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From garbage to product and service systems: A longitudinal Finnish case study of waste management evolution

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ABSTRACT

This longitudinal case study analyses the development of the pioneering waste management (WM) system in the Vaasa region of Western Finland, since the late 1980s to the present. It reflects the general features of the evolving WM from the one-bag system and throwaway culture towards today's circular economy and product service systems.

The Vaasa region is an excellent example of how WM has evolved in Finland, which also follows the main direction of travel in Europe. The main features have been: (1) closing of dumping sites, minimizing dumping of waste and concentrating dumping to well-organized and environmentally managed sites; (2) development of comprehensive source separation systems for reuse of materials and energy; (3) building of waste treatment systems, consisting of different technical solutions connected with reuse and energy generation solutions.

This evolution has resulted in expanding regional collaboration, where large investments are integrated within larger areas and consortia. The share of reused materials has grown significantly and dumping has decreased to close to zero. The practices of the circular economy are emerging and partly established. In this evolution, praxis does not immediately follow after "a brilliant idea", but only after the societal structuring process, including paradigmatic changes in attitudes, social norms, policies and regulation, customer behaviour, economic structures, and separate and systemic technological solutions and value chains.

This research can add value both in terms of knowledge and science, and in being a change agents more practically. In the future, a strategic shift from WM to material management, and from public service to feasible businesses will be the next steps.

1. Introduction

The circular economy and product service systems (PSSs) are highly desirable within industrial ecosystems. They have been preceded by the agendas of circulation, reuse of waste, waste management and, ultimately, the one-bag garbage system, i.e., the 'throwaway' culture. This tradition has until very recently been considered as separate from other activities of human culture.

WM contains separate activities within material management systems, such as separation and collection at sources, regional collection and logistical systems, pre-treatment and treatment, refining, utilisation and disposal of end products. Until recently, these have all lacked interconnectivity, but lately they are about to be integrated into PSSs and the circular economy (e.g. Rada and Cioca, 2017; Ragazzi et al., 2017; Lakatos et al., 2018; Perey et al., 2018; Rada et al., 2018; Tomić and Schneider, 2020). This links with the human–nature relationship and reflects the way humankind has utilized natural resources.

The framework can be positioned in the 'big picture' (Fig. 1; Peura, 2013a,b) as parts of the dynamic interaction between society and environment, as follows:

Human activities, such as producing waste, emissions or other unwanted 'side-products' ('Society'; lower half of Fig. 1) affect ecosystems ('Environment'; upper half of Fig. 1), at different scales and in different habitats. The impacts can be seen in the state of the environment and resources, well-being and growth of the population (depletion of natural resources, climate change).

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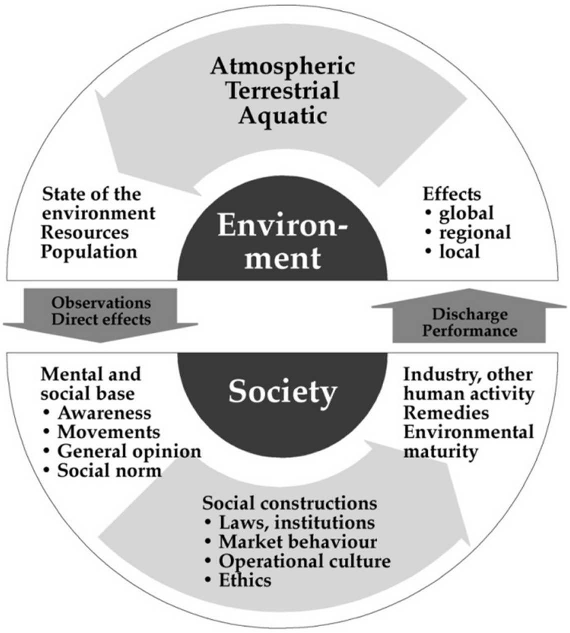

Fig. 1. Dynamics between the environment and society (Peura, 2013a,b).

The impacts are reflected in society through observations and direct effects to health (Giusti, 2009) and hygiene (Velasco et al., 2021), resources (Nižetić et al., 2019), and state of the world (Arantes et al., 2020), which can be harmful effects calling for change. Developing understanding and societal change for addressing negative impacts is a long and complicated process, where the development of social norms and societal structuring precede practical responses.

Environmental impacts may change as a result of the changed and potentially sustainable behaviour (e.g., reforming WM).

As a temporally developing system, this circle makes a spiral that corresponds to social self-reflection (Beck et al., 1994), according to which humankind corrects its actions. The material economy, from 'throwaway' to WM and the circular economy is part of the system. The tradition of creating maximal material conditions for living has resulted in deterioration of the global environment and explosive population growth, depletion of natural resources, waste and negative hygiene impacts (e.g. Worster, 1988; Ponting, 1992; Crosby, 1996; Livi-Bacci, 1999; McNeill, 2001; Peura, 2013a,b).

This paper aims to understand the evolution of material treatment about how the throwaway culture and WM are evolving towards modern circulation and how the 'old' garbage is being transformed into products and services. The perspective is twofold: first, we consider the systems for handling the materials, second, the development of the material flows. This reflects the following research questions:

1. What is the development path of system evolution, material handling and waste collection? Individual waste producers can introduce initiatives that may lead to a systemic change, but they are not capable of practical actions without a system, for instance collection of certain waste fraction alone at source is not possible without an infrastructure for regional collection and reuse. The presupposition is that the importance of system is critical for the development of WM.
2. What are the basic parameters in the Vaasa region, i.e., waste volumes and share of reuse, from the early 1980s until the present? The rationale is that by these generally accepted parameters we highlight the development and its impacts in the Vaasa region specifically within the WM and its way towards circular economy.
3. What generalizations can be drawn from our case study? The case in the Vaasa region was in the forefront nationally, even globally. We expect to add value to the understanding of how WM has evolved and what will be the next steps towards circular economy and PSSs, not only in the Vaasa region, but also more widely.

Our scientific approach consists of constructive research (finding practical solutions with scientific relevance; Kasanen et al., 1993), and conceptual integration (combining several disciplines coherently; Ylikoski and Kokkonen, 2009).

The paper proceeds as follows: Section 2 outlines the theoretic background and approach, Section 3 describes the study area, data and methods, and Section 4 provides the results. In Section 5, we discuss the results and research questions and make concluding remarks.

2. Theoretical background

2.1. The evolution of waste: The concept

According to Finland's Waste Act (Jätelaki 1072/93; in effect 1994), waste is '…[a] material or thing that the possessor has abandoned or is going to abandon or is obliged to abandon'. In waste-related research, the definition has been vaguer as it is complex in the context of several materials. Often, material becomes waste when dumping is cheaper than utilisation, i.e. the potential income is smaller than the cost of reuse. This can change over time: waste is a shifting concept, affected by the evolution of recycling, ideology and technology of utilization, legislation and general opinion nationally and internationally.

Typical examples are the side products from agriculture, such as manure and logging residues. Usually waste is an unwanted 'side product' (Varjani et al., 2021). The former 'throwaway' is analogous to the historical pattern of humankind's way of utilizing natural resources according to the 'philosophy' of unlimited growth and resources (e.g., Peura, 2013a,b).

This is also reflected in WM in its development towards the circular economy (Shyam et al., 2021). The boundary between WM and other material management is problematic and becoming even vaguer. The key is efficient material management and its economic and practical relevance. Legislation needs to follow these demands and the circular economy will require systemic thinking (e.g., Salmenperä et al., 2021).

Philosophically, this means applying conceptual integration, including technology, economics, green economics and general sustainability. There are, however, more than 300 definitions for 'sustainable development' within environmental management (e.g., IUCN, 1980; WCED, 1987; Markandya et al., 2002; Johnston et al., 2007; Chichilnisky, 2011), which highlights the challenges in reaching a clear definition. Economics studies how people interact with value, especially production, logistics, goods and services (Krugman and Wells, 2012). Green economics is concerned with social justice (Pierce, 1992; Cato, 2009; Cato and Rear, 2020) and sustainability. In our study, we focus on material flows and value in a regional setting.

2.2. The evolution of waste systems

The developing material well-being, especially in 1900s started the throwaway culture, when natural resources were seemingly unlimited and the characteristic behaviour was carelessness towards resources and the environment.

There are many historical examples of how formerly productive regions have been exhausted, permanently deteriorated and abandoned, and the population has moved to reside in other places (e.g., Worster, 1988; Ponting, 1992; Crosby, 1996; Livi-Bacci, 1999; McNeill, 2001). Environmental sociology has provided this phase with the suitable concept of 'robbery' ('raubwirtschaft' in German, introduced by Ernst Friedrich in 1904, summarized by Massa, 1999) meaning overexploitation of resources and carelessness toward the environment, offspring and future availability of resources (Massa, 1999; Peura, 2013a,b).

This phase gave rise to the need for managing waste. The standard solution was to dump all unwanted materials and products. Vast amounts of useful materials were dumped, resulting in unhygienic, malodorous and poisonous dirt from hazardous waste (Nemerow, 2007), leakages to waterbodies (Naveen et al., 2018) and other negative impacts (Shershneva et al., 2017). The results included eutrophication, pollution and even poisoning of waterbodies and the environment more generally, smells, hygienic and other discomforts, but also reservation of large land areas, not possible top use to any other purposes.

Today, managing solid waste as efficiently as possible is among the most important municipal duties (Hoornweg and Bhada-Tata, 2012, Berticelli et al., 2020; Iqbal et al., 2020; Tsypkin et al., 2020; Banda et al., 2021; Zhang et al., 2021). The meaning of this has changed over time. The approach from only managing waste has progressed towards the concept of the circular economy, where materials, energy and experiences move forward in loops (Babbitt et al., 2021; Contreras-Lisperguer et al., 2021). Korhonen et al. (2018) proposed the following definition:

> ‘[The] circular economy is an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow…by using cyclical materials flows, renewable energy sources and cascading-type energy flows. [It]…contributes to all the three dimensions of sustainable development…limits the throughput flow to a level that nature tolerates and utilizes ecosystem cycles in economic cycles by respecting their natural reproduction rates.’

This entity is also a value chain and business model that describes the full range of activities needed to create a product or service. Within WM, the goal is to analyse how value and waste flows are related. Within the circular economy, WM value chains and PSSs may be attractive business models for stakeholders. PSS is an integrated combination of products and services (Baines et al., 2007), and feasibility is the normal stakeholder requirement for business. Waste plans, bound by legislation, policies, regulations, local conditions, agreements and stakeholders, result in specific preconditions and boundaries by region (Anshassi et al., 2019; Cohen and Gil, 2021). Consequently, feasible regional PSSs are unique.

Importantly, the practical steps of WM have been based on growing awareness and gradual development of general opinion supporting changes towards reuse and circulation (Grodzinska-Jurczak et al., 2003; De Feo and De Gisi, 2010; Rada et al., 2016; Savastano et al., 2019; Kala et al., 2020). Societal structuring, including shifting legislation, European Union (EU) and national norms, incentives and motivation by subsidies for investments, taxes, obligations etc. for promoting circular economy have also been necessary (Hartley et al., 2020; Fidélis et al., 2021).

3. Research area, data and methods

3.1. Research area

This paper studies the evolution of WM in the Vaasa region of Western Finland. The initial area covers the city of Vaasa and the neighbouring municipality Mustasaari, which together established the WM company ‘Ab Avfallsservice Stormossen Jätehuolto Oy (ASJ)’ in 1984. Several other municipalities later joined the company (Nygård, 2015): Maksamaa (1997); Vähäkyrö, Isokyrö, Vöyri and Maalahti (1999); Korsnäs (2002); Maksamaa merged with Vöyri (2011); and Oravainen merged with Vöyri (2015).

The core of our study is this consortium (Fig. 2; cf. supporting information), although the regional collaboration has expanded substantially since then (Fig. 3).

In 2019, the total number of inhabitants was 105,619, compared to 95,234 in 1989 (Statistics Finland; cf. supporting information). Only the

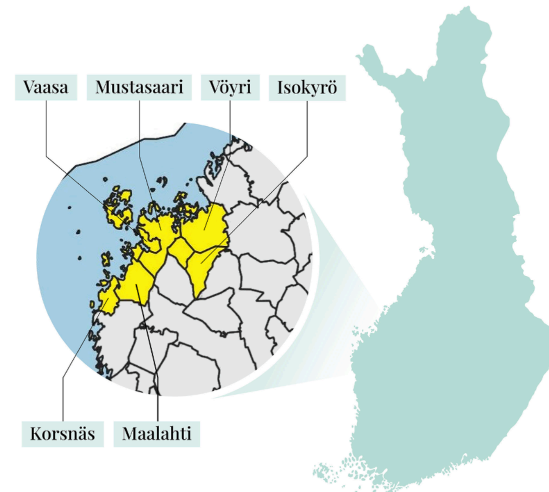

Fig. 2. The research area: the waste management collaboration area of Ab Avfallsservice Stormossen Jätehuolto Oy (ASJ).

city of Vaasa and Mustasaari have experienced population growth in 30 years; the surrounding areas have simultaneously experienced a significant loss of population. The total land area covers 3108 km^2.

In 2019, Vaasa and Mustasaari covered 82% of the consortium population. Regional distribution of inhabitants affects WM. Compared to the other five municipalities, the population density and the share of people living in population centres are the highest in Vaasa and the second highest in Mustasaari (Statistics Finland). Vaasa is urban and industrialized, including the largest energy technology concentration in Scandinavia, surrounded by smaller rural communities with strong agriculture and forestry industries.

Employment has traditionally and nationally been good in rural Ostrobothnia, mainly because of a high share of primary production and small- and medium-sized enterprises, both with high employment capacity. The annual employment rate changes can be significant.

The main components of the WM system in Vaasa region are: 1 Comprehensive collection of reusable materials and hazardous waste; 2 Stormossen biogas plant; 3 Westenergy waste incineration plant; and 4 Collaboration with other WM companies.

Since the mid-1990s, several other waste companies close to the Vaasa region have collaborated with ASJ. Each company has had its own concept and timing of utilizing the plants of ASJ. In this research, the focus is in the initial ASJ area. The other WM companies deliver or have delivered parts of their waste either to Stormossen or Westenergy or both. This waste flow will be studied as ‘materials from outside’; as they do not belong to the research area, their whole waste systems or waste composition will not be treated here.

Stormossen is the biogas plant established by ASJ. It is an important part of Finland’s WM history. When the plant became operational in 1990, it was the first anaerobic digestion unit in Finland. It was initiated when the ideas and practices of WM were just about to start their transition towards waste reuse. Already in the early 1990s, ASJ was considered a national model for developing the WM strategy and praxis nationally.

Westenergy was founded in 2007 to manage the energy recovery from waste, by five WM companies, Botniarosk, Lakeuden Etappi, Millespakka, Vestia and Stormossen, all located in Western Finland (Fig. 3). This extended Westenergy’s operation area to 62 municipalities (originally 47), covering 20% of Finland’s municipalities. In 2007, Westenergy was the largest investment in Finland, totalling approximately €170 m.

The whole evolution, from reforming WM within the initial area since 1980s towards large systemic change and circular economy for a vast region, has been in the forefront nationally, even globally. This is

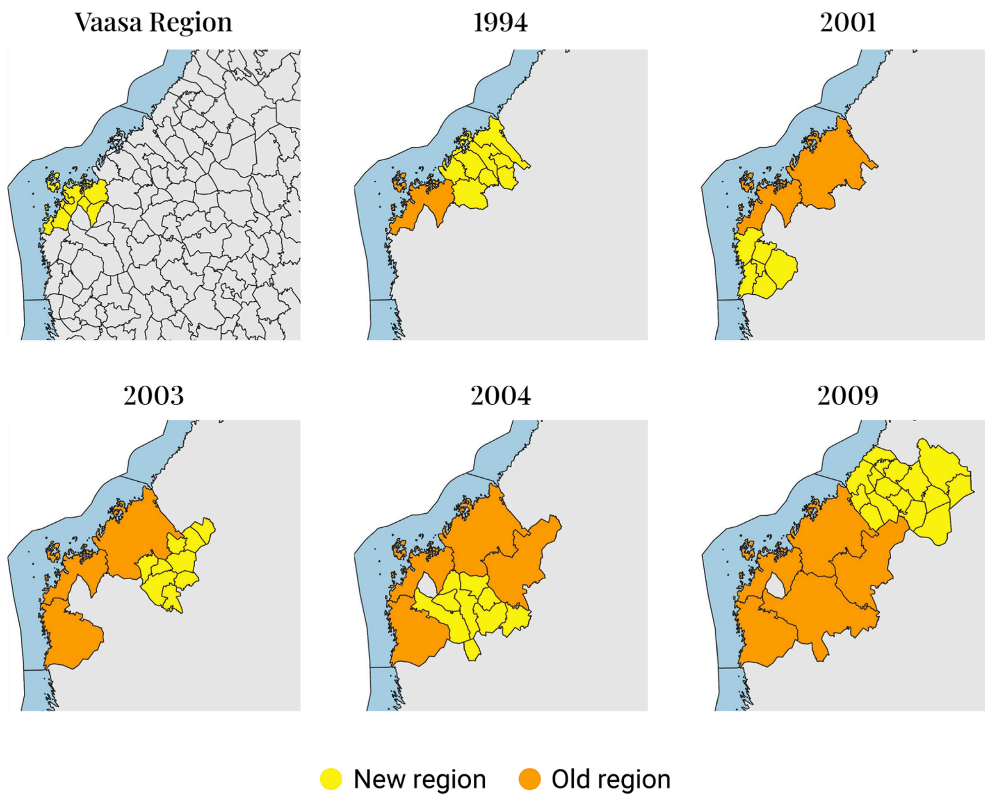

Fig. 3. The expanding operational area of ASJ from the initial to the present.

the reason why this study has been carried out longitudinally, by which we expect to be able to add value to the research and branch more generally.

The first Waste Management Act in Finland was given in 1978 (in effect 1979), before which only waste disposal was regulated by the Public Health legislation (in more detail: Kettunen and Vuorisalo, 2005). Then, the main concerns were health and environmental issues, especially leakages to waterbodies, and the rapidly growing waste volumes (Kettunen and Vuorisalo, 2005). Today, the Finnish waste legislation is largely based on EU legislation, but in some cases, it includes stricter standards and limits than those applied in the EU as a whole (Ministry of the Environment, 2021). The WM reform was started in mid 1990s, when Finland joined the EU, and the National Waste Act came into effect in 1994. Since then more than 20 decrees have been issued. The present Waste Act came into effect in May 2012. The legislation includes regulations for the promoting the utilisation of wastes, organisation of the waste management, preventing of the littering and cleaning of the littered areas. In addition, the legislation includes the regulations for preventing the formation of waste and the reduction of the amount and harmfulness of waste (Piippo, 2013; Ministry of the Environment, 2021). The whole waste legislation is a compilation of a large number of acts, decrees and decisions, also linking to laws of many other branches; the main regulations have been collated in Appendix (Ministry of the Environment, 2021).

3.2. Data and methods

The data consist of documented and reported, and partly unreported, statistics from the relevant WM companies. In their annual reports and on their websites, all companies have published their strategic choices, waste collection and recycling systems, changes to them and, most relevant for this study, the waste material flows within their regions (ASJ, 2021; Westenergy, 2021).

These reports have been analysed and four key people (including: CEOs of ASJ and Westenergy, operational manager of ASJ, head of business intelligence of Westenergy) were interviewed face-to-face, by phone and by email to complement our understanding. The main objective of the interviews and group discussion was to get complementary, unpublished information regarding statistics of material flows but also to “test” the preliminary results of our study, and to get some complementary understanding behind statistics and the empirical results. The method was qualitative discourse analysis without a structured questionnaire. The sample was limited to the very key persons, who had been personally involved in the evolution of the regional WM system, and who had the necessary knowledge and materials for making a structured analysis. Some initial data and results from the early years until the mid-1990s were obtained from Sairinen (1994) and Isaksson et al. (1996).

To obtain national reference data and background information, we also consulted Statistics Finland for official annual statistics, interviewed one key person within the environmental administration (expert at the Regional Centre for Economic Development, Transport and Environment), and used European statistics (Eurostat, 2020). The review and analysis of the evolution of WM and the circular economy have included both scientific and grey literature, which comprehensively illustrates the chronology and main features of this transition.

4. Results

4.1. Development of the regional collaboration and strategy

The WM solutions in the Vaasa region were already being considered attractive in the neighbouring municipalities at the time of their establishment. They all faced the same duties for renewal of their WM practices, including closing several old dumping sites and reorganizing the collection and treatment systems, including reuse of waste. By the early 1990s, Stormossen offered a competitive solution for the treatment of biodegradable materials that usually contributed to a third of household waste. This resulted in expanding of ASJ to comprise most of the neighbouring municipalities.

During the last years of 1900s and early into the 2000s, attitudes and opinions evolved, regulations changed and technologies developed, meaning that the practices in WM were changing. The demands to close most dumping sites, organize reuse of waste and minimize the amount of waste resulted in several collaboration consortia across Finland.

The novel solutions in the Vaasa region also attracted other stakeholders. The first to act in terms of strategy and collaboration was Ekorosk, the WM company of the Pietarsaari region north of Vaasa. The expansion continued; in 2001, BotniaRosk (the WM company south of Vaasa) and in 2003, Millespakka (the rural WM company east of Vaasa) began to collaborate with ASJ and deliver their separately collected organic waste to Stormossen (Fig. 3).

Lakeuden Etappi, the WM company in the Seinäjoki region east of Vaasa, delivered organic waste to Stormossen temporarily in 2004–2008 (they went on to establish their own biogas plant). Since 2009, the Vestia WM company further north of Vaasa started to deliver organic waste (Fig. 3), but in 2013, BotniaRosk ended use of Stormossen.

The strategic development of waste treatment proceeded in tandem with regional collaboration. First, Ekorosk initiated its own incineration solution but relied on Stormossen for their organic waste; the collaboration with Ekorosk was established in 1994 (Nygård, 2015; Figs. 4–5). At the time, the landscape can be summarized as follows:

Stormossen was at the heart of the WM solution for the whole Vaasa region and a part of WM in the Pietarsaari region;
ASJ was considered as a potential WM centre for a larger region, because it had the capacity for treating large waste volumes in a qualified manner and modern technology;
ASJ was considered as a national model used to develop WM solutions nationally
It contributed directly to the WM Act (in force 1994), which underlined the importance of sustainable development, minimizing and utilizing waste, and set new requirements for WM systems.

This collaboration strategy is illustrated in Fig. 4. The idea was to

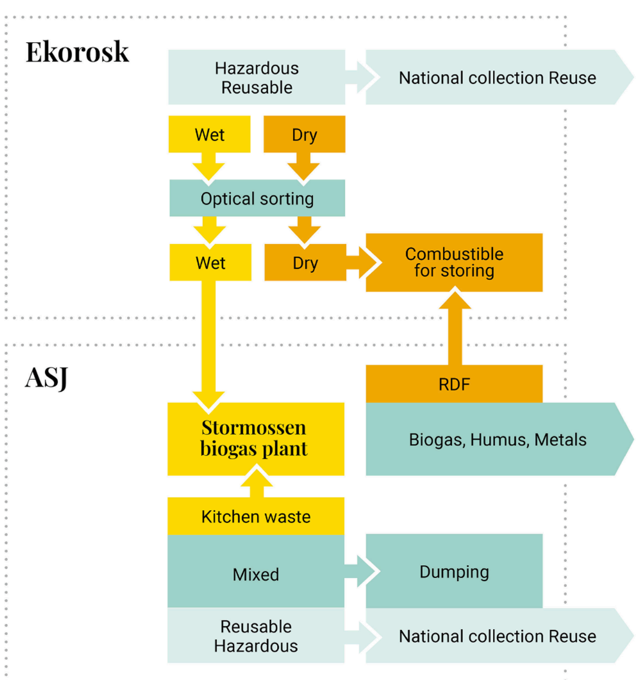

Fig. 4. The waste management strategy and organization in the Vaasa (ASJ) and Pietarsaari (Ekorosk) regions in the early 1990s.

integrate biogas treatment for organic waste in Stormossen and the incineration of combustible waste in Ekorosk for both regions, accompanied with extensive collection of reusable and hazardous waste. The incineration plant was under planning in the mid-1990s, but after it was built it soon accidentally burned down and the Vaasa region stopped using this service.

After 2007, when Westenergy was established, the waste treatment concept of the Vaasa region was finalized into its present form. It enabled the utilization of the energy content of such waste that otherwise was impossible to reuse. The consortium and owners are as described in Section 3.1. Until then, the other WM companies used Stormossen in their waste treatment and as a part of their WM strategy. The development of Westenergy completed the WM strategy for a larger region. The whole waste treatment system, consisting of Stormossen and Westenergy, is illustrated in Fig. 5.

4.2. *Waste collection*

The waste collection system has evolved along with the strategic development within ASJ and in the collaborating regions. The first system with waste separation at source was initiated in the early 1990s, as problems with biogas treatment necessitated change. Prior to this and typical for Finland, there was a long tradition of collection and reuse of paper and cardboard and scrap metal. The collection systems, however, relied on individuals voluntarily delivering their materials to a few collecting points, some located at properties, such as apartment houses in the city. They were integrated into the WM collection system in the early 1990s.

The one-bag system was in use until 1992, although at the same time there were some general collection stations and the separation of waste for reuse was voluntary. The network of general collection stations was supplemented to cover the whole area. They consisted of unoccupied 'eco points' and 'reuse stations' (waste reception stations). The eco points were for smaller waste amounts and weekly use, serving some 400–500 inhabitants each, mainly in areas of detached houses. In 1995, there were around 100 eco points in the Vaasa region. This network was completed by 10 occupied controlled reuse stations for all types of waste, each serving around 4000–5000 inhabitants (Isaksson et al., 1996).

The collection system developed as shown in Fig. 6. The main feature has been to include collection of all reusable waste fractions and hazardous waste in all general collection stations, including apartment houses, estates and gatherings with five or more households. For detached houses, the collection covered only 'kitchen' (organic materials) and 'mixed' waste (dumping), and all other fractions were to be delivered to general collection stations.

The largest reform took place when Westenergy was established. The most important change was to introduce source separation and collection of biowaste destined for the biogas treatment plant (Stormossen), and to improve the quality of the combustible fraction for incineration (Westenergy) by more efficient sorting at source. These adjustments finalized the waste collection system of the Vaasa region. Stormossen and Westenergy have accepted only source-separated organic and combustible waste fractions from other WM companies. This collection system remains in operation today.

4.3. *Development of material flows*

The amount of municipal waste within the initial Vaasa region (Vaasa, Mustasaari), was 62,300 tons per year in 1990 (Peura et al., 1991; supporting information). This estimate was based on a statistical calculation (Peura et al., 1991) and earlier research results of how much and which kind of waste is produced by communities. Since then, no research about waste production has been carried out. Therefore, all subsequent results about waste volumes and shares of different fractions are based on the statistics documented by WM companies about the

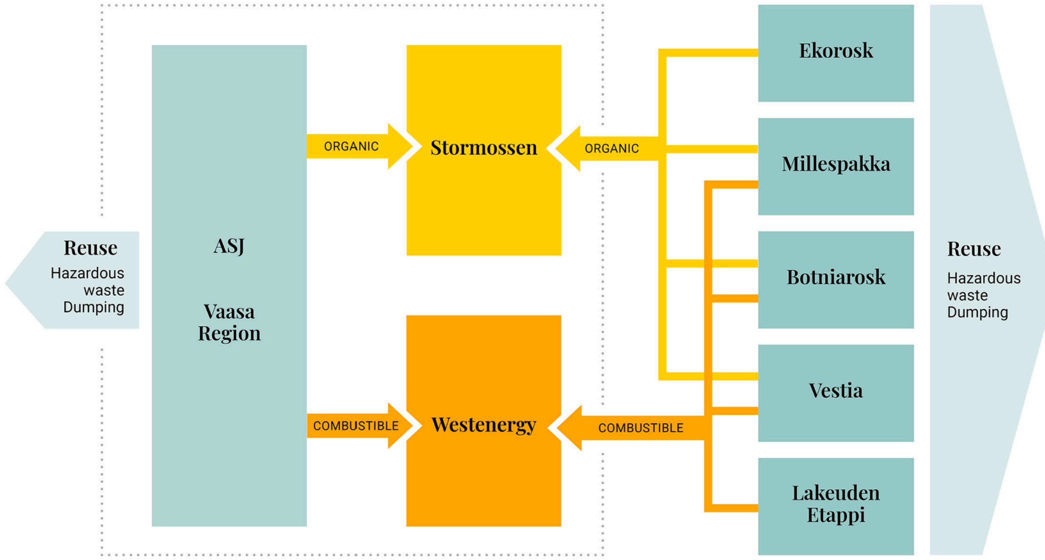

Fig. 5. The treatment system for organic (Stormossen biogas plant) and combustible (Westenergy incineration plant) waste of the Vaasa region in collaboration with other waste management companies.

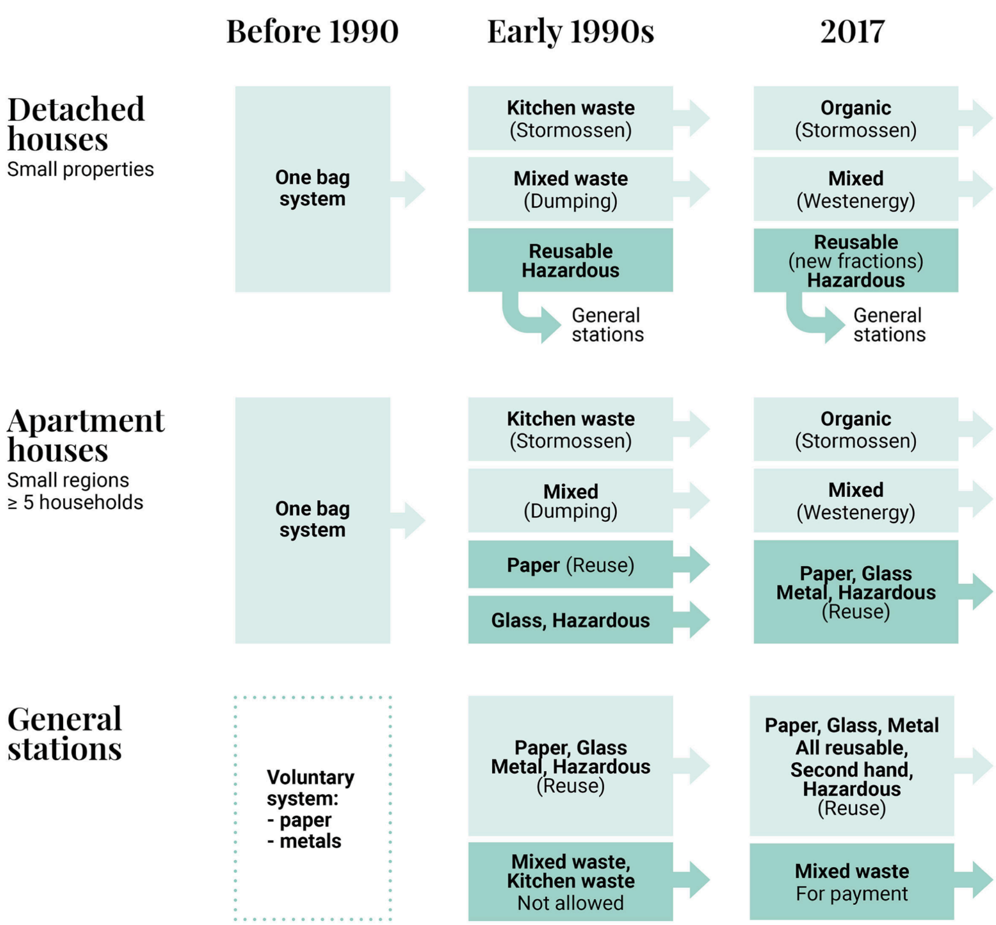

Fig. 6. The waste collection system of the Vaasa region since late 1980s.

waste or materials collected and delivered to the treatment system.

The main part of waste in the early 1990s was produced by industry and the city of Vaasa. The areas that later joined ASJ increased the waste volume by around a third. The organic fraction contributed to about a third of all household waste.

The first results of how the waste and material flows evolved during the early years of ASJ were reported in the mid-1990s (Isaksson et al., 1996). This is summarized in Fig. 7, which shows substantial development in the following aspects: Waste dumping decreased significantly, as in the 1980s, almost all waste was dumped, but in 1993, the share of

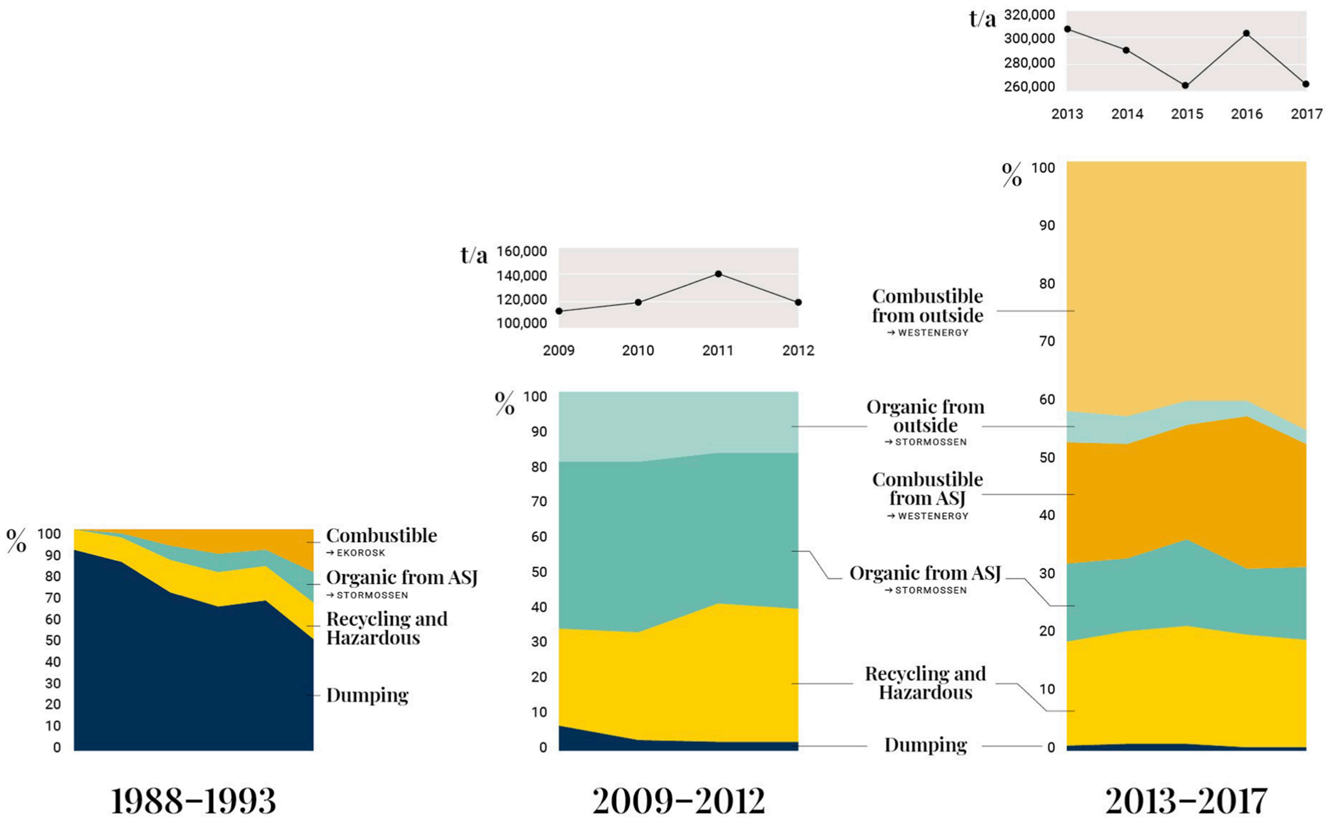

Fig. 7. The efficiency of waste management in the Vaasa region since the late 1980s.

dumping was around 50%. Waste utilization had become routine, as people were used to collecting reusable things and materials and results improved continuously.

Simultaneously, the number of dumping sites was successfully decreased, as most were completely closed and several were in the process of closing. The closing procedure was strictly regulated with certain mandatory processes, e.g., management of wastewater, collection of landfill gases and landscaping the environment. These processes were expensive, required high expertise and took a lot of time to plan and carry out.

The rejects from the mixed waste and biogas treatment were problematic because they included impurities, making them difficult to reuse and to sell. This resulted in the need for continuous dumping and the need to develop the system. This was done by reforming the collection system and the strategy. More careful source separation enabled use of a larger share of materials. Despite this, there would remain a significant share of unusable waste, but which could be used as energy by strictly controlled incineration. This reasoning led to the establishment of Westenergy.

The efficiency of the reformed WM until the mid-1990s (Fig. 7) implies that dumping was the main solution for industrial waste and some 40% of all municipal waste was still dumped. The share of waste utilization had improved remarkably during 1990s.

The volumes of waste delivered to the treatment system in the Vaasa region (Stormossen and Westenergy), both from the initial Vaasa region and the collaborating WM companies, and separately collected materials to recycling and hazardous waste in the Vaasa region, are illustrated in Fig. 7 (also: supporting information). The amounts increased by around a third when other WM companies started to use Stormossen. Simultaneously, positive development continued in terms of more efficient collection of hazardous waste and waste reuse and, especially, decreased waste dumping. Within the initial Vaasa region, only 3% of waste was dumped in 2012, and for the whole waste volume treated in Stormossen, only 2.5%, and the recycling efficiency reached 45% of all waste by 2012. Correspondingly, the anaerobic "waste to energy" efficiency was some 50% within the initial area and 60–65% for the whole consortium (Fig. 7).

This development has continued until the present day. Since late 2012, when Westenergy started, the amount of waste treated by ASJ has more than tripled. Combustible waste from outside ASJ is twice that of ASJ. In the Vaasa region, the volume of waste treated in Stormossen has decreased, presumably as a result of less efficient sorting of biowaste, which means that organic waste partly gets into incineration. In 2017, only 0.5% of all waste was dumped (1% from the initial ASJ), and as much as 60% of all waste (35–40% within the initial ASJ) was recovered into energy by Westenergy (Fig. 7; supporting information).

Therefore, the main features have been: Decreased share of waste dumping and dumping sites; Increased volume of reuse of waste; Highly efficient collection of hazardous waste; Separate collection and use of organic waste; and Use of the energy content of waste by incineration. The development also shows that almost 100% in 1980s and as late as mid 1990s still some 40% reusable, recyclable and recoverable materials were dumped.

5. Concluding discussion

5.1. Research question 1: Waste collection and system evolution

Stormossen was the first and still is one of the very few biogas plants to exist as part of a regional WM system. Westenergy is the first permitted waste incineration plant for decades in Finland, enabled by a high-quality sorting system and emission control. Both solutions have generated interest nationwide and several other regions have either joined the consortium or use its services. The initial idea was that no changes to the waste collection system would be needed. However, because of a number of technical problems (e.g., ASJ 1992; Rintala and

Järvinen, 1993), the collection system had to be adapted to the needs arising from the treatment plant: Pre-treatment was unable to handle inappropriate fractions; Hazardous waste disturbed the fermentation (inhibition, harmful changes); and End products contained contaminants (heavy metals, oil, solvents).

The alignment of pre-treatment, fermentation and waste collection systems was a long learning process. The transition to source separation was the only way to improve the quality of incoming waste (Sairinen, 1994). This has led to the revision of the strategy, collection and organization, which differed significantly from the original plan, the 'one-bag system'. This meant that the strategy was effectively inverted, as first, the waste treatment plant was erected and then the WM strategy and waste collection system were adjusted to overcome problems.

This development took place in times of changing visions of the whole WM branch. During its establishment, ASJ still adhered to the throwaway approach, as although it had initiated new thinking, it was only focused on the end of the value chain. ASJ was, however, at the forefront of forming the new vision and praxis of the emerging vision of reuse of waste.

Regional collaboration added a new dimension and provided a model for the evolving WM. Large investments served wider consortia, which, accompanied by wider collection and reuse systems, gave way to the present WM strategy. Today, the direction of travel is towards the circular economy and PSS. The most important feature is to obtain economically and functionally optimal material management systems, where the borderline with WM is vanishing.

The ideology and principles of recycling, general opinions and people's readiness were clear by the early 1990s (Uusitalo, 1986; Isaksson et al., 1996) and prepared the ground for renewal, even demanded it. Despite this, the first solutions were technology-driven 'end-of-pipe' (EOP) solutions and not comprehensively recycling-based. The evolution in the Vaasa region was largely similar, as the EOP was the initial response that later had to be redirected towards a more proactive strategy. The general evolution and legislation pressure accompanied by other strong drivers such as environmental policies have prepared the ground for adding value to EOP solutions by means of proactive environmental policy. This process brought not only cultural foundation but also improved the material, economical and operational bases for expanding the renewed praxis.

It is important to note that circulation will only be possible in networks where waste producers can join as members. The establishment of a complete infrastructure is impossible if one of these actors is missing. This kind of infrastructure intensity applies today also within the energy transition (Peura, 2013a). Unfortunately, there is no data about social impacts of the WM reform. The main environmental impacts arose from the old dumping sites, which all have now been closed. The new one within the ASJ area is very strictly regulated and practically has a closed loop for leakage water and decent filtering of exhaust gases from incineration.

Except for efficient recycling, recovery of waste to energy and utilisation of reject from biogas treatment, the idea of CE has been promoted by the Circular Economy Hub. It is a devoted area for businesses, and it has all necessary infrastructures (electricity, heating, other energies, smart web connections, logistics etc.) all organised by the public sector. This will provide synergies for companies of being close to raw materials, energy, partners etc. and it enables positive operational environment for even smaller enterprises. Within the ASJ, a suitable area for the CE Hub has already been reserved and the practical organisation is underway.

Similar studies in terms of WM PSSs have been conducted by Carvalho et al. (2020) and Casazza et al. (2019), but it seems that WM has not widely been considered and studied as a PSS. Therefore, the approach proposed in the present study may be of value to study and address existing waste issues worldwide. PSSs are also business models and the economic feasibility shown with the help of PSS business models will help companies to adopt sustainable and profitable activities in WM and the circular economy.

5.2. Research question 2: Waste volumes and share of reuse

The main objective for reforming WM – reducing dumping to be close to negligible – has been very successful and the Vaasa region now only has one dumping site. The amounts of materials within the WM system, however, has increased, probably because control and documentation have become more efficient. It would appear that more materials have become parts of WM and recycled materials have been documented within the system. The share of treated organic waste has decreased, supposedly because a larger share has gone to the combustible fraction and the efficiency of source separation has decreased. Recycling has become more common.

The development nationwide has followed a similar path, as dumping decreased significantly after 2010, while in the Vaasa region this happened some 10 years earlier (Figs. 7 and 8). The share of energy recovery is higher within ASJ than in the rest of Finland. However, Finland is among the top five countries in Europe for waste utilization and avoiding disposal, and first in energy recovery (Fig. 8). Despite this, the EU noted that Finland was at risk of failing to meet the 2020 target of 50% preparation for recycling of municipal waste (EU, 2018), implying the prioritization of reuse before incineration. This is based on EU's waste hierarchy (European commission, 2012), according to which the first priority is prevention, followed by preparing for reuse, and only then recycling and recovery.

There are stark differences between European countries in the share of waste disposal and utilization (Fig. 8). Several countries have serious challenges to increase energy and material recovery. Some recent work to try to address these challenges include a sociotechnical approach (Tomić and Schneider, 2020) to tackle PESTEL (Political, Economic, Social, Technological, Environmental and Legal) problems, data collection and analysis (Velvizhi and Billewar, 2021) to understand how WM processes actually work and knowledge management frameworks (Abila, 2020) to encourage people – the key players – to become involved. There is potential economic value as material and energy provide motivation, but local conditions can be challenging. The question is how to learn from successful countries.

5.3. Research question 3: Generalizing from the Vaasa region

The main observations in this study were the following: (1) Involvement grew from individuals to cover the whole population, and regional WM collaboration became steadily established; (2) The collection system expanded from a few points to complete regional networks; (3) The one-bag system was replaced by source separation; (4) Waste dumping decreased almost to negligible levels; (5) Recycling evolved to handle separate materials (energy, reuse, biowaste); (6) The expansion of feasible economic activity in WM enabled start-ups and innovative PSSs.

These steps of WM development in the Vaasa region are well aligned with the principles of the circular economy, i.e., a reduced need for natural resources, waste minimization and optimization of environmental, social, material and economic values of materials, components and products over their lifecycles (Velenturf and Purnell, 2021).

The renewal of Finland's WM systems was initiated in the early 1980s. Together with examples elsewhere from Europe it represented a larger scale paradigm shift, which led to whole-branch change. The Vaasa region pioneered regional collaboration with large investments and integration for maximum benefit. The way in which the PSS evolved in the region may be unique, under specific local conditions with stakeholders and successful local systems can rarely be copied to other places. Borders between WM, material handling and energy were gradually blurred. In establishing functioning PSSs, regions may skip some of the steps described here and first create regional PSS concepts, prepare roadmaps for achieving PSSs, etc.

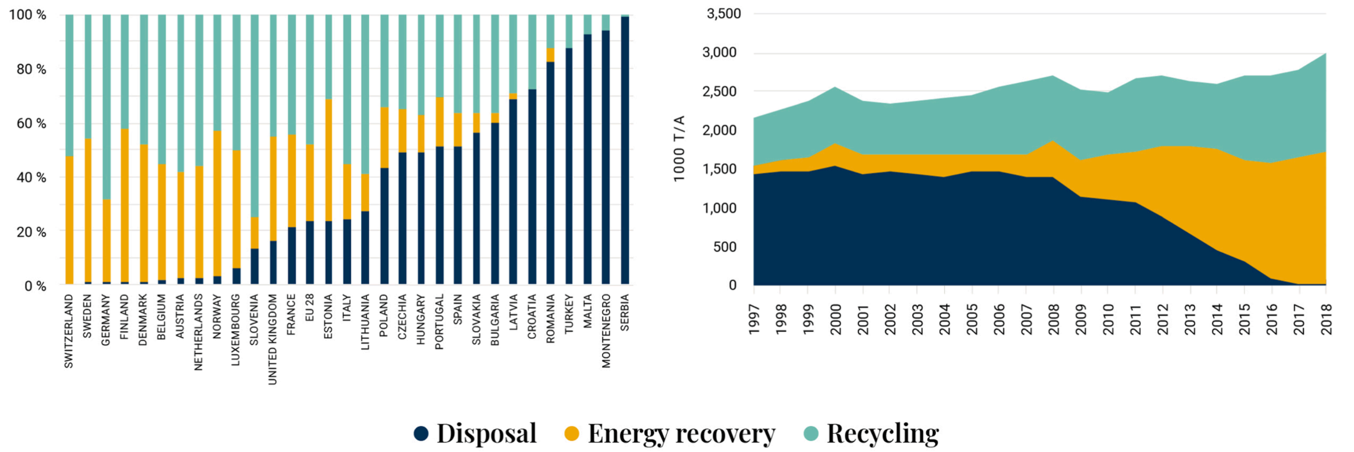

Fig. 8. Municipal waste by waste management operations in European countries (left; 2018; source: Eurostat, 2020) and in Finland (right; 1997–2018; source: Statistics Finland, 2021).

Network of locally functioning PSSs can create a system-of-systems (SoS; Maier, 1998; Boardman and Sauser, 2006), i.e., an interconnected network of regional PSSs that are capable of both independent operation and interoperation to achieve broader, national goals. SoS has five key characteristics (Maier, 1998): 'operational…[and] managerial independence of component systems, geographical distribution, emergent behaviour, and evolutionary development processes, and identified operational…and managerial independence'.

Some drivers guiding WM systems development include financial benefits for municipalities (Di Foggia and Beccarello, 2020) and individuals (Abila and Kantola, 2020), and avoiding serious hazards caused by certain waste fractions, like e-waste (Leclerc and Badami, 2020). Policy makers play a major role in municipalities. Supportive policies are key enablers, together with economic benefits to build and maintain such successful systems.

Reforming systems often have 'built in' conflicting interests. WM systems require large volumes of waste (and gate fees) for economic feasibility, while the regulatory aim is to minimize waste (Hukkinen, 1994; Isaksson et al., 1996; Peura, 2013a,b). It is in the interest of individual waste producers to pay as little as possible. Source separation might be expensive for the system and for clients, but it still is necessary for utilizing waste. Hukkinen (1994) expressed that Stormossen will continuously face the challenge of securing a suitable volume of waste for the plant. The strategic objectives contradict the tactical, praxis-based aims.

Another important point is the division and organization of work. Usually, growth and growing density force communities to improve division of labour. Internal conflicts are characteristic of the development of organizations, as they rise from real need: division of labour together with a changing operational environment result in solutions that improve an organization's capacity and efficiency (Rhenman et al., 1965). This development can be seen in the WM evolution, as collection and treatment of waste, and control were separated all into organisations of their own.

Because investments in treatment facilities, such as fermentation and incineration plants, are substantial, different regions and collecting systems may choose different treatment solutions beyond the regional boundaries of their system. This has been seen in our case, especially after Westenergy was built. Several collaboration regions chose Westenergy as part of their treatment portfolio; for Westenergy, this has been economically favourable via the collection of gate fees.

5.4. From limitations and weaknesses to value added and future prospects

The main limitations of our research are associated with the character of case study and its methodology. Usually case studies are unique and original, which makes the generalisation of their results challenging. As for the methods, our data was elaborated into a longitudinal timeline in retrospective from different and uneven set of original materials. For both reasons, statistical analyses and testing were not meaningful, and the main generalising conclusions were more qualitative reasoning (abductive reasoning and conceptual integration; Arbnor and Bjerke 2009; Kasanen et al., 1993; also Peura, 2013b) than quantitative analyses, according to strong findings, though. The main weakness related to any societal process and even disruptive changes applies also to the evolution of WM: praxis does not follow immediately after "a brilliant idea", but only after the idea has gone through societal evolution. The societal structuring process takes a long time, including paradigmatic changes in attitudes, social norms, policies and regulation, customer behaviour, separate and systemic technological solutions including the formation of value chains, and economic structures, all completely analogous to today's energy transition (widely summarised: Peura, 2013a). We believe, however, that highlighting functioning examples of how WM has evolved step-by-step towards circular economy, learning from unsuccessful and successful steps in this case, is a powerful way to show how the evolution has been carried out and can proceed. By this also case studies, such as our research, can add value both in terms of knowledge and science, and in being a change agent (e.g. Rogers, 1995) for those who still are in an earlier stage of WM evolution.

The logical next step in the very near future, already partly taken, will be the strategic shift from WM to material management, and from exclusively public service to the inclusion of feasible businesses. The utilisation of unused regional resources relates strongly to improved regional economy, as is the case in using renewable energy (Peura et al., 2018). This development would enable division of roles, responsibilities, and specialisation between WM companies, enabling concentration and capacity for selected technical solutions, letting others take the responsibility for other solutions.

Today, biogas already has a very high economic value, and its use as transport fuel is expanding. Biogas is produced not only from organic waste but also other suitable materials, not treated within WM. Even incineration enjoys a high social acceptance, producing a large share of district heating energy for the city of Vaasa. The business operational environment is highly positive, and perception and social acceptance is very high for CE. One example of promoting systematically the preconditions for CE, is the Circular Economy Hub. Already existing PSSs in the region act as components of the CE ecosystem of the future. However, there is still much research and work to be done to achieve such CE ecosystem.

5.5. Concluding remarks

This longitudinal case study analyses the development of the pioneering WM system in the Vaasa region of Western Finland, since the late 1980s to the present. It reflects the general features of the evolving WM system, from the one-bag system and throwaway culture towards a circular economy and modern PSSs. WM is closely related to general material management and even humankind's relationship with the use of natural resources and the environment.

The WM evolution in this case study can be crystallized in the following stages: (1) One-bag system, dumping, 'throwaway culture'; (2) Gradual introduction of use of certain waste fractions; (3) Establishment of waste treatment plants and regional WM organizations; (4) Development of alternative solutions for waste treatment, large investments, introduction of source separation and differentiation of reusable materials and products; (5) Expanding regional collaboration consortia and a circular strategy; (6) Expanding the economic base for circulation, the interface between WM and other material management becoming unclear; (7) Expanding the circular economy; 8) Functioning WM PSSs.

Regionally operating municipal waste facilities have been important in organizing the necessary networks capable of large-scale solutions and ensuring the commitment of relevant stakeholders. In the early 2000s, across Finland WM was mostly organized by regional companies, each owned by several municipalities (Nygård, 2018). Today, consortia and solutions are emerging that integrate WM and the production of renewable energy, creating PSSs and praxis for the circular economy. WM is approaching normal material management, where conflicting internal interests lead to division of tasks into separate organizations, but simultaneously favour larger sizes for both solutions and companies. The Vaasa region was the national forerunner in this process that showed the way for the rest of the country.

The main priorities of WM, as are generally accepted in Europe, are minimization of waste and reuse of things and materials, both of which are prioritized over energy use (Jätelaki 1072/1993; Nygård, 2016, 2018; European commission, 2012), as implied by the EU (2018). Many waste fractions have transformed to become reusable, thus minimizing the amount of waste, while the volume of production has not decreased. Energy recovery has been important in minimizing dumping, although incineration has not been among the main priorities of WM.

Functioning examples of even paradigmatic changes from the old throwaway culture to circular economy, as documented in this research, can add value both in terms of knowledge and science, and in being a change agents more practically. The logical next step in the future is the strategic shift from WM to material management, and from public service to feasible businesses. The unused and well available resources, i.e. waste fractions, return as parts of material loops and circulation, and they provide even the economic base for this development.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2022.01.025.

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