waste disposed of in landfills approaches zero) and achieves more sustainable results. For each waste stream or type of processing, several research methods are applied, respecting the reusability of data and methods and forming a complex approach allowing to make thoughtful and more sustainable choices and make decisions about waste processing and regeneration technologies to be used as well as measures to be implemented for the transition to a circular economy and financial sources because not all aspects can be evaluated with one method. Such an approach would be applicable both at the national level in economic processes and also at the level of companies.

Structure of the thesis

The basis of the dissertation is a set of ten scientific publications where attention is emphasized on the evaluation of the selection and decision-making of the management methods of individual waste streams. Since the Thesis is developed on the basis of the publications, specific references to them are not inserted in the text of the Thesis.

As part of the Doctoral Thesis, (I) a macroeconomic assessment of the transition to a circular economy has been carried out; (II) an analysis of interrelated policy and waste collection, recycling and regeneration engineering solutions for waste streams such as used paper has been conducted; (III) a multi-criteria analysis of the use of waste for energy production has been carried out; and (IV) an evaluation of the role of green workplaces within the framework of the waste management system in the transition to the circular economy has been performed. The issue requires a multi-dimensional and methodological approach. Multicriteria analysis, TOPSIS analysis method, statistical data collection and further analysis, comparative analysis and cost-benefit analysis, interviews and impact modelling were used as part of the Thesis. The research evaluated the stages, tasks and activities of sustainable waste management, the impact of waste on the environment and climate change, social aspects, the economic instruments used in waste management policy and the impact of external factors (the impact of the COVID-19 pandemic).

Various methods were used in the course of this research to evaluate aspects of the circular economy in the efficient use of resources and the reduction of the amount of waste and thoughtful management in accordance with the hierarchy of waste management (Fig. 6), (Table 1).

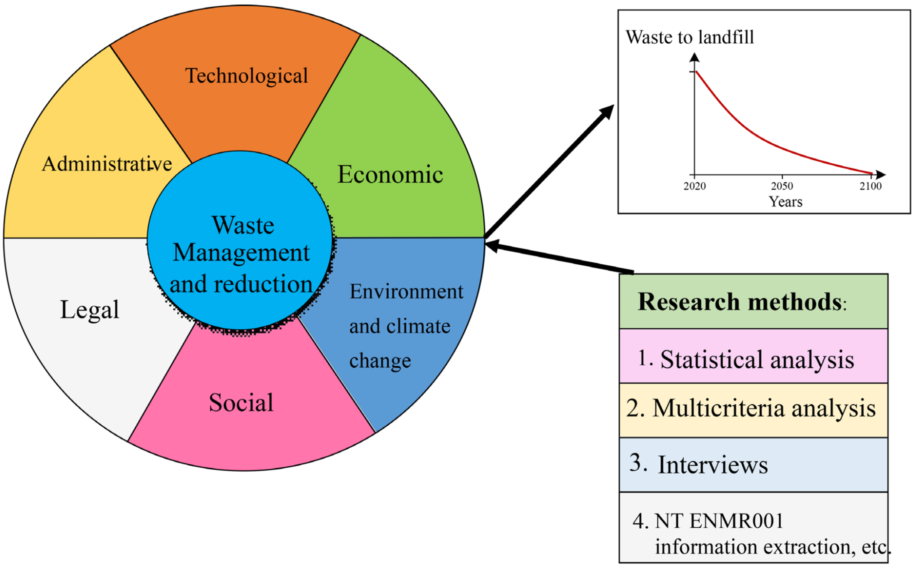

Fig. 6. Application of different research methods to choose an alternative and to use in decision-making.

Table 1

An overview of the methods and publications of the Doctoral Thesis when making assessment for the selection of the most effective waste recycling/recovery technologies/methods and management alternatives for different waste streams for decision-making

User level	Method	Publi-cation	Publication Title	Connection
Global and national	Statistical data collection method and method of determining waste composition "NT ENVIR 001"	1	**Towards efficient waste management in Latvia: an empirical assessment of waste composition.**	Prerequisites for transition to a circular economy, efficient use of resources and reduction of waste.
National, sectoral	Multicriteria analysis	2	**Paper waste recycling. Circular economy aspects.**	1. Recycling and regeneration. 2. Resource consumption and long-term benefits.
National, sectoral	TOPSIS multicriteria analysis	3	**Circular economy analysis. Ranking of energy resources from waste.**	1. Recycling and regeneration. 2. Resource consumption and long-term benefits.

Table 1 continued

National, sectoral	Statistical data collection and analysis, comparative analysis and cost and benefit analysis	4	**Analysis and economic evaluation of deposit refund system.**	1. Re-use. 2. Recycling and regeneration.
Entrepreneurial and individual	Critical analysis, case studies, synthesis and comparative analysis	5	**The goals of Waste Framework Directive as mechanism securing transition to circular economy**	Prerequisites for transition to a circular economy, efficient use of resources and reduction of waste.
National	Modelling	6	**Sustainable national policy planning with conflicting goals.**	1. Sustainable development. 2. Prerequisites for transition to a circular economy, efficient use of resources and reduction of waste.
National, entrepreneurial, individual	Secondary data analysis, structured interviews, critical data analysis, comparative analysis	7	**Challenges of textile industry in the framework of circular economy: case from Latvia.**	1. Recycling and regeneration. 2. Resource consumption and long-term benefits. 3. Social aspects.
Global, national, sectoral, entrepreneurial	TOPSIS multi-criteria analysis	8	**Role of green jobs in the reduction of waste and in waste management.**	1. Sustainable development. 2. Prerequisites for transition to a circular economy, efficient use of resources and reduction of waste. 3. Social aspects.
Global and national	Secondary data analysis, impact modelling	9	**Influence of COVID-19 on waste management and circular economy.**	1. Resource consumption and long-term benefits. 2. Social aspects.
Global and national	Critical analysis, case studies, development of a matrix for the circular economy action plan	10	**Alignment of circular economy business models for framing national sustainable economic development.**	1.Resource consumption and long-term benefits. 2. Prerequisites for transition to a circular economy, efficient use of resources and reduction of waste.

It was important to find out whether the application and combination of different research and analysis methods with the aim of determining the best/most effective waste recycling/regeneration alternative for different waste streams are applicable and help to make decisions in selecting technologies and operations .

In the creation and management of research data, the FAIR data principles are used for the involved parties, which means that the data can be found, are accessible, interoperable, and reusable. The FAIR principles (Fig. 7) apply not only to the creation and use of data, but also to research methods, with special emphasis on the reusability of data and methods. This approach was used in conducting the research.

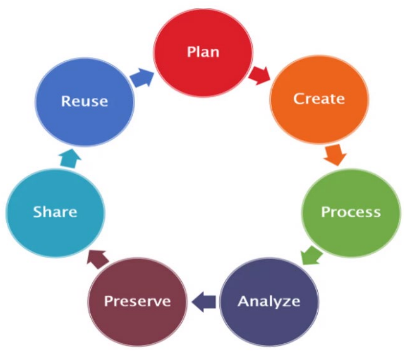

Fig. 7. FAIR data and approach.

Approbation of the scientific research

Scientific publications

7 articles are indexed in SCOPUS and 7 articles and papers are indexed in conference proceedings in Web of Science.

1. Vesere R., Kalnins S. N., D Blumberga D. Role of Green Jobs in the Reduction of Waste and Waste Management, Environmental and Climate Technologies 25 (1), 1128–1141, 2020 IEEE 61st International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), DOI:10.1109/RTUCON51174.2020.9316553; indexed in SCOPUS and Web of Science.

2. Vesere R., Lauka D., Blumberga D., Kalnins S. N. Circular Economy analysis. Ranking of energy resources from waste, 2020 IEEE 61st International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), DOI:10.1109/RTUCON51174.2020.9316553); indexed in SCOPUS and Web of Science.

3. Kubule A., Kļavenieks K., Vesere R., Blumberga D. Towards efficient waste management in Latvia: an empirical assessment of waste composition, Institute of Energy Systems and Environment, Riga Technical University, Environmental and Climate Technologies, 2019, Vol. 23, No. 2, pp. 114–130. ISSN 1691-5208. e-ISSN 2255-8837. DOI:10.2478/rtuect-2019-0059; indexed in SCOPUS and Web of Science.

4. Ozola Z. U., Vesere R., Blumberga D., Kalnins S. N. Paper Waste Recycling. Circular Economy Aspects, Institute of Energy Systems and Environment, Riga Technical University, Environmental and Climate Technologies, 2019, Vol. 23, No. 3, pp. 260–273. ISSN 1691-5208. e-ISSN 2255-8837. DOI:10.2478/rtuect-2019-0094; indexed in SCOPUS and Web of Science.

5. Atstaja D., Luksevica L., Cudecka-Purina N., Vesere R., Susniene R. Analysis and Economic Evaluation of Deposit Refund System, "SOCIETY. INTEGRATION. EDUCATION. Proceedings of the International Scientific Conference. Volume VI, May 24–25, 2019, pp. 17–27; indexed in Web of Science.

6. Cudecka-Purina N., Atstaja D., Vesere R. The goals of waste Framework Directive as mechanism securing transition to Circular Economy, New Challenges of Economic and Business Development – 2019: Incentives for Sustainable Economic Growth, collection of articles; indexed in Web of Science.

7. Cilinskis E., Vesere R., Blumberga A., Blumberga D. Sustainable National Policy Planning with Conflicting Goals, Institute of Energy Systems and Environment, Riga Technical University, Energy Procedia, Latvia, Riga, 12–14 October 2016. Germany: Elsevier, 2017, pp. 259–264. ISSN 1876-6102. DOI: 10.1016/j.egypro.2017.04.063; indexed in SCOPUS and Web of Science.

8. Atstāja D., Cudečka-Puriņa N., Vesere R., Abele L., Spivakovsky S. Challenges of textile industry in the framework of Circular Economy: case from Latvia, International Conference on Sustainable, Circular Management and Environmental Engineering (ISCMEE 2021), E3SWeb of Conferences ISCMEE, 2021, 255, 01014, DOI: https://doi.org/10.1051/e3sconf/202125501014; indexed in SCOPUS and Web of Science.

9. Atstaja D., Cudečka-Puriņa N., Vesere R. Influence of COVID-19 on waste management and Circular Economy, Knowledge management Competence for achieving competitive advantage of professional growth and development. Collective monograph, BA School of Business and Finance, Riga, Latvia 2021.

10. Atstaja D., Cudecka-Purina N., Hrinchenko R., Koval V., Grasis J., Vesere R. Alignment of Circular Economy Business models for framing national sustainable economic development, Acta Innovations, 2022, No. 42: 5–14, DOI:10.32933/ActaInnovations.42.1; indexed in SCOPUS and Web of Science.

Presentations of the results at scientific conferences

1. Atstaja D., Luksevica L., Cudecka-Purina N., Vesere R. Analysis and Economic Evaluation of Deposit Refund System // SOCIETY. INTEGRATION. EDUCATION. VI International Scientific and Practical Conference. November 2017, Rezekne Academy of Technologies, Rezekne, Latvia.

2. Cudecka-Purina N., Atstaja D., Vesere R. The Goals of wase framework directive as mechanism securing transition to circular economy, New Challenges of Economic and Business Development 2019: Incentives for Sustainable Economic Growth: PROCEEDINGS 11th international scientific conference, Faculty of Business, Management and Economics, University of Latvia, May 2019, Riga, Latvia.

3. Ozola Z. U., Vesere R., Kalnins S. N., Jansone Z., Blumberga D. Paper Waste Recycling. Circular Economy Aspects // International Scientific Conference Environmental and Climate Technologies, CONECT 2019, May 2019, Riga, Latvia.

4. Klavenieks K., Kubule A., Vesere R., Blumberga D. Towards efficient waste management in Latvia: an empirical assessment of waste composition // International Scientific Conference of Environmental and Climate Technologies, CONECT 2019, May 2019, Riga, Latvia.

5. Atstaja D., Cudecka-Purina N., Vesere R. Application of circular economy business models to Latvian economics, 13th Annual Scientific Baltic Business Management Conference "Business and finance multi-perspectives of the Digital Age (ASBBMC), February 2020, Riga, Latvia.

6. Vesere R., Kalnins S.N., Blumberga D., Circular Economy analysis. Ranking of energy resources from waste, International Scientific Conference of Environmental and Climate Technologies, CONECT 2020, May 2020, Riga, Latvia.

7. Vesere R., Kalnins S.N., Lauka D., Blumberga D. Circular Economy analysis. Ranking of energy resources from waste, IEEE 61st International Scientific Conference on Power and Electrical Engineering of Riga Technical University RTUCON 2020, November 2020, Riga, Latvia.

8. Atstāja D., Cudečka-Puriņa N., Vesere R., Abele L. Challenges of textile industry in the framework of Circular Economy: case from Latvia, International Conference on Sustainable, Circular Management and Environmental Engineering (ISCMEE 2021), April 2021, online: Zoom, Odesa, Ukraine.

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Practical significance

The methods used in the development of the Doctoral Thesis show that in order to choose technologies or make decisions in the field of waste management and circular economy, it is necessary to use different research methods and to use them in combination with one another because not all aspects can be evaluated with one method. The use of research methods in the field of waste management and circular economy will make choices and decisions thoughtful and justified. They will be useful for:

1) entrepreneurs in choosing technologies in waste management;
2) planners and policy makers in the evaluation of effectiveness of the existing circular economy strategy, the evaluation of economic sectors in order to develop short-term and long-term action plans, in providing practical solutions and creating an approach enabling to respond to crisis situations as effectively as possible and create strategies for crisis situations;
3) financial donors in evaluating the compliance of the applied and supported projects with progress towards the circular economy model and priorities.

When applying research methods to choose technologies and make decisions in the field of waste management and the circular economy, the combination of the methods is necessary due to the complexities in waste management, which means that not all aspects can be evaluated with one method.

In the creation and management of research data, it is important that the parties involved use the principles which are defined to promote the maximum use of research data, that is, FAIR data is findable, accessible, interoperable and reusable. The FAIR approach applies not only to the creation and use of data, but also to research methods, with special emphasis on the reusability of data and methods. The methods used in the development of the work can be used for the selection of other waste management methods and technologies, for the selection of measures and for policy making in the field of waste management and circular economy, and it is necessary to use them to implement meaningful measures. These measures are to be based on comparable indicators, indicators and data, as well as through the application of methods.

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1. Literature review – waste management system in transition to a circular economy model

The need to develop guidelines for the national model for transition to the circular economy is closely related to the specifics and strategy of the transition from the linear economy with appropriate financial stimulating measures to ensure the fulfilment of environmental requirements and environmental quality assurance in all areas of production. Studies on the transition from the linear to circular economy, which can be developed and implemented as part of a green recovery package, show the roles of stakeholders in the implementation of circular economy in companies, which has not been thoroughly studied[12], [13]. It has been concluded that sustainable business models are able to produce and maintain environmental, social and economic value [14]–[18].

1.1. Methods of processing and regeneration of individual waste streams

In the world, on average 58 % of paper waste is recycled. Europe has the highest paper recycling rate in the world. Already in 2017, 72.3 % of the total paper waste in Europe was recycled. It is also important to note the fact that there are types of paper waste that cannot be recycled, such as coffee filters. Considering this non-recyclable waste, the maximum recycling percentage is theoretically estimated to be 78 % instead of 100 %. The priority is the prevention of waste, as well as the impact of the paper and cardboard production process on the environment and the collection and recycling of these products [19], [20].

Waste prevention is the highest point in the waste management hierarchy. Incineration of waste with energy extraction and beneficial use is permissible in cases where the specific waste cannot be processed for economical or technical reasons but at the same time has a high calorific value. At the same time, the use of energy obtained from appropriate treatment of waste provides many benefits, including reducing greenhouse gas emissions, diversifying the energy supply, ensuring the use of local energy resources, and reducing dependence on fossil fuel markets (especially oil and gas) [21], [22].

In order for waste to be used for processing as efficiently as possible and for the obtained raw material or product to have the highest possible added value, it is important how the waste is collected and prepared for processing or regeneration. Waste can be used efficiently if it is collected separately. This can be done in two ways – using shared collection containers or through a deposit system. In both cases, the principle of producer responsibility is implemented. As part of the packaging deposit system, an additional deposit fee is applied to beverage packaging (glass bottles, PET bottles, cans), which can be recovered by the consumer by handing over the used packaging to a point of sale or at specially designated acceptance points [23]–[27]. Products such as water, soft drinks and alcoholic drinks with an alcohol content of up to 10 % (beer, cider, cocktails, etc.) are included in the deposit system. One of the solutions proposed by several researchers in their studies is that the system includes all packaging materials, with exceptions for some products [24], [26], [28]. By implementing the deposit system, countries contribute to the reduction of increasing environmental pollution. The deposit system was introduced in Latvia on February 1, 2022.

1.2. Development of waste management system as a component of circular economy, implementation of goals and of business

Textile products play a vital role in our society, providing us with clothes, shoes, carpets, curtains, furniture, etc. for homes, offices and public buildings. The total textile waste in Latvia is about 27,000 t, which is 3–5 % of the total household waste generated in the country, or about 14.3 kg of clothes per inhabitant [29]. After disposal, only 20 % of clothing waste is collected for reuse and recycling at the global level [30], [31]. When evaluating the strategies implemented by textile companies in terms of the circular economy, it was identified that these companies are engaged in social entrepreneurship.

The year 2020 has gone down in history as a turning point in many aspects. Waste management and the circular economy are no exception. The outbreak of the coronavirus disease (COVID-19) in late 2019 was much more than a global health crisis. The COVID-19 pandemic has distorted the assumptions of how the world works, revealing the absolute lack of resilience of the dominant economic model to respond to unplanned shocks and crises [32]–[34]. The pandemic has changed the dynamics of waste generation, creating challenges for policy makers and workers involved in the provision of medical services [35]. A completely new stream of waste found its way to the streets and household waste bins: personal protective equipment (PPE). The pandemic has forced many countries to seriously consider the need for a circular economy framework at the national level [36]. The transition to a circular economy requires systemic change and a holistic, integrated approach that takes into account the links within and between sectors, throughout the value chain and within value chains, as well as among civil society and stakeholders [37]. The circular economy of the company can be applied by creating a business model or transforming existing business elements [38]–[41] (Fig. 1.1).

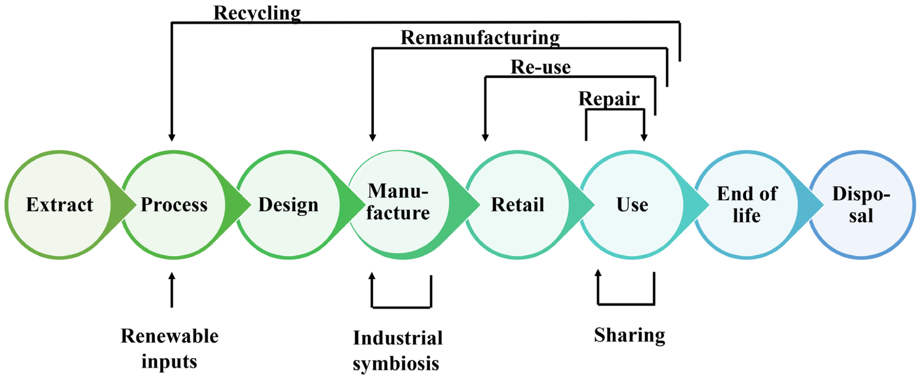


Fig. 1.1. Impact of the circular economy on linear business processes [41].

1.3. The role of green jobs in the circular economy model for the effective use of resources and for waste volume reduction and management

During the Doctoral research, one of the aspects of sustainable development and circular economy was also assessed – the social aspect and progress, based on the experience and research of various countries, with an emphasis on green business, green workplaces, the aspects and approaches that motivate their development, and public initiatives promoting them. It is widely recognized that a successful transition to a green, resource- and energy-efficient economy will transform labour markets [42]–[48]. Green jobs help to improve energy and raw material efficiency, limit greenhouse gas emissions, reduce the amount of waste in general and that which is landfilled in particular, as well as reduce pollution emissions into the environment and protect and restore the ecosystem [42]–[45]. In order to promote the adaptation of the workforce, as well as education and training systems, targeted action by state institutions is needed to support transition to an effective response of education and training systems to new skills and qualification requirements. This requires reviewing and updating qualifications and relevant education and training programmes [42], [46].

2. Research methods

In the course of the research work, various research methods were used and the experience gained in areas related to waste management and the transition to a circular economy. The Doctoral Thesis offers a methodological approach that interlinks national policy indicators and industry models in order to create more effective decision-making mechanisms.

2.1. Research methods for choosing priority technologies in waste management for individual waste streams in Latvia

Multi-criteria decision-making method (TOPSIS)

The evaluation of alternatives according to qualitative and quantitative criteria was also used in order to be able to choose the most optimal technology and method for using waste for energy production. To choose the optimal technology and method for waste use in energy production, the assessment of alternatives in accordance with qualitative and quantitative criteria was made. In both cases, technological solutions are evaluated and the multi-criteria decision-making method (TOPSIS) was applied.

The TOPSIS Multi-criteria decision-making method presents the possibility to choose an unlimited number of criteria and alternatives [49]–[51] and TOPSIS results allow for the comparison of alternatives in a convenient and easy-to-understand manner.

Using the TOPSIS analysis method, a decision-making matrix D is created, consisting of criteria and alternatives, as shown in formula (2.1):

$$D = \begin{matrix} & \begin{matrix} C_1 & \cdots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} & \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \end{matrix}, \qquad (2.1)$$

where:

$A_1 \ldots A_m$ – alternatives for comparison;

$C_1 \ldots$ iC_n – criteria according to which the comparison is made;

x_{ij} – performance/value of alternative i (i is alternative 1 to m) according to criterion j (j from 1 to n).

In the case of evaluating waste as an energy material, applying the TOPSIS method, five alternatives were chosen as a method for evaluating alternatives based on qualitative and quantitative criteria – waste as an energy resource, which was evaluated based on four criteria: technological, economic, social, as well as environmental and climate aspects.

For each criterion, its individual weight w_i is determined (2.2).

$$\sum_{i=1}^{n} w_i = 1 \qquad (2.2)$$

The weight of the criteria is set based on expert opinion.

When the decision-making matrix is developed, a normalization of the values is conducted, and a normalized decision-making matrix is prepared (2.3).

$$D_{\text{norm}} = \begin{matrix} & C_1 & \cdots & C_n \\ A_1 & r_{11} & \cdots & r_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ A_m & r_{m1} & \cdots & r_{mn} \end{matrix}, \quad (2.3)$$

where r_{ij} is normalized value of alternative i according to criterion j.

The normalized value is calculated using the following formula (2.4):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}. \quad (2.4)$$

In the next step the normalized values are multiplied by weight w_i of the corresponding criterion i, resulting in the normalized weighted value p_{ij}, as indicated in formula (2.5):

$$p_{ij} = w_i \cdot r_{ij}. \quad (2.5)$$

The normalized weighted decision-making matrix D_{sv} provides the basis for the TOPSIS analysis (2.6).

$$D_{\text{sv}} = \begin{matrix} & C_1 & \cdots & C_n \\ A_1 & p_{11} & \cdots & p_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ A_m & p_{m1} & \cdots & p_{mn} \end{matrix} \quad (2.6)$$

Then, the distance of each alternative from the positive ideal solution and negative ideal solution was calculated. The result is a value that shows the distance of the alternatives from the ideal positive solution and the ideal negative solution.

The multi-criteria analysis method was also used in the assessment of paper waste recycling technologies and methods. In this case, it was based on a gradual principle and included five steps – criteria selection, data entry, method application, result extraction and analysis (Fig. 2.1).

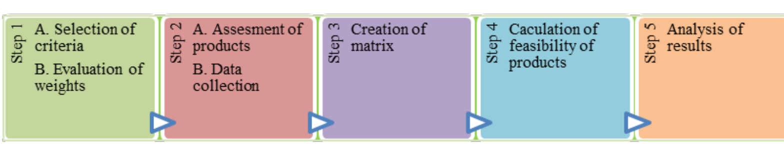


Fig. 2.1. Methodological approach step-by-step.

The criteria have been created in such a way that they can be compared using the specific indicator – per ton of waste.

Multi-criteria analysis TOPSIS was also used to evaluate the role of green companies, green workplaces and public activities in the development of the circular economy, including the waste management system.

NT ENVIR 001 method for obtaining information

In order to evaluate which of the alternatives is the most advantageous or disadvantageous, which recycling technological solution is more sustainable, the flow, volume and availability of raw materials (appropriately prepared waste) is an important aspect. In order to obtain detailed information on the composition of unsorted household waste in cities in Latvia, to ensure a wide geographical coverage and to enable the collected data to be used in the future for the evaluation of the aspects that affect the composition of unsorted household waste and which would allow the analysis of the applied experimental methods, the physical sorting method "Nordtest" was applied – NT ENVIR 001 [52], as well as the developed methodological tool for improving the accuracy and comparability of solid waste analysis data (SWA Tool) [53] and CEN Standards and Technical Recommendations [54]. The NT ENVIR 001 [52] method has been developed to provide a uniform approach to waste composition analysis and is primarily intended for Northern European countries. Analysing the application possibilities of this method in Latvia, it was concluded that there are no limitations to either methodological or material-technical solutions, as a result of which the method can be recognized as appropriate for conditions in the country. In order to obtain the most comprehensive data on unsorted domestic waste flows in the country, 32 cities in different regions of Latvia were selected for the study based on the number of inhabitants and the administrative division of territories. The classification of waste fractions to be sorted was determined according to NT ENVIR 001 methodology [52] and standard LVS EN 15440: 2011 "Solid regenerated fuel – biomass content determination methods" [55].

Data preparation and preliminary analysis was carried out using MS Excel software; for further statistical data analysis on the analysis of interrelationships between waste composition and socio-economic factors, both MS Excel and Statgraf software.

2.2. Research methods related to reaching the goals of waste management and the circular economy

This section examines the application of various research methods for the selection of alternatives and decision-making on the economic and social aspects of waste management.

Statistical analysis, cost-benefit analysis and mathematical modelling

As part of the study, the application of the deposit system at the level of the European Union was analysed determining its sustainable development in the future and an economic evaluation of the deposit system was carried out when introducing it in Latvia. Statistical analysis, scientific analysis, content analysis (method of textual data analysis), cost-benefit analysis and mathematical modelling were all used in the process of analysis and economic evaluation of the deposit system.

A Venn diagram, or set diagram, which represents all possible logical relationships among sets of a finite number, represents the range of products and packages relevant to the deposit system (see Fig. 2.2).

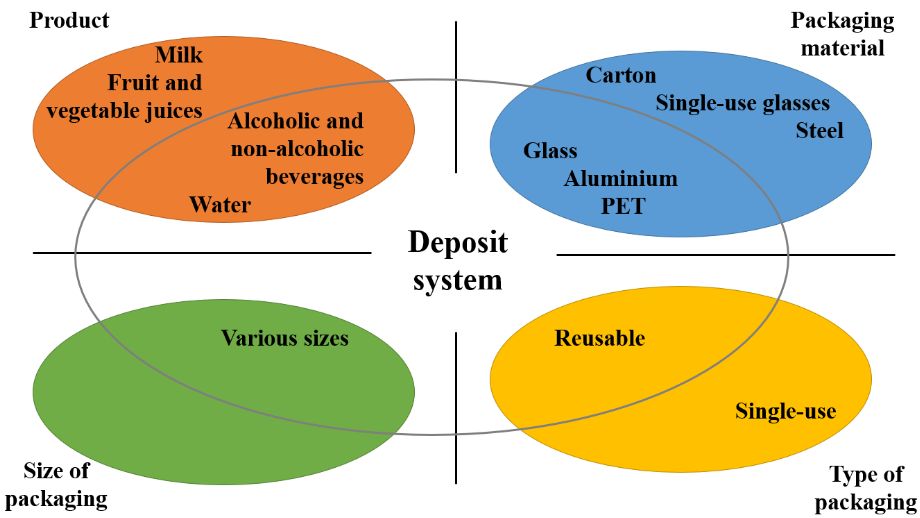
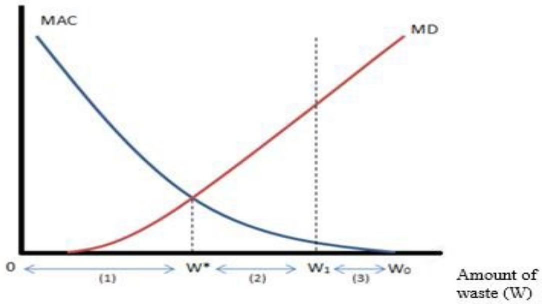


Fig. 2.2. Types of products and packaging in the deposit system.

The types of products that are included in the deposit system are water, non-alcoholic beverages and alcoholic beverages that contain less than 10 % alcohol (beer, cider, cocktails, etc.) [45], [46].

The optimal volume of waste is illustrated in Fig. 2.3.



(1) Generated waste
(2) Waste that needs to be diverted from landfill to recycling or re-use, via the deposit system
(3) Actual waste recycling and reduction in landfill

Fig. 2.3. Amount of waste and optimal management [29].

The marginal cost reduction curve (MAC-marginal abatement costs) includes the costs of treating an additional unit of waste, and the marginal damage curve (MD-marginal damage) includes the damage to public welfare caused by an additional unit of waste (calculated in euro). The optimal waste level (W*) is located at the intersection of MAC and MD. To the left of this point, the cost of reducing waste is greater than the benefit of harm (MAC>MD), which would mean a reduction in the welfare for society. To the right of this point are the benefits of returning used packaging. The benefit from the reduced amount of waste is greater than the cost (MAC<MD), which leads to the conclusion that it is beneficial for society to reduce waste amounts.

If it is assumed that the amount of waste in the economy is equal to W1, then the waste is recycled and reduced to W0–W1 and it is clear that W1–W* is the level of waste that can be reduced by introducing a deposit system. When introducing a deposit system, it is important to assess what advantages the system will be able to provide and whether the advantages will outweigh the disadvantages. Consumers' willingness to return used packaging and the marginal costs incurred by consumers when returning used packaging are illustrated in Fig. 2.4.

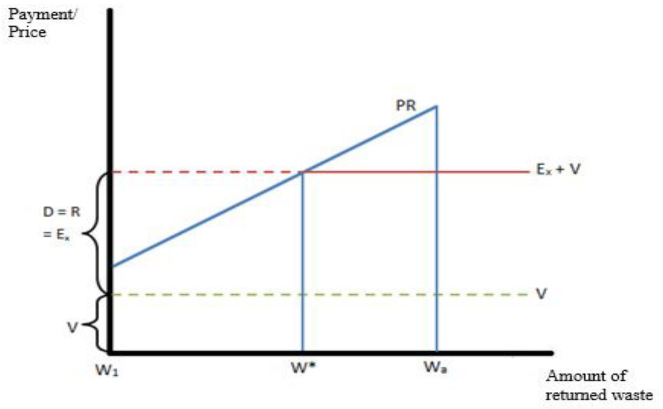


Fig. 2.4. Diagram of the deposit system.

The PR curve derives from W1, which is the pollution level – the maximum amount of waste not recycled by society.

Assuming that the manufacturer maximizes profit, it can be seen that the manufacturer wants to use the returned packaging for reuse in order to reduce the cost of production. This is why the manufacturer would like a deposit system to be implemented, but to make the deposit system profitable for the manufacturer, the manufacturer offers compensation that is less than the cost of the reuse of the returned packaging (R<V).

The purpose of the cost-benefit analysis is to assess the contribution of the introduction of the deposit system to public welfare [56], [57]. In order to evaluate the benefits and losses of the deposit system, the calculation uses indicator NPV – net present value. The net present value is calculated according to formula (2.7) [58].

$$NPV(t) = \sum_{i=t}^{T} \frac{CF(i)}{(1+r)^i} - ICO, \quad (2.7)$$

where *CF* is cash flow; *i* is time period; *r* is discount value; and *ICO* is initial investment value.

In addition to a cost-benefit analysis, a sensitivity analysis, multi-criteria analysis and analysis of relevant alternatives were also performed to gain additional confidence in the results obtained. In order to make the cost-benefit analysis more accurate, it is important to perform not only a sensitivity analysis, but also a statistical analysis of the beverage packaging. The average package handling fees of producer responsibility systems (RAS) were taken into account in the calculation of total packaging management costs. Within the framework of the study, no significant changes in macroeconomic indicators (population, purchasing power, GDP, etc.) were foreseen.

Economic assessment of paper recycling

A cost modeling approach is used to forecast or estimate the future costs of a manufactured good or service based on facts and figures available at a given moment (Fig. 2.5). The cost models are flexible and can be applied to all industries involved in the recycling and sorting of paper and cardboard waste. Considering the practical application of cost equations, it can be observed that in the real world, the factors of production change every day and therefore the input data or parameters must be changed continuously.

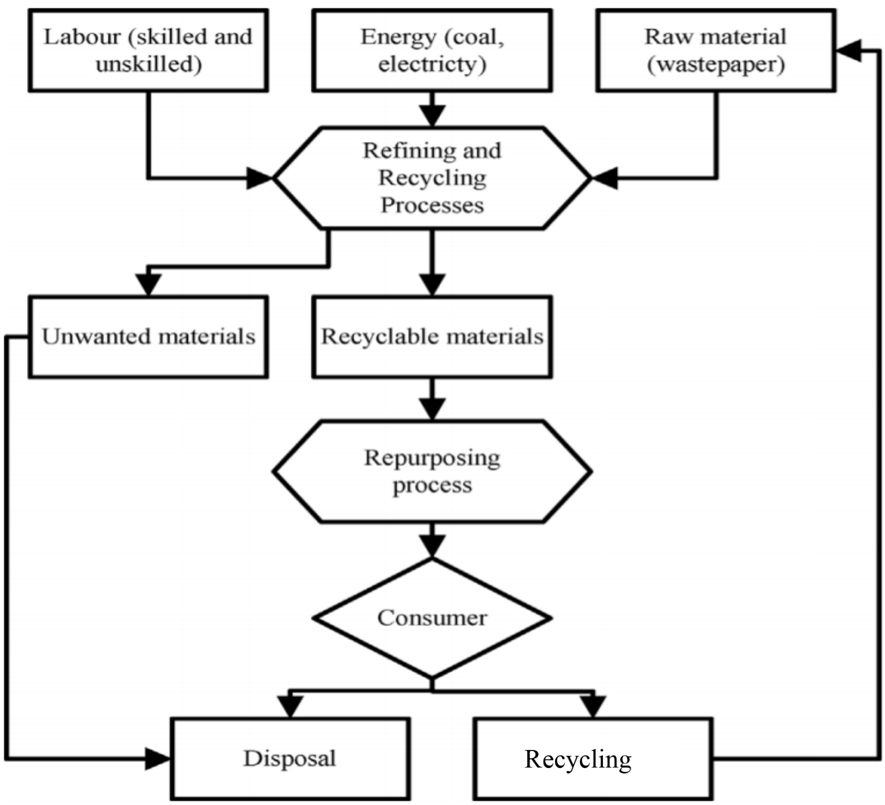


Fig. 2.5. Paper waste recycling and recycling cost assessment diagram.

Secondary data analysis and structured interviews for primary data collection

In assessing the challenges of the textile industry in the transition to a circular economy, **secondary data analysis and structured interviews** were used to obtain primary data, based on critical data analysis and comparative analysis. Secondary data analysis is a data analysis approach in which pre-existing data are analysed. Interviews were used to collect primary data, during which companies were questioned using well-formulated questions and also offering a fixed range of answers. The focus of analysis is on extracting, exploring, comparing, contrasting and interpreting meaningful patterns or themes. As part of the research, the analysis was conducted of companies engaged in the production of clothing or textile products in Latvia. Out of 176 companies, only four companies are actively working in full compliance with circular economy principles (OWA Ltd, *Mans Peldkostīms* Ltd, *Zīle*, Print Art Ltd). The approach and operation of these companies were evaluated, and they were involved in the structured interviews.

Critical analysis, case studies, synthesis and comparative analysis

While developing the Thesis, the existing circular economy strategies in the European Union were analysed in order to determine the main priority areas and goals with the help of critical analysis, case studies, synthesis and comparative analysis. Examples of several companies in Latvia which are applying the circular economy approach were collected, evaluated and analysed. Case studies are part of qualitative research – that is, research that focuses on the in-depth study of phenomena, rather than using statistics to draw general conclusions. It must be noted, that at the time of assessment, none of the Baltic countries had yet to draft a circular economy strategy.

Economic assessment, secondary data analysis

Economic evaluation and secondary data analysis were used when analysing the application of circular economy business models in the Latvian economy. The assessment was limited to the analysis of circular economy examples in Latvia, taking into account the lack of such a scientific background in Latvia. The aim of the research was to develop a decision-making matrix that would offer an appropriate business model structure for decision-makers and policy makers. A tool for making decisions based on the developed circular economy business model selection matrix will be of practical importance. Economic analysis is based on the principle that project investments should be evaluated according to their opportunity costs, and results need to be assessed according to the consumer's willingness to pay.

Modelling impact

Analysing the application of circular economy business models in the economy of Latvia and the impact of Covid-19 on the world economy, as well as looking at the situation in Latvia, the dynamics of individual policy instrument systems, their impact on the overall waste management system in the country and the transition to a circular economy were analysed. By applying impact modelling, an overview of the negative and positive consequences of the pandemic was constructed using a sound and sustainable risk assessment, and a set of recommendations was prepared for policy makers to stimulate the adoption of a circular economy and to create a more resilient, sustainable and low-carbon economy (see Fig. 2.6).

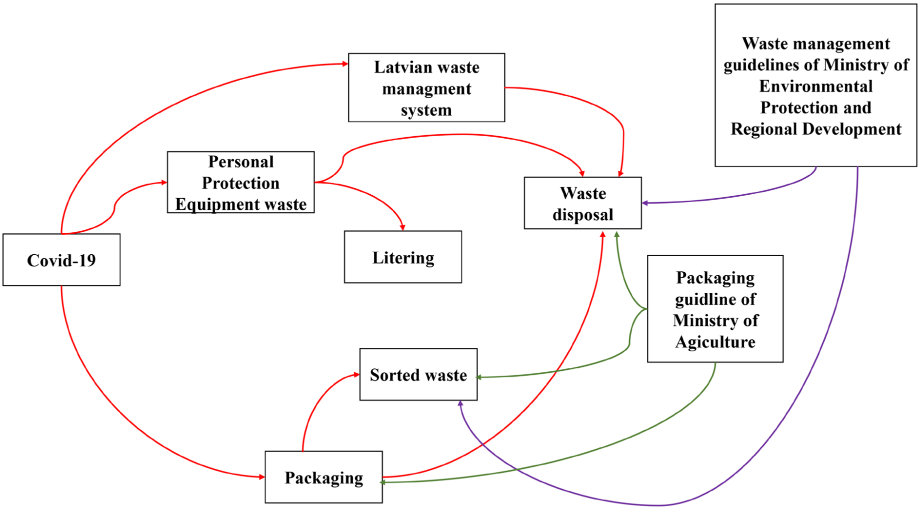


Fig. 2.6. Covid-19 and the impact assessment of Latvia's waste management system.

Figure 2.6 illustrates the impact of Covid-19 on Latvia's waste management system:

1) the red lines indicate the impact of Covid-19;
2) the purple lines indicate the impact of the guidelines of the Ministry of Environmental Protection and Regional Development of the Republic of Latvia;
3) the green lines indicate the impact of guidelines of the Ministry of Health and Ministry of Agriculture.

2.3. Research methods in relation to the role of green entrepreneurship, green jobs and environmental NGOs in waste management

In the course of the doctoral research, the role and place of green companies, green workplaces (GWP) and the environmental activities of civil societies in waste management and the transition to a circular economy model were evaluated, observing the hierarchy of waste management and emphasizing waste volume reduction and prevention, waste processing and energy production from waste, where the most effective results can be achieved by implementing separate waste collection. During the research, for the purpose of conducting a survey, a questionnaire was prepared on the role and place of green companies, green workplaces and the activities of environmental NGOs in the development of the waste management system, especially promoting the reduction and prevention of waste and developing the separate collection of waste. In the course of the research, a questionnaire was also prepared on the role and contribution of associations, foundations and non-governmental organizations in the development of the waste management system, including reduction and prevention of waste volumes and separate collection. As part of the questionnaire, 20 environmental experts and 25 students were previously invited to rank specific organizations depending on their role and contribution to waste management, as well as to justify the ranking. For the further assessment of the role of green companies, green workplaces and public activities in the development of the circular economy, including the waste management system, the previously described multi-criteria analysis TOPSIS was used.

3. Results and analysis

3.1. Assessment of paper waste recycling technology and method

When waste is reused, the level of harmful emissions is reduced compared to the production of raw materials, which can also improve the sustainability of products. Four product groups based on different production methods were selected and compared for analysis: cellulose nanocrystals (CNC) and cellulose nanofibers (CNF), packaging material for eggs, reusable paper and cardboard. The indicators are based on investments, electricity and water consumption which is necessary for the recycling of paper waste, as well as data on how much CO_2 emissions are generated in the production process. The indicators were selected according to their importance and impact on the environment and the main raw materials for ensuring the processes. Looking at the obtained results of the multi-criteria analysis, it is evident that the highest indicators according to the calculations are attributed to reusable paper. The second is the production of CNC and CNF, or the production of cellulose nanofibers and cellulose nanocrystals, but the worst results appear for the production of cardboard and egg packaging.

To make it easier to understand and evaluate which product should be preferred for production, the results were converted into qualitative assessment units. The obtained data were placed in the matrix and converted into the numbers from 1 to 5, where 1 is the lowest rating and 5 the highest (see Table 3.1).

Table 3.1

Compilation of Information Converted into Number Values

Technological approach. Paper recycling products	Required investment	Energy consumption	Water consumption	Impact on climate
CNC/CNF production (produced from processing sludge)	5	2	5	2
Egg packaging	3	5	3	4
Recycled paper	2	2	3	3
Carton production	3	5	3	4

The results of the multi-criteria analysis are summarized in Fig. 3.1. The results show that the production of cellulose nanocrystals and cellulose nanofibers have advantages in comparison with egg packaging and the production of carton, however the recycled paper production within this group of four products is the least favourable as this is related to the comparatively large investments needed and high maintenance costs.

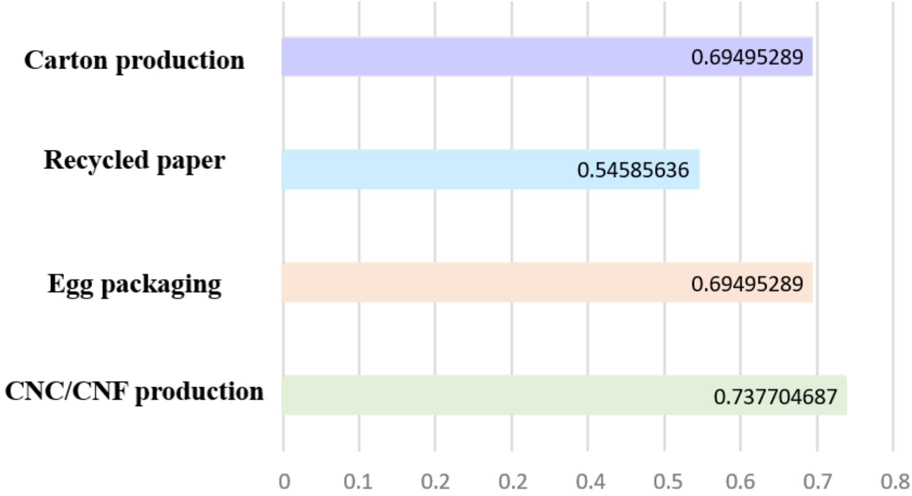


Fig. 3.1. Diagram of the results of the multi-criteria analysis on paper products.

3.2. Waste assessed as an energy resource

Considering that there are different ways and methods of using waste as energy resources, it is important to understand which types of waste preparation and use play the most important role in turning waste into an energy resource. During the study, the use of waste as a potential energy resource was analysed – obtaining energy from waste, burning it in heating systems and in the cement production process, producing fuel from tires, obtaining biogas from biological waste and using landfill gas for energy production. The distribution of waste as a potential energy resource is shown in Fig. 3.2.

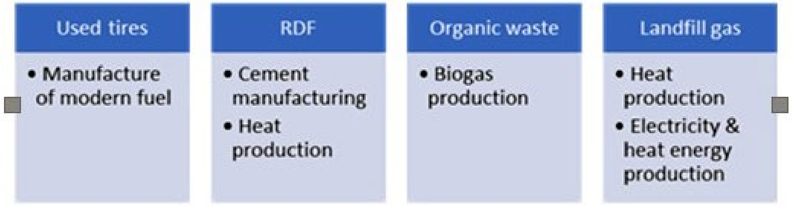


Fig. 3.2. Distribution of waste as a potential energy resource.

By applying the TOPSIS analysis method, a decision-making matrix D was developed that consists of criteria and alternatives as shown in Subsection 2.1. In this case, five alternatives are selected – waste as an energy resource that is evaluated based on four criteria: technological, economic, social and environmental and climate aspects (Table 3.2).

Table 3.2

Decision-making Matrix and Assessment of the Possibility of Using Waste as an Energy Resource (1 – the lowest; 5 – the highest)

No.	**Waste – resource**	**Aspect**			
		Technological	**Economic**	**Social**	**Environmental and climate**
1.	Tires for the production of modern fuel	4	3	4	4
2.	RDF energy production	5	4	3	4
3.	Organic waste in biogas production	5	4	4	4
4.	Waste incineration for heating	2	3	4	3
5.	Landfill gases for energy production	3	4	3	3

The value resulting from the calculations indicates the closeness of the alternative to the ideal positive solution and its distance from the ideal negative solution. The results of ranking the energy generation methods from waste by applying the TOPSIS method are illustrated in Fig. 3.3.

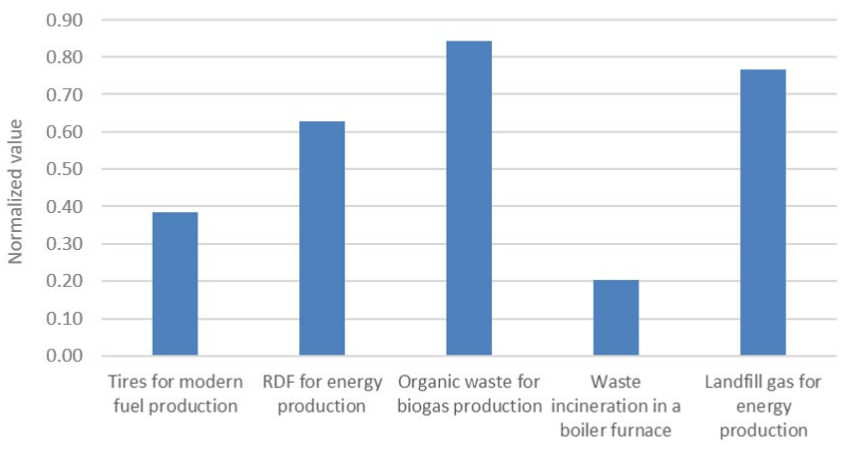


Fig. 3.3. Results of ranking methods for energy generation from waste via TOPSIS.

The results clearly show that the most optimal of the selected alternatives is the use of biodegradable (organic) waste for biogas production. This opens up opportunities to obtain biofuel for transport. At the same time, biogas production should be seen in connection with the compost extraction process, so that resources are used with maximum efficiency and with greater added value. Using biodegradable waste to produce biogas reduces the amount of waste that goes to landfill. Taking into consideration the current criteria weights, the use of landfill gas for energy production ranks second. The amounts of energy production using landfill gas correlate with the production of biogas from organic waste. The greater the share of organic waste that is used for biogas production, the less such waste will end up in a landfill, which will result in a reduction in landfill gas production volumes, the collection of which is determined as a mandatory measure for landfill operators. By more intensively using organic waste for recycling and energy production, it is possible to significantly reduce the amount of landfill gases, which, according to the results, is one of the most undesirable methods of energy production evaluated in this study.

The use of RDF for energy production ranks third, but the use of tires for modern fuel production is closer to the most negative solution than the ideal positive solution, in fact, it is one of the last choices among the waste-to-energy methods reviewed. The most unprofitable solution is burning waste in an incinerator, which poses the greatest threat to the environment and human health. When building infrastructure for energy recovery from waste, it is necessary to plan for different materials for fuel that can be used in a given facility.

3.3. Determining the composition of unsorted household waste

When determining the composition of unsorted household waste, 160 samples of unsorted household waste were collected and sorted within the framework of the study – five samples from each city were included in the study. The results of determining the composition of waste describe the composition of unsorted household waste at waste generation sites. The collected results show that the largest share in the total waste flow is biodegradable waste, which on average makes up 29.17 % of the total volume of waste. The actual share of biodegradable waste (BNA) is even higher, because in the separated fraction "Fine" BNA makes up ~50 % of the total amount, so the total amount of BNA (excluding paper, cardboard, wood, etc. materials that are biodegradable but are included in other categories) is equivalent to 38 .77 % of the total amount of household waste. Materials suitable for recycling: paper, cardboard, plastic, glass, and metal make up 32.9 % of the total amount of waste. Thus, almost 60 % of the waste, which is currently subject to the unsorted waste management system in Latvia, could potentially be separated, ensuring a higher quality of regenerated materials.

The experimentally obtained data on the distribution of unsorted solid household waste in the cities of Latvia were used for the further development of a mathematical model. The aim of this model is to explain the variability of unsorted municipal waste (NSA) (dependent variables) based on the distribution of measured waste fractions.

In addition to the experimentally determined waste compositions, data on total waste generation and population in cities in Latvia were obtained for statistics. The available data on the distribution of waste fractions can be analysed either as experimentally collected (five data points for each city) or by averaging the values for each city (Fig. 3.4).

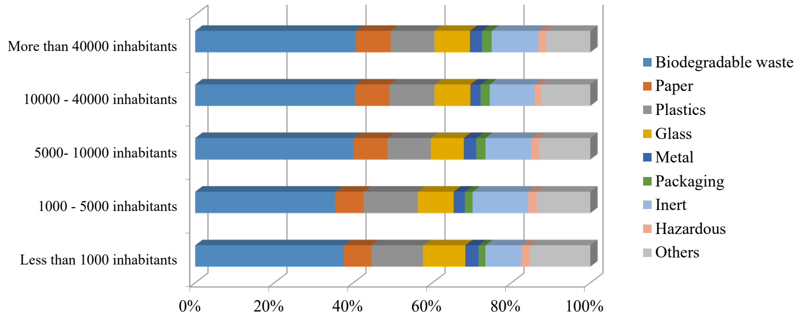


Fig. 3.4. Waste composition in groups of cities (grouped according to population size).

3.4. Application of the deposit system in packaging

The introduction of the deposit system in Latvia will bring benefits to households – in the first year it is estimated that the benefit can reach 1192 thousand euros, while in the tenth year the benefits will increase to an estimated 2,003 thousand euros, making the total benefits in ten years 16 095 thousand euros. Income when introducing the deposit system will increase, as it will be possible to hand over more types of containers (including various glass bottles).

When making a decision on the introduction of a deposit system in Latvia, it is recommended to decide on the acceptance of cardboard beverage packaging in vending machines, because it is technically possible – it would allow more waste to be managed. With the inclusion of cardboard beverage packaging in the deposit system, the volume of recycling would increase. By including carton beverage packaging in the deposit system, the amount of recovery would increase by 9 %, amounting to 63 %. With the introduction of the deposit system (including cardboard), the amount of recycling for both ordinary packaging and deposit packaging would be 21,086 tons, or 16.7 % higher than the amount of total packaging recycling without the deposit system.

The benefits will come from a reduction in costs that are currently born by the national budget in organizing countrywide clean-up programmes in Latvia, and a reduction in the pollution generated from greenhouse gases – the savings would amount to 19–25.7 million tons CO_2 annually.

Within the framework of the study, no significant changes in macroeconomic indicators (population, purchasing power, GDP, etc.) were foreseen.

With the development of technologies, it is important to regularly analyse and evaluate the packaging materials already included in the recycling system, not only the regeneration technologies, methods and possibilities, but also the inclusion of new packaging materials and beverages in the deposit system.

3.5. Decision-making process in transition to a circular economy

The use of various business models allows to reduce the consumption of materials and resources for production as well as to complete the life cycle of products through further processing and recycling. These models are based on the following:

1) circular delivery models;
2) resource regeneration/recovery models focussing on recycling waste into secondary materials (or raw materials into secondary materials);
3) models designated for product life extension;
4) sharing models;
5) models geared towards product service systems.

Upon analysing the types of product services, the main ones are highlighted. Product-oriented business model is focused on selling products. Some additional services can be added, such as maintenance services. The use-oriented product is still the main player, owned by the manufacturer-company and offered to the customer. The one that is results-oriented is whereby the consumer and service provider agree about the result in the business model.

The concept of the circular business model is considered a strong enabler for companies that want to implement circular economy practices in their operations. Business models must be designed in such a way that the value contained in the resources can be preserved and used when the resource loops need to be slowed down and closed. In the course of the research, a matrix was developed for the development of a national circular economy strategy. In this case, it would be an assessment of the implementation of industrial symbiosis. As part of the work process, a process of information flows for decision-making has been developed in order to evaluate the transition to the circular economy and choose the most suitable business model.

The business models need to be designed in a way that the value contained in the resources can be preserved and used when the resource loops need to be slowed down and closed. In the course of the research, a matrix was prepared for the development of the national circular economy strategy – a process of information flows for decision-making in order to evaluate the transition to the circular economy and choose the most suitable business model (Fig. 3.5).

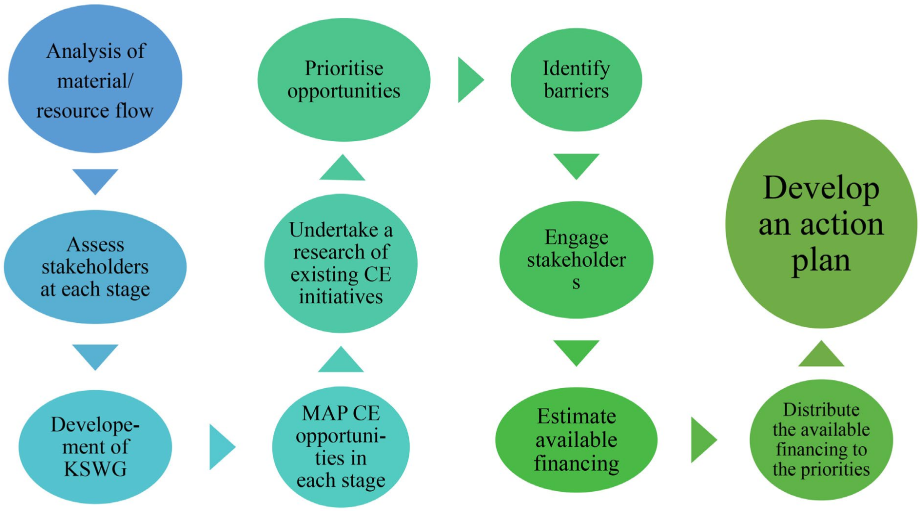


Fig. 3.5. Matrix for developing a circular economy action plan (KSWG – key stakeholder working group).

Applying this step-by-step approach, policymakers will be able to develop the most comprehensive action plan, which will evaluate and take into account all areas of the economy that are addressed by the circular economy, identify existing circular economy initiatives and set priorities at each stage of the circular economy. Next, further research is needed, related to the practical development of the matrix part of the action plan, developing opportunities for and identifying obstacles to the implementation of the circular economy, evaluating resource cycles in companies, developing cost comparisons, implementing the principles of the circular economy and without elements of the circular economy.

In terms of the application of circular economy principles in the **textile industry**, structured interviews were conducted with representatives of companies of the industry. The interviews were structured with eight questions posed in an open manner. The surveyed companies are open to the circular economy and already actively integrate elements of the circular approach in their business models. In addition, they are open to the integration of these principles even more deeply, although individual interviewees emphasized the lack of knowledge about certain elements of the circular economy and government financial support in this regard (see Fig. 3.6).

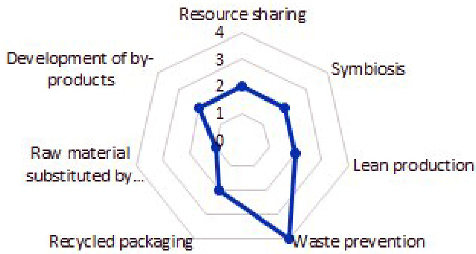


Fig. 3.6. Application of circular economy principles in a business model for the textile industry.

From the conducted literature research, case study analysis and conducted interviews, it was concluded that, firstly, if the country wants to promote social entrepreneurship, it is important to understand the approval process of the status of the enterprise and grant of support and to make it as simple as possible. Therefore, it is necessary to develop a transparent and clear set of rules so that companies can claim the status of a social enterprise.

Circular economy principles can be practiced at all levels now and in the future, from face mask disinfection to the implementation of smart regional policies and strategies that maximize resource use, reduce pollution and create countless business opportunities [59]. Smart industrial policies are necessary to promote both market and state forces, internal and external learning. It is hard to imagine how a country can move into completely new industries requiring new infrastructures, institutions, and skills without smart industrial policies and state support [60].

3.6. Results of the research in terms of green businesses, green jobs and environmentally friendly activities of society in waste management

The respondents involved in the survey had the task of evaluating green companies, green jobs (GJ) and society's green activities, determining which group has the most important influence or creates the largest impact on the aspects of education, innovative thinking, the economy, social benefits, environmental and climate, and motivation to achieve circular economy goals.

The multi-criteria TOPSIS analysis was used to evaluate the role of green companies, green workplaces and public activities in the development of the circular economy, including the waste management system [47].

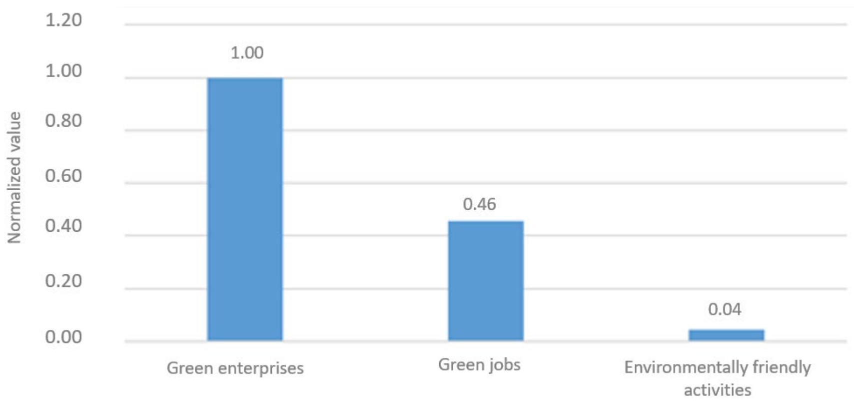


Fig. 3.7. Results of the ranking of green companies, green jobs and the society's green activities using TOPSIS.

The results during the course of the analysis, through surveys, calculation of the average indicators and applying the multi-criteria decision-making method TOPSIS, the (Fig. 3.7.) illustrate that, from the chosen alternatives, the most effective results in terms of the circular economy model in relation to the separate collection of waste and waste recycling can be achieved via green companies.

3.7. Results and analysis – summary

The methods used in the research show that, in order to choose technologies or to make decisions on waste management and the circular economy, it is necessary to combine a variety of research methods and use these in combination, because not all of the aspects can be assessed with one method. The use of research methods in the field of waste management and the circular economy ensure that the choices and the decisions made are thoughtful and reasonable (Fig. 3.8).

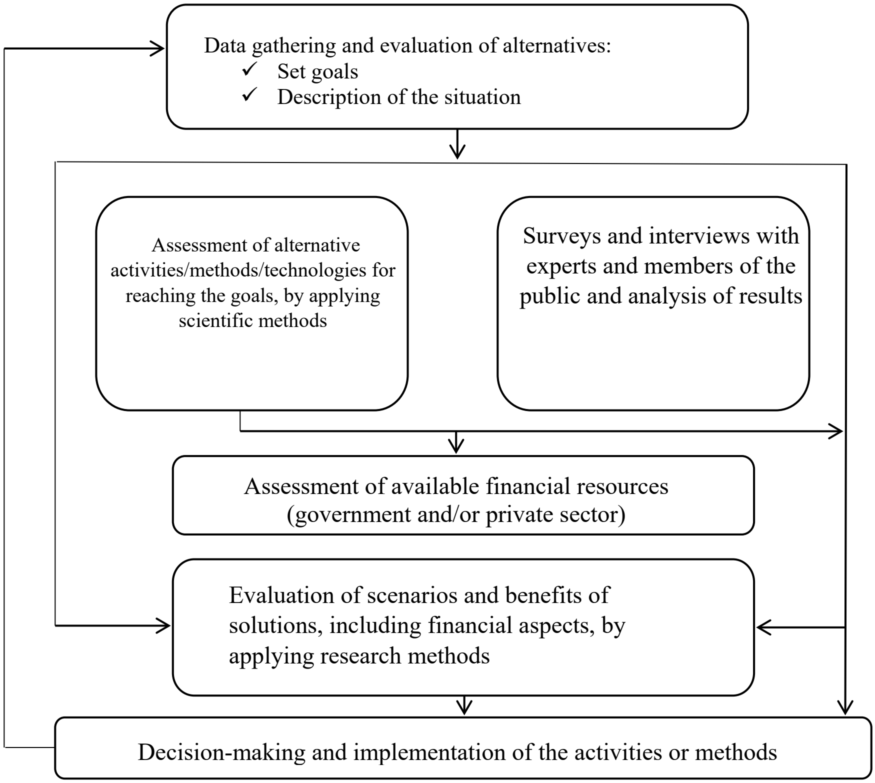


Fig. 3.8. Decision-making process.

The use of scientific research methods in the evaluation of alternative solutions in the field of waste management and circular economy can help:

1) entrepreneurs to choose technologies in waste management;
2) planners and policy makers to evaluate the effectiveness of the existing circular economy strategy, to evaluate economic sectors in order to develop short-term and long-term action plans, to provide practical solutions and create an approach in order to be able to respond to crisis situations as effectively as possible and create strategies for crisis situations;
3) financial donors to evaluate the compliance of the applied and supported projects with progress towards the circular economy model and priorities.

In the creation and management of research data, it is important that the parties involved use the principles which are defined to promote the maximum use of research data, that is, FAIR data which is findable, accessible, interoperable, reusable. The FAIR principles apply not only to the creation and use of data, but also to research methods, with special emphasis on reusability of data and methods. The methods used in the development of the work can be used for the selection of other waste flow management methods and technologies, for the selection of measures and for policy making in the field of waste management and circular economy, and it is desirable to use them to implement meaningful measures based on comparable indicators, indicators and data, and the research of methods and measures.

The results of the multi-criteria analysis used in the research conducted on paper waste showed that the production of cellulose nanofibers and cellulose nanocrystals has advantages compared to the production of egg packaging and cardboard, but the production of reusable paper is economically beneficial. The production of cellulose nanofibers and nanopaper has potential in the future paper recycling market, as it can be produced from paper mill sludge from the paper recycling process.

By introducing the deposit system, the recovery volume of beverage packaging would increase by 3 %, while the volume of recycling would increase by 5.4 %. On the other hand, including cardboard packaging in the deposit system, the amount of recovery would increase by 9 % and the amount of recycling by 16.7 %. In accordance with the new EU goals regarding waste disposal and recycling, including packaging recycling, the costs of waste management will increase significantly in the near future, which could significantly change the mentioned costs and be an essential basis for the introduction of the deposit system. By increasing the deposit rate for beverage packaging from 0.10 to 0.13 EUR, the introduction of the deposit system would generate benefits of 82 thousand EUR within ten years, as well as motivate the consumer to return the used packaging.

Textile waste is a new fraction of waste that has specific targets in the EU Waste Directive, so it is extremely important to promote social enterprises in the field of textile production and recycling. It is necessary to promote sensible consumption and stop the trend of fast fashion, as well as encourage recycling activities to reduce the amount of textile waste that ends up in landfill or is incinerated.

The government needs to promote social entrepreneurship by simplifying the approval process and taking into account that social enterprises are founded not only according to Milton Friedman's quote "The business of business is business", but they primarily aim to solve certain social problems. Therefore, it is necessary to develop a transparent and clear set of rules so that the company can apply for the status of a social enterprise, thereby reducing bureaucratic burden. The government should promote the introduction of circular economy elements into the daily operation of a social enterprise.

The production of energy from waste differs in accordance with technological solutions, with innovations for the production of products producing a higher added value and depending on the place and methods of extraction of raw materials. The use of waste as an energy resource in Latvia has potential, in compliance with the set waste management goals for 2035. Therefore, up to 25 % of the amount of household waste generated in 2035 can be used for energy production and further use.

Since the vast array of activities related to waste and green activities are in the realm of green companies – waste collection, transportation, sorting, treatment, recycling, recovery and disposal, preparation for reuse, repair and repair of products, provision of advice, development and production of recycling technologies and equipment and development of products and packaging with the aim of reducing the amount of waste generated and the amount of waste to be disposed of – the performance of these companies allows to achieve the goals of waste management in the most efficient way and with the maximum numerical value.

The most important motivating tools for the development of green companies are environmental protection requirements related to environmental impact assessment, pollution reduction and prevention options, and economic aspects. The economic aspects that contribute to the development of green companies are related to the motivational tax policy established in the country, the cost of the production of goods and the provision of services, and the motivational policy of market demand for processed products. In the development of green workplaces and society's green activities, the most important motivating aspects are environmental and climate aspects, but the least important are economic aspects. No barriers to the development of circular economy-related green jobs related to waste management and prevention have been identified.

Conclusions

1. The research results confirm the proposed hypothesis of the study, which is the assumption that usage of scientific research methods in the decision-making and decision-making process supports Latvia in reaching the status of a resource-efficient country in the long term which implements a circular economy model and a zero waste strategy (the amount of generated waste decreases and the amount of waste disposed of in landfills approaches zero) and achieves more sustainable results. For each waste stream or type of processing, several research methods are applied, respecting the reusability of data and methods, forming a complex approach and allowing to make thoughtful and more sustainable choices and make decisions about waste processing and regeneration technologies to be used as well as measures to be implemented for the transition to a circular economy and financial sources, because not all aspects can be evaluated with one method. This approach should also be observed in economic processes, both in the case of choosing technological solutions and raw materials, in the case of choosing policy instruments, and in the decision-making process, including the process of choosing financial instruments and support.

2. The results of the research conducted with the multi-criteria decision-making methods (TOPSIS), analysing waste as potential energy resource, clearly shows that the most desirable of the selected alternatives is the use of organic waste for biogas production. This opens up opportunities to obtain biofuel for road transport. Waste recovery can

generally help reduce landfill waste and greenhouse gas emissions. The most disadvantageous solution for the selected criteria is the burning of waste in a boiler furnace; it is the most ineffective method and poses great threat to the surrounding environment and human health.

3. For the evaluation of the efficiency of green companies, green workplaces and society's green activities in the field of waste management, those implementing the activities should be linked to the hierarchy of waste within the framework of the circular economy model – the amount of generated waste decreases, the amount of buried waste decreases, the amount of recyclable and recycled waste increases. However, different indicators apply to each group, as green companies are created with the aim of securing efficient waste management. On the other hand, the role and importance of green workplaces and society's green activities is related not only to appropriate waste management, but also to reducing the amount of waste and preventing the generation of waste. Further research is needed on the development of green skills, competences, and green workplaces in companies as a response to market and policy instruments.

4. The analysis carried out during the research allowed us to conclude that the year 2020 with the pandemic has provided good stimulus for the circular economy, despite the fact that it has led the world economy in many areas to a recession and survival mode. Therefore, it is very important to look for opportunities so that the revival of the national economy takes place faster and moves in the direction of sustainability. Currently, it is important for policy makers in Latvia, as well as in other countries, to evaluate the effectiveness of existing or planned circular economy strategies, to consider those sectors of the economy most severely impacted in order to develop short-term and long-term action plans that will not only promote the transition to a circular economy model, but also ensure reasonable practical solutions, including policy support, mentoring and financial instruments and to build an approach to be able to respond and develop crisis strategies as effectively as possible.

Recommendations

Recommendations have been prepared as part of the Thesis, which will be useful for policy makers at the national and local government levels, financial providers, entrepreneurs, and universities.

1. The production of energy from waste differs in terms of technological solutions, innovations for the production of products with higher added value, as well as in terms of the location and methods of extraction of raw materials. The use of waste as an energy resource in Europe has potential, especially considering the set waste management goals for 2035. To

ensure that only 10 % of the total amount of household waste generated is disposed of in landfill, it is not enough to achieve only the goal of recycling waste. Therefore, it is an important question what to do with 25 % of the amount of generated household waste – to increase the amount of processed waste or to regenerate this amount of waste – to obtain energy from it for further use. These are the aspects that policy makers, entrepreneurs and funders should take into account when developing the diversification of the use of energy resources, while observing one of the objectives of the waste policy, when moving to a circular economy – preventing the generation of waste, which will result in a decrease in the amount of waste as a fuel material. However, it can be a solution at least in the near term in the energy resource crisis.

2. Scientists in cooperation with policy makers should continue to evaluate the further use of biomethane produced in biogas stations in vehicles, balancing its use with the use of compressed natural gas, thus making the use of such fuel even "greener" and improving and developing new, effective solutions.

3. At the national and municipal levels, the activities of non-governmental organizations should be purposefully directed towards the transition of society from waste management to reducing the amount of waste and preventing waste generation.

4. It is important for policymakers in Latvia to evaluate the effectiveness of the existing circular economy strategy, consider the most impacted sectors of the economy in order to develop short-term and long-term action plans that will not only promote the transition to a circular economy, but also provide reasonable practical solutions, including policy support, mentoring and financial instruments in the long term and create an approach to be able to respond to crisis situations as efficiently as possible and create crisis strategies.

5. State administrative institutions responsible for the fields of welfare, economy and environmental protection have to collaborate to develop guidelines for companies on circular economy elements and practical aspects of how to move from linear to circular economy business models, introducing aspects such as resource sharing, equipment sharing, use of symbiosis, when one company's waste can become another company's new/raw material, the use of recycled and/or recyclable materials both in the production process and packaging, etc.

6. State administrative institutions responsible for the areas of welfare and environmental protection need to develop a transparent and clear set of rules so that companies can claim the status of a social enterprise, thereby reducing bureaucratic burden. The government should promote the introduction of circular economy elements into the daily operation of a social enterprise.

6. Courses on sustainable development, efficient use of resources, circular economy and waste management should be included in university programs related to business, economics, financial management, technical education and engineering.

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Rudīte Vesere was born in 1962 in Riga. She obtained a Professional Master's degree in Chemistry and a Teaching Qualification from the University of Latvia. In 1997, she obtained a Master's degree in Environmental Science and Management from the University of Latvia, and in 2001, a Master's degree in Social Sciences in Management Science. She continued her education by attending various training courses in Sweden and Japan. R. Vesere perfected her knowledge by undertaking studies in the Riga Technical University doctoral study programme "Environmental Engineering".

R. Vesere has more than 20 years of work experience in the environmental protection sector, including waste management. Since December 1996, R. Vesere has been working in the Environmental Protection Department of the Ministry of Environmental Protection and Regional Development, and since 2011 she has been the Head of the Department. The areas of her responsibility are planning and development of legal basis and policy documents of Latvian environmental protection. Special areas of her responsibility are waste management and use of economic instruments in environmental policy, including application of natural resources tax and development of circular economy policy. In 2010, R. Vesere received a Letter of Appreciation of the Cabinet of Ministers for significant contribution in the field of environmental protection, successfully involving municipalities and entrepreneurs in the fulfillment of the obligations of the Latvian state in the field of waste management and packaging.