Environmental and Climate Technologies
2025, vol. 29, no. 1, pp. 581–599
https://doi.org/10.2478/rtuect-2025-0040
https://content.sciendo.com

Social Life Cycle Assessment of Healthcare Waste Supply Chains

Julija GUSCA[1]*, Inga KONDRATENKO[2], Beate ZLAUGOTNE[3], Jelena PUBULE[4], Anda ZANDBERGA[5], Silvija Nora KALNINS[6]

[1–6]*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12-1, Riga, LV-1048, Latvia*

Received 09.04.2025; accepted 10.09.2025

***Abstract* – Along with the growth of the healthcare waste (HCW) sector, the significance of properly managed waste generated in medical institutions has also grown, both to protect public health and to ensure sustainability. While recent research, including studies driven by the COVID-19 pandemic, has highlighted the technological, economic and environmental dimensions of the infectious HCW (iHCW) supply chain, the social aspects remain underexplored. These social factors, often identified as behavioural barriers, hinder the effective deployment and adoption of iHCW even when circular economy-based approaches are environmentally and economically viable. This study applies a Social Life Cycle Assessment (S-LCA) to two iHCW management supply chains in Latvia: (1) University Hospital → thermal treatment plant → landfill disposal and (2) Regional Hospital → chemical treatment plant → energy recovery. The S-LCA methodology follows the United Nations Environment Programme/Society of Environmental Toxicology and Chemistry (UNEP/SETAC) guidelines, with data collected through interviews and structured across 5 categories, 6 subcategories and 82 indicators. The results of the S-LCA demonstrate that waste management companies dealing with HCW have high socially responsibility rates (average score 75 %), mainly due to high requirements set nationally for all waste management companies to qualify for participation in the tender procedures (ISO 9001, ISO 14001, ISO 45001, ISO 50001). In contrast, hospitals, as government- or municipality-funded entities, possess well-structured documentation and formal commitments in areas aligned with national priorities, such sub-categories as forced labour and child labour, equal opportunities and non-discrimination. From the perspective of social hotspots identified throughout the supply chains, the lowest performance was noted in subcategories such as "Poverty alleviation" (aggregated weighted score 43 %), "Education provided in the local community" (54 %), "Corruption" (57 %) and "Local employment" (58 %). This trend of social hotspots is not exclusive to the iHCW supply chains; it largely mirrors the wider national context and the waste management sector as a whole.**

***Keywords* – Case study; medical waste; social hotspots; supply chain.**

1. INTRODUCTION

As populations grow and the demand and provision of healthcare services increases, each year healthcare generates millions of tons of waste worldwide. Over the past 30 years, the healthcare system has become an increasingly technologically and operationally complex system, resulting in environmental impacts, for example from healthcare waste [1].

* Corresponding author.
E-mail address: julija.gusca@rtu.lv

©2025 Author(s). This is an open access article licensed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0).

Healthcare waste (HCW) is divided into non-hazardous waste and hazardous waste, which can be biological, chemical or physically hazardous [2]. The main hazardous characteristic of HCW is linked to its potential infectiousness or capacity to cause infectious diseases as it may contain viable microorganisms [2]. However, if the management of HCW (incl. treatment) is properly organised, the risk of contamination is very low [3], [4].

Preferred treatment (sterilization) technologies for infectious HCW (hereinafter iHCW) are low-heat thermal processes (autoclaves, vacuum autoclaves without shredder, autoclaves with integrated shredder, microwave technologies, friction thermal treatment (rotoclaving), chemical processes and incineration [5]. Waste incineration for energy recovery, according to the waste hierarchy and following the circular economy framework, is the lowest preferred option after landfilling, however it is still widely used for HCW due to its economic viability [6]. After disinfection and passing the microbial inactivation test, HCW is considered as non-hazardous municipal waste [5] and thus, from the circular economy perspective, might be considered as a valuable resource. However, the composition of HCWs must also be taken into account in the circular economy, as it is not homogeneous and varies within the country due to the specific profile of each health institution [7].

To aspire for sustainability in the healthcare sector, it is important to understand the multifactorial (technical, economic, social and environmental) nature of the healthcare waste sector. Circular economy concepts, with the potential to provide economic, social and environmental benefits can facilitate achieving sustainability in the healthcare sector (see Fig. 1).

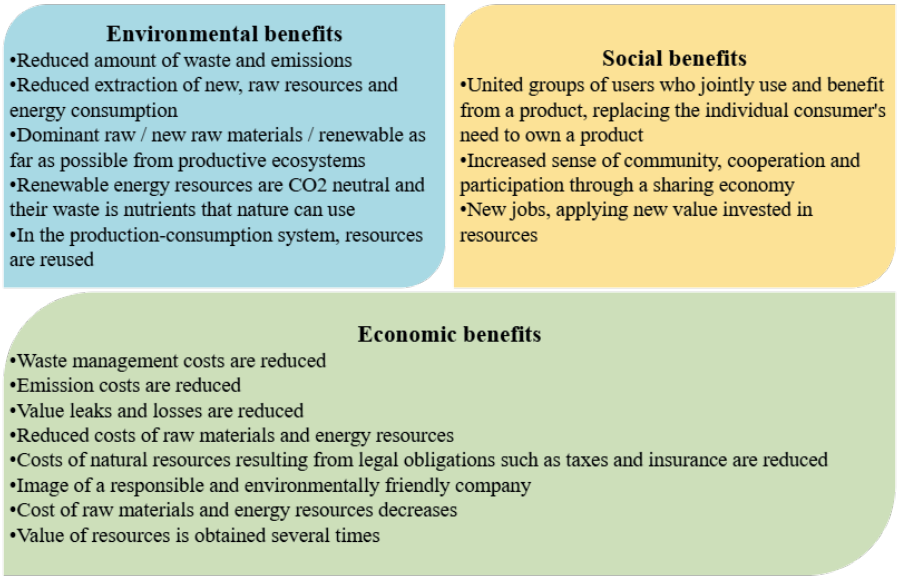

Fig. 1. Environmental, social and economic benefits of the circular economy [8].

Social assessment is increasingly relevant for a circular economy, as the transition from well-established processes to new models leads to interaction among stakeholders and may result in additional previously unknown impacts [9]. Social issues are also becoming particularly relevant for companies regarding corporate social responsibility (CSR). CSR in Europe is regulated by the European Union (EU) Corporate Sustainability Reporting Directive (CSRD) which came into force in 2023 and aims to assess the impact of a

company's corporate activities on society and the environment, so that stakeholders can assess risks and sustainability [10]. The CSRD requires all large and listed small and medium-sized enterprises to report using common standards and sets out different standards for companies outside the EU [10]. The CSRD reporting is guided by the European Sustainability Reporting Standards (ESRS) which incorporates various regulatory frameworks – the International Labor Organization, Global Reporting Initiative standards, International Integrated Reporting Council recommendations, the ISO 26000 standard and the UN Global Compact [11]. At this point, the social life cycle assessment (S-LCA) properly fits into CSR methodological framework by (1) identifying specific stakeholder concerns (gaps and risks) and areas needing improvement in products or services and in launching CSR initiatives, (2) enabling transparent and credible reporting, (3) serving as a tool to monitor progress within the supply chain [12]. The scope of S-LCA, as defined by the United Nations Environmental Programme's (UNEP) /Society of Environmental Toxicology and Chemistry (SETAC) (2009) is designed to promote the improvement of social conditions and the overall socio-economic performance of a product throughout its life cycle for all its stakeholders [13]. This includes issues such as child labour, unpaid wages, safety issues and others [9]. To ensure a robust and coherent S-LCA, the UNEP/ SETAC Life Cycle Initiative published guidelines for the Social Life Cycle Assessment (S-LCA) of goods and services [10], where stakeholder categories include workers, local communities, value chain actors (not including consumers), consumers, society and children [13], [14]. In October 2024, a new standard on S-LCA entered into force: ISO 14075:2024 "Environmental management – Principles and framework for social life cycle assessment" [15], based on the UNEP/SETAC S-LCA guidelines. Overall S-LCA follows the general environmental LCA methodological approach defined in ISO 14040 standard and includes goal and scope, inventory, impact assessment and interpretation phases [10]. Incorporating localized stakeholder data and assessment is necessary to improve the granularity of S-LCA [16]. Results from surveys of involved stakeholders are considered as input values according to guidelines.

Messman *et al.* [17], in their extensive research on the analysis of environmental and social indicators for assessing hospital sustainability, have concluded that patients, often declared as clients, are the stakeholder group about which many studies to date have focused on. This includes the service and medical quality, patients' well-being aspects and accessibility of the medical services to all population groups, incl. vulnerable groups [18]. Studies related to the link between sustainability and employees is characterized by a much smaller number of studies and covers such indicators as public commitment to human rights and labour-related key-performance indicators, fair labour practices and decent work [19] and psychological well-being of healthcare workers [14]. Nonetheless, minimal attention is paid to stakeholders such as local communities and society along upstream value chains and beyond the hospital.

Despite the critical role of the health sector and related stakeholders in ensuring the social sustainability of society, the current number of S-LCA studies conducted in the health waste sector is critically low [21], [22] rising above 120 research papers for waste management in general without a link to the health sector.

The aim of the research is to carry out a S-LCA of two HCW management supply chains (from iHCW to end-of-life stage) in Latvia: the first supply chain covers iHCW generation in a multipurpose University Hospital (hereinafter University Hospital), its transportation and treatment in a large scale thermal treatment plant and disposal of treated waste in a landfill; the second – generation of iHCW in a multipurpose Regional Hospital (hereinafter Regional Hospital), its transportation and treatment in a large scale chemical treatment plant and use of treated iHCW as a fuel.

2. METHODOLOGY

The methodology for the research is based on the UNEP SETAC guidelines and the data sheets on S-LCA. Data inventory was organised *via* one-on-one interviews covering iHCW supply chains relevant categories, subcategories and indicators (see Annex), supplemented with in-person audit at facilities, as well as checking the documentation referred to during the interviews.

2.1. Goal and Scope

The goal of the present S-LCA is to define the social performance (including social risk and achievement fields) significant and limited to the iHCW supply chain. The present research analyses two supply chains (Fig. 2): (1) linear supply chain (hereinafter "Supply chain 1") related to treatment of iHCW via chemical treatment technology and disposal of treated HCW at a landfill and (2) circular supply chain (hereinafter "Supply chain 2") related to treatment of iHCW via thermal treatment technology and the use of treated HCW for refuse-derived fuel (RDF) production. Within the study, "Supply chain 2" is identified as a circular economy scenario since the treated HCW is not landfilled but instead used as RDF.

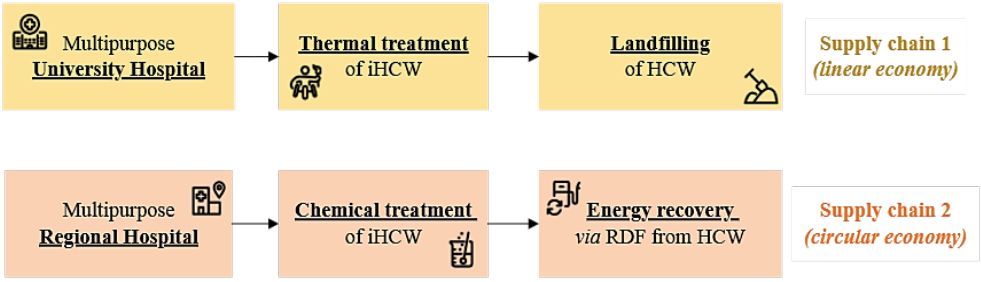

Fig. 2. Analysed supply chains.

Considering the applied methodology (interview-based case study analysis), the findings of the survey have several limitations:

- The findings are valid within the boundaries of the specific system and considering the defined limitations.
- Only operations (generation, transport, treatment and end-of-life) related to iHCW are included in the study, i.e., although some findings may be relevant to other HCW, these were not further explored in this study.
- The findings are specific to the performance of the studied companies and, therefore, cannot be directly generalized to other similar iHCW supply chains. However, they can provide insights for identifying potential social hotspots.
- The research is not a comparative S-LCA, thus the results of the "Supply chain 1" or any stage of the supply chain cannot be compared with "Supply chain 2".

System Boundaries

The technological system boundaries of the present S-LCA are "gate-to-gate": from generation of the iHCW in hospitals to end-of-life stage of the iHCW – landfill ("Supply chain 1") or energy recovery plant ("Supply chain 2"). The system boundaries are shown in Fig. 3.

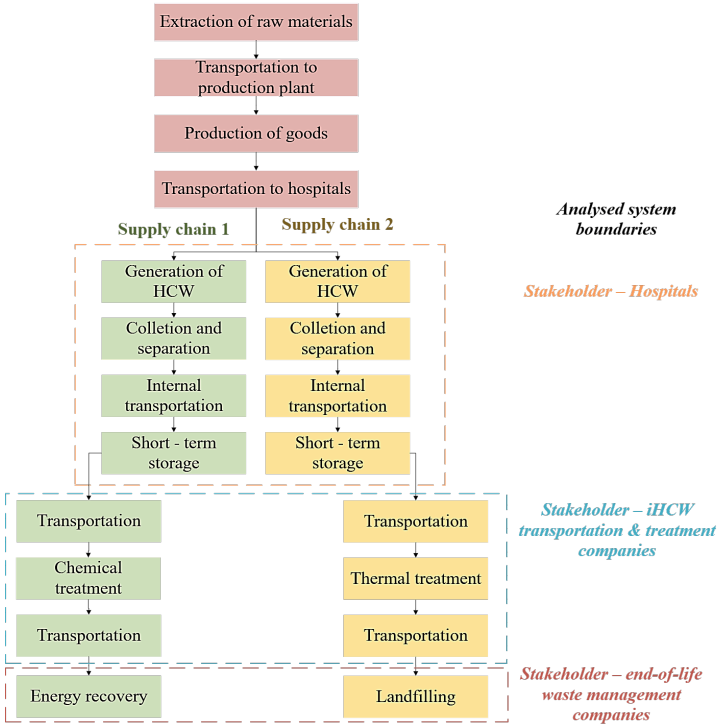

Fig. 3. Technological system boundaries of "Supply chain 2".

The time boundaries of the present S-LCA are from February to June 2023, when the data collection and interviewing process was performed. The geographical boundaries (and also legal boundaries) of the S-LCA cover Latvia (all the processes except the use of RDF for energy production in "Supply chain 2") and Estonia (use of RDF in "Supply chain 2").

2.2. Social Life Cycle Inventory

2.2.1. Data Collection

To ensure correspondence of the S-LCA to five principles – usable, transparent, suitably/appropriately robust, inclusive, comprehensive – data collection for the social life cycle inventory was extracted from questionnaires and supplemented with specific documentation of the entities responsible for the unit processes analysed.

Structured interviews (questionnaire based) are carried out to gather the necessary information. The questionnaire was structured according to the UNEP guidelines and includes categories, subcategories and indicators (see Annex). The indicators are designed for all supply chain stages: healthcare facility – a place where the HCW is generated, transportation and treatment of iHCW – iHCW treatment plant and end-of-life stage of treated HCW – landfill management company and energy production from the RDF (HCW based) company.

Five to six main social impact categories (Workers, Local communities, Value chain actors, Consumers, Society and Children) were selected in each of the three supply chain stages (iHCW generation in hospitals, iHCW Transportation and Treatment, End-of-Life). 74 indicators have been further selected under the stage "iHCW generation – Hospital", 82

indicators under the stage "iHCW transportation & treatment" and 47 indicators under the stage "End-of-Life".

The sub-categories of each major category and their indicators are analysed to determine more fully the true impact of the product. Indicators not only show current conditions or trends, but also provide an understanding of how activities affect the different dimensions of sustainability – economic, environmental and social [23], [24].

The survey involved two hospitals, two iHCW transportation and treatment companies, one landfill operation company and one energy recovery company. To maintain confidentiality, the names of the companies involved in the interviews are not disclosed. The following personnel from these companies participated in the survey:

- iHCW generation stage: technical managers responsible for overall management of the waste management processes at the hospitals (6 persons), nurses or nursing assistants – taking part in waste segregation as part of a daily routine during the medical services (5) persons, technicians – responsible for collection of waste bins (12 persons).
- iHCW transportation and treatment stage: technical managers responsible for compliance of the transportation and treatment technologies to national requirements (2 persons), drivers (7 persons), HCW treatment unit operators (4 persons).
- HCW end-of-life stage: landfill manager (1 person), technical manager/client manager of energy production plant (1 person).

2.2.2. Weighting of Indicators and Scoring

To ensure proper interpretation of qualitative data obtained during the interviews, the following ranking methodology is proposed.

- Step 1: Weighting of indicators. The weighting process is designed to ensure proportional allocation of importance across indicators. The weight of each indicator is calculated by dividing 1 by the total number of elements at each hierarchical level within a stage. Specifically, this involves dividing 1 by the product of: the number of categories in the stage (C), the number of sub-categories within each category (SC_c) and the number of indicators within each sub-category (I_{sc}) (Eq. 1).

$$\text{Indicator weight} = \frac{1}{C \times SC_c \times I_{sc}}, \tag{1}$$

where

C number of categories;
SC_c number of sub-categories in a category;
I_{sc} number of indicators in a sub-category.

- Step 2: Performance score. To standardise the evaluation of supply chain actors against the defined indicators, each indicator is assigned a performance score on a 0–100 % scale, as seen in Table 1.

TABLE 1. SCORING THE SURVEY RESULTS

Score, %	Description
100	ideal performance or best in class
75	beyond compliance or slightly above average performance
50	neutral performance, compliant with local and international laws and/or basic societal expectations
25	slightly below compliance level or slightly below average performance
0	starkly below compliance level or starkly below average performance

- Step 3: Weighted performance score. The weighted performance score is calculated to reflect both the importance of the indicator (its weight) and the level of performance achieved (its score). Since multiplying the indicator's weight by its raw score does not directly yield a percentage on the desired 0–100 % scale, the resulting value is normalised against the maximum attainable score for that indicator. This ensures that the final weighted performance score is expressed on a 0–100 % scale.
- Step 4 (optional): Aggregation for Reporting. For reporting and presentation purposes, weighted indicator scores may be aggregated within their respective sub-categories and categories. This allows results to be displayed at different levels of detail, depending on the intended audience or reporting needs.

3. RESULTS AND DISCUSSION

3.1. Description of "Supply Chain 1"

iHCW is generated at the multipurpose University Hospital which includes such healthcare profiles as: Therapy, Chronic patient care, Intensive Care, Surgery, Gynecology, Maternity, Pediatrics, Traumatology, Neurology, Urology, Otorhinolaryngology, Stroke Unit, Infections, Pathology of pregnancy, Psychiatry, Rehabilitation, Cardiology, Nephrology, Interventional cardiology, Oncology, Palliative care, Pulmonology, Gastroenterology, Neurosurgery, Vascular Surgery, Endocrinology, Thoracic surgery, Ophthalmology and Emergency 24/7. Based on data from 2022, the average University Hospital's bed occupancy rate is 1927 bed days/month. HCW is collected in three streams: infectious waste, sharps and pathological waste. The amount of the iHCW generated per bed day is 0.320 kg/bed day. The University Hospital is certified according to ISO 9001 and ISO 14001. The University Hospital actively engages with the public on sustainability issues through various media channels. It also participates in informal education initiatives for both children and adults, fostering environmental awareness and promoting sustainable practices.

The next supply chain incorporates iHCW transportation and the thermal treatment of it at the plant. In addition to managing iHCW, the thermal treatment company is also responsible for the collection and transportation of municipal waste. The company is certified according to ISO14001. The company occasionally participates in innovation projects to improve the treatment process and actively promotes awareness among students and junior scientists through technical excursions and on-site practical training.

The technological description of the transportation and thermal treatment stage includes:

- The generated iHCW is transported via specialized trucks from the University Hospital to the thermal treatment plant.
- The sterilization technology is based on an integrated steam treatment system featuring an inclined horizontal stainless steel pressure vessel with a rotating inner drum containing vanes in the internal surface of the drum, post-sterilization shredding of disinfected waste and pressing to remove any excess liquid.
- After treatment and microbial inactivation testing, the iHCW is reclassified as non-hazardous municipal waste and, in compliance with legal acts, can be disposed in a sanitary landfill. Transportation to the landfill is handled by the thermal treatment company using its own specialized transport vehicles.

The sanitary landfill management company oversees the end-of-life activities of treated iHCW – landfilling. The landfill management company is a significant actor in the field of sustainable waste management at the national level and takes active part in the implementation of innovative waste recycling and recovery practices for general municipal

waste; however, treated iHCW is not currently included in the company's innovative initiatives. The company operates their own educational and research centre and actively participates in educational and scientific innovation projects. Annually, it researches and integrates modernized and optimized recycling, recovery and waste minimization practices into its daily operations. The landfill management company is certified under ISO 9001 and ISO 14001. It aligns with the principles of the United Nations Global Compact Initiative, the Ten Guiding Principles of Corporate Social Responsibility and international human rights and workers' rights in its general activities. Additionally, the company is a member of the Employers' Confederation of Latvia.

3.2. S-LCA Results for "Supply Chain 1"

3.2.1. S-LCA Results for iHCW Generation at University Hospital

According to the results of the S-LCA performed for the "Supply chain 1" specifically for the stage "iHCW generation at the multipurpose University Hospital", we can conclude that the Hospital performs close to excellent in the category "Worker" (94 %) and above average in the categories "Local community" (72 %) and "Value chain actors" (70 %). The results in this category are quite logical, as the analysed University Hospital is one of the largest hospitals in Latvia with many employees (over 2700 people). In order to manage such an institution, it has a large administration: there is a human resources department, a trade union and a department for lifelong education.

As regards the contractual framework for employment relations, Latvia is highly regulated and employers, in particular public authorities, comply with the country's labour laws. However, there is still a certain gap in terms of competitive remuneration in the medical sector – this applies to the remuneration of nurses, orderlies and support staff. The hospital is not currently focused solely on employing local labour: given that the health sector is experiencing a shortage of medical and support staff, the main criteria for recruitment are meeting the selection criteria and agreeing to a set salary. The hospital also advertises some vacancies for employment and internships for high school and other students, as well as pupils. There is a high demand for these positions and thus they are always filled.

At the same time, the performance in categories "Society" (42 %) and "Children" (42 %) is below average. While the University Hospital has effective and regular communication and awareness campaigns engaging the public and children, these are rarely linked with HCW management issues. Similarly, in the field of advancements in technology – these are linked with medical innovations, IT, while in the field of iHCW management – there are few R&D activities. The overall performance of the University Hospital at the level of sub-categories is provided in Fig. 4.

3.2.2. S-LCA Results of iHCW Transportation and Treatment via Thermal Treatment

Results of the "Supply chain 1" stage "iHCW transportation & thermal treatment" are above 50 % in all categories: "Worker" 92 %, "Local community" 73 %, "Value chain actors" 79 %, "Consumer" 71 %, "Society" 58 %, "Children" 58 %. The selection of the iHCW transport and recycling company is carried out through an open tender procedure. In tenders for the provision of waste management services for both hazardous and non-hazardous municipal waste, the client often requires, as a minimum performance requirement, the presence of environmental and social responsibility certificates. Thus, those waste management companies that participate in open tenders are more likely to have organisational and environmental management systems and high social responsibility governing principles in place. This explains the high scores in this supply chain phase. The overall performance of

the iHCW transportation and thermal treatment company in the analysed S-LCA subcategories is presented in Fig. 5.

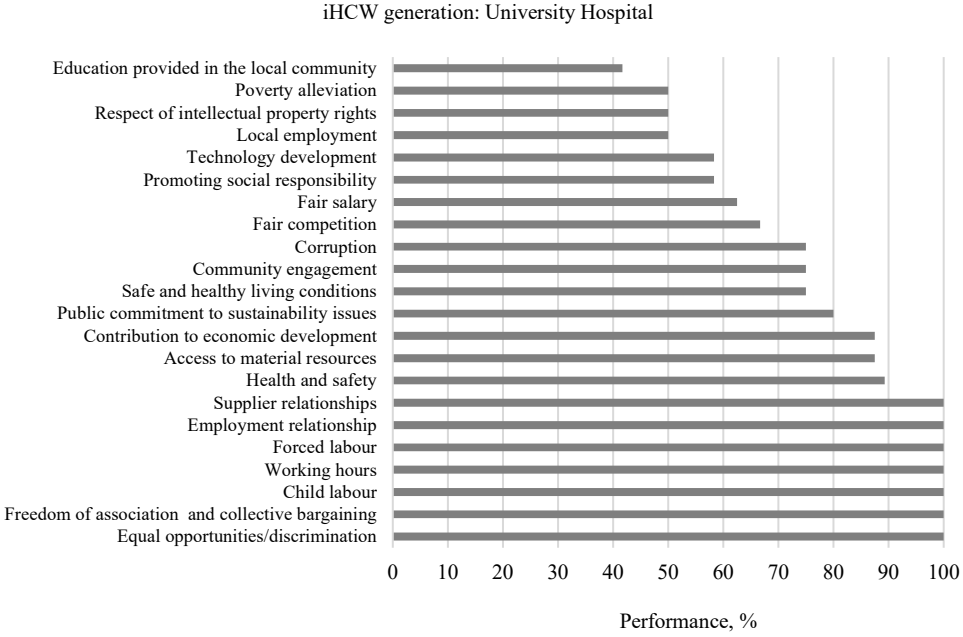

Fig. 4. S-LCA results at sub-categories level for “Supply chain 1” stage “iHCW generation at the University Hospital”.

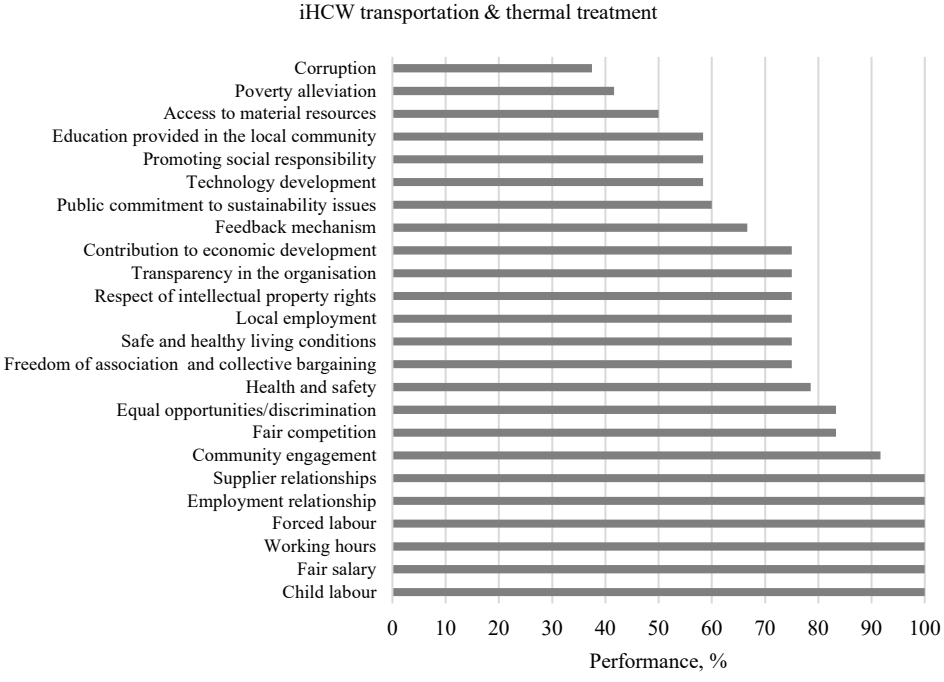

Fig. 5. S-LCA results at sub-categories level for “Supply chain 1” stage “iHCW transportation and thermal treatment”.

The performance in the range of 50–60 % is reached in indicators such as: existence of ISO 26000 certificates, definition of advantages for locals in terms of employment, publicly available sustainability report, action plan to resolve complaints made by society, active participation in fighting corruption and bribery, organisation's formalised commitment to reduce poverty.

3.2.3. S-LCA Results of iHCW End-of-Life Stage at Landfill

The end-of-life stage of the iHCW treated via the thermal disinfection treatment unit ends at the landfill. For several years, the analysed thermal HCW treatment company has been seeking for potential solutions for the valorisation of the treated HCW, however with no success. Treated HCW is transported to the municipal landfill plant and landfilled. Results of the "Supply chain 1" stage "End-of-Life – Landfilling" shows high performance (above 70 %) in all categories: "Local community" 78 %, "Value chain actors" 92 %, "Client" 78 %, "Society" 78 %, "Children" 100 %.

Similarly, to the stage of "iHCW transportation and thermal treatment", the landfill management company actively participates in open tenders, demanding proven actions in environmental management and organisational management. The landfill company operates its educational centre, ensuring continuous collaboration with the public, schools and universities in public awareness activities, environmental education and R&D.

The performance of the treated HCW end-of-life stage at landfill in the analysed S-LCA subcategories is illustrated in Fig. 6. The performance in the range of 40–50 % is reached in such indicators as: locally employed persons, integration of ethical, social, environmental and regarding gender equality criterions in purchasing policy, distribution policy and contract signatures.

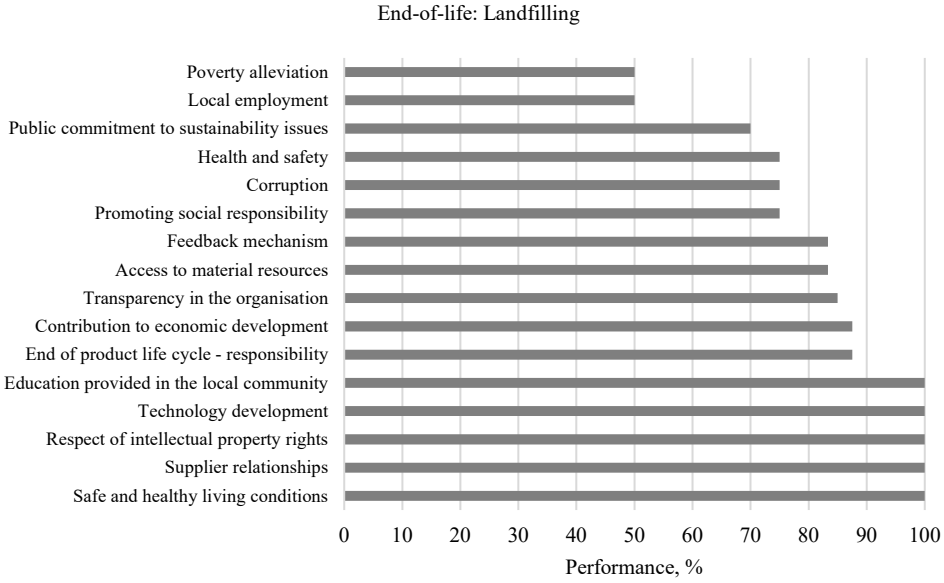

Fig. 6. S-LCA results at sub-categories level for "Supply chain 1" stage "End-of-Life – Landfilling".

3.3. Description of "Supply Chain 2"

iHCW is generated at the multipurpose Regional Hospital which includes the following healthcare profiles: Therapy, Traumatology, Neurology, Gynaecology, Maternity, Chronic patient care, Intensive Care, Surgery, Rehabilitation, Ambulatory, Paediatrics and Emergency 24/7. Based on data from 2022, the Regional Hospital's bed occupancy rate is about 840 bed days/month. HCW is collected in three streams: infectious waste, sharps and pathological waste. The amount of iHCW generated per bed day is approximately 0.240 kg/bed day. The Regional Hospital has implemented neither the Quality management system nor the Environmental management system. The Regional Hospital is actively communicating via media channels, also actively taking part in informal education activities for children and adults, mostly in the healthcare field.

After collection at the Regional Hospital, the generated iHCW is transported by the iHCW transportation and treatment company via specialised trucks to the iHCW chemical treatment facility. The iHCW treatment plant utilizes a technology that uses ClO_2 to treat iHCW from various healthcare facilities in the country. Besides iHCW management, the company also manages hazardous waste (electrical and electronic waste, chemicals, etc.) ensuring collection, transportation, recycling and short-term storage. The iHCW chemical treatment company is certified according to ISO 9001, ISO14001, ISO45001 and ISO50001. The chemical treatment company actively participates in innovation projects aimed at improving treatment processes, exploring alternatives to reduce environmental pollution and promoting waste valorization. Additionally, it plays a significant role in raising awareness among pupils, students and young scientists through initiatives such as technical excursions and hands-on practical activities.

After the treatment process at the plant in Latvia, the disinfected HCW is transported via specialised trucks to the energy generation plant in Estonia, where the treated HCW is used as RDF to generate electricity and heat. The energy production company is specialised in energy generation from waste (incineration of municipal and hazardous waste and use of RDF for energy production) for over 20 years. The RDF-based energy generation company is certified according to ISO 9001, ISO 14001 and ISO 18001 standards and is a member of the association of national professional waste management organisations.

3.4. S-LCA Results for "Supply Chain 2"

3.4.1. S-LCA Results for iHCW Generation at Regional Hospital

According to the results of the S-LCA performed for the "Supply 2" for the stage "iHCW generation at Regional Hospital", we can conclude that the Regional Hospital performs an average at a cumulative score level which equals 64 %: "Worker" 94 %, "Local community" 57 % and "Value chain actors" 69 %, "Society" 59 %, "Children" 42 %.

The highest score is reached in the category "Worker" (94 %). Similarly to the University Hospital, public legal entities strictly follow procedures related to employment issues and have well developed administrative departments to follow and advance the process. Still, the main question of concern is linked with a competitive salary for medical personnel and technical support staff.

The hospital is not currently focused solely on employing local labour; however, the share of non-local staff is not high. The hospital does not advertise internship vacancies for high school students; however, medical students are employed on a regular basis.

Due to limited financial and human resources, the hospital has not implemented or maintained certified systems for organisational, environmental management or corporate responsibility.

The hospital occasionally participates in educational projects for children and young people, but these are usually related to public health and disease prevention and the HCW topic is rarely mentioned during these educational sessions.

The overall performance of the Regional Hospital at the level of sub-categories is shown in Fig. 7. Low performance, below 35 %, appears in the following indicators: fair salary, organisation's poverty alleviation program, contingency planning measures, disaster, emergency management plan, training programs and recovery/restoration plans; and formalised commitment to reduce poverty.

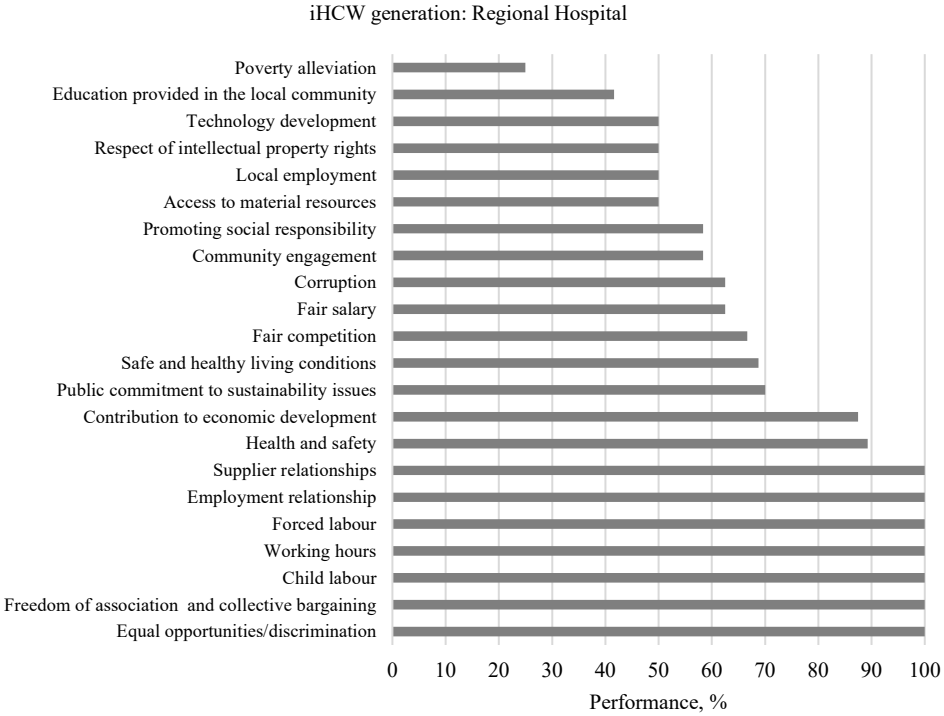

Fig. 7. S-LCA results at sub-categories level for "Supply chain 2" stage "iHCW generation at the Regional Hospital".

3.4.2. S-LCA Results for iHCW Transportation & Chemical Treatment Stage

Results of the S-LCA for "Supply chain 2" stage "HCW transportation & chemical treatment" are above 58 % in all categories: "Worker" 91 %, "Local community" 60 %, "Value chain actors" 75 %, "Consumer" 82 %, "Society" 58 %, "Children" 58 %.

Besides managing iHCW, the company is involved in the management of hazardous waste at the national level. Tender requirements for hazardous waste management are very strict and demand the presence of environmental and organisational certificates, proper transportation vehicles and labour protection mechanisms, including health and safety issues. This explains the high scores in this supply chain phase.

In addition, the chemical treatment company is actively involved in school educational programs; however, like "Supply Chain 1", iHCW is rarely included as a topic in these open lessons and public awareness campaigns. The company also maintains a dialogue with the local community on environmental pollution generated from waste management activities, including complaint procedures and dissemination activities.

The overall performance of the HCW transportation and chemical treatment company in the analysed S-LCA subcategories is provided in Fig. 8.

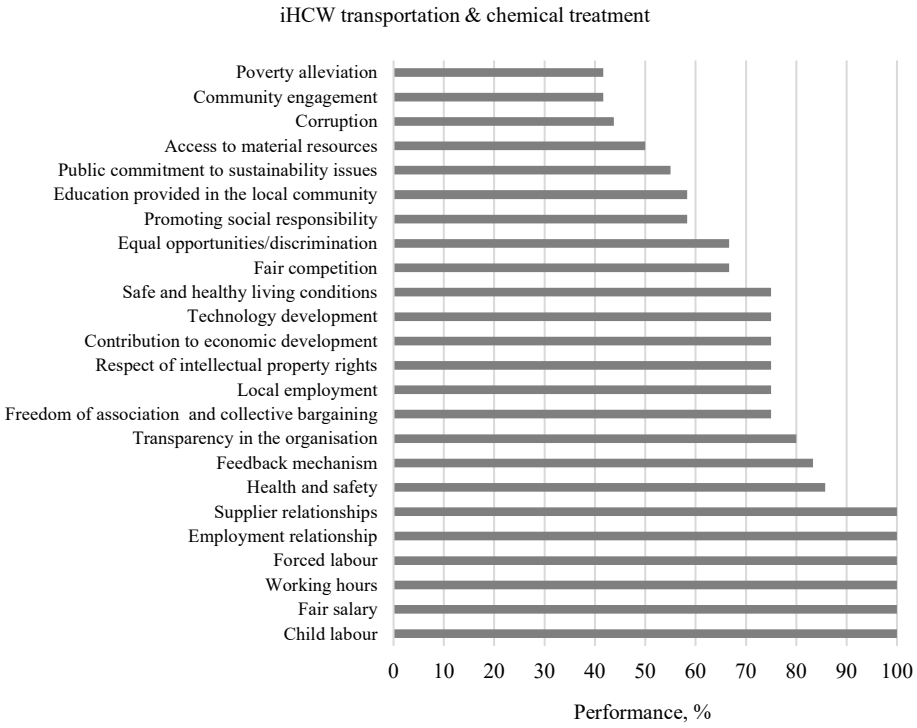

Fig. 8. S-LCA results at sub-categories level for "Supply chain 2" stage "iHCW transportation and chemical treatment".

The low performance, below 35 %, is presented in the following indicators: written documents on active participation to fight corruption and bribery; convictions related to corruption and bribery; poverty alleviation program, formalised commitment to reduce poverty.

3.4.3. S-LCA Results for HCW End-of-Life Stage via Generation of Energy from RDF

The S-LCA performance results of the "Supply Chain 2" stage "End-of-Life – Energy generation from RDF" vary across impact categories. There is high performance (around 70 % and above) in categories such as "Local community" 71 % "Value chain actors" 85 % "Client" 71 %, "Society" 67 %. However, the score in the category "Children" is 25 %, as the company minimally participates in educating and awareness-raising activities for children and youth. Overall performance of the "End-of-Life – Energy production from RDF stage is given in Fig. 9.

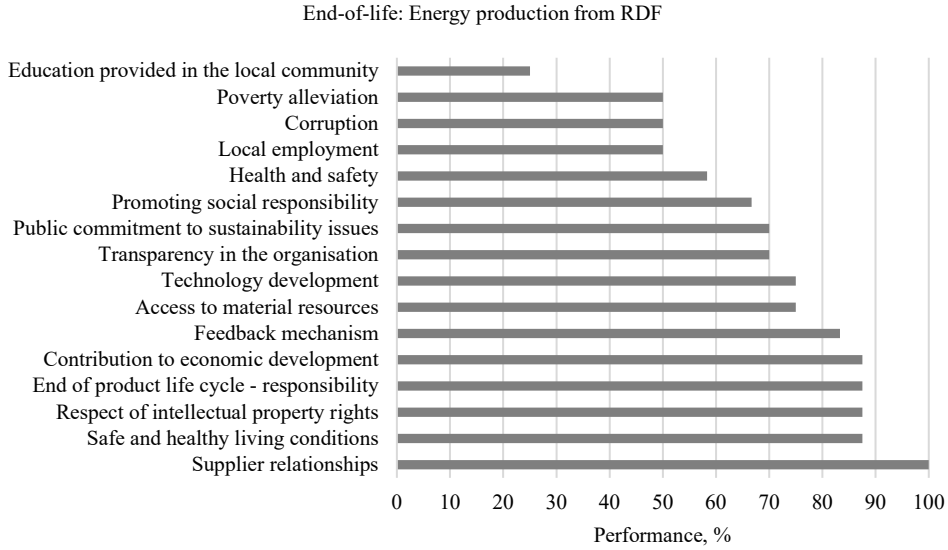

Fig. 9. S-LCA results at sub-categories level for "Supply chain 2" stage "End-of-life – energy generation from RDF".

The low performance, below 35 %, is presented in the following indicators: involvement in school programmes, presence of policy, leadership and budget for early learning, presence of systems promoting community and student participation.

3.5. Social Hotspots in iHCW Supply Chains

When reviewing the outcomes of the two supply chains, it becomes clear that, despite minor differences, the indicators and subcategories where the iHCW supply chain actors excel and struggle are predominantly the same. This trend largely mirrors the general landscape of the country and the waste management industry as a whole. Below, we outline and discuss the social hotspots (subcategories with aggregated weighted score among all the supply chains and supply chain actors below 60 %) highlighted in this research.

3.5.1. Category "Society", Subcategory "Poverty Alleviation" (Aggregated Weighted Score – 43 %)

Poverty alleviation is a proactive organizational measure aimed at reducing poverty by enhancing access to basic needs, social services and economic opportunities for vulnerable populations. The companies analysed in this study did not demonstrate any strategies, action plans or investments specifically focused on poverty alleviation, except those defined at national level. At the healthcare providers level services and supporting activities are provided to various vulnerable population groups, including low-income individuals, people with disabilities, the elderly, Ukrainian refugees and Ukrainian medical practitioners, ensuring access to specifically tailored healthcare, social assistance and integration programs. At the waste management companies (covers two supply chain stages – "iHCW transportation & chemical treatment" and "Landfill"), a special focus was given in creating opportunities to support vulnerable populations by offering employment in collection, sorting and recycling operations and social services, highlighting the dual environmental and social benefits of these initiatives.

Already in 2020, the State Audit Office of Latvia recommended that all relevant public institutions incorporate national poverty reduction targets into their operations, aligning sectors and organizations with the Sustainable Development Goals and national public policies through a cohesive action plan [25], [26] this takes the form of general statements included in strategies of hospitals' (as government- or municipality-funded entities).

3.5.2. Category "Children", Subcategory "Education Provided in the Local Community" (Aggregated Weighted Score – 54 %)

Education, in this subcategory, refers to the efforts of an organization or supply chain actor to provide or support learning opportunities for the local community, thereby enhancing knowledge, skills and social development beyond its direct economic activities. While all supply chain actors represented in this study (hospitals, waste treatment companies, landfill and RDF-based energy recovery company) actively engage in educational initiatives, these activities are not specifically oriented towards HCW management. For example, both hospitals have introduced children's awareness programs at different levels – more extensive and diverse in the University Hospital, due to its larger overall budget, and more limited but defined in the Regional Hospital. However, these programs focus primarily on general health topics such as healthy lifestyles, disease prevention and the importance of regular check-ups, without addressing HCW management, the risks of disease prevalence or proper handling of healthcare waste during hospital visits.

A similar situation was observed in the transportation and treatment stage of iHCW. Likely due to the infectious nature of iHCW, the potential for disease transmission and the complexity of the subject matter, this topic tends to be a "blindspot" and rarely included in children's educational materials. Instead, transportation and treatment companies direct their awareness-raising efforts towards older audiences on HCW issues (e.g., university students, the general public) or focus on other waste streams under their responsibility, such as household hazardous waste (batteries, electrical and electronic appliances, etc.). An exception is the landfill company, which operates its own information and study centre and has developed specific training programs on various waste streams, including treated iHCW.

3.5.3. Category "Society", Subcategory "Corruption" (Aggregated Weighted Score – 57 %)

Corruption, categorized under "Society" according to the S-LCA guidelines, refers to the misuse of entrusted power for personal gain. The indicator evaluates both the presence of preventive strategies within an organization and any indications of corrupt activities. Over the last decade, anti-corruption has emerged as a significant issue in Latvia, supported by a robust institutional framework spearheaded by the Corruption Prevention and Combating Bureau (KNAB). Despite these initiatives, Transparency International's Corruption Perceptions Index (CPI) rated Latvia at 59 points in 2024 – one point lower than its score in 2023 [27]. This outcome is below the EU average of 64 and underscores ongoing difficulties, as Latvia's score has fluctuated between 55 and 60 points over the past decade without showing consistent advancement. While a score lower than 50 signifies severe corruption risks, Latvia remains slightly above this benchmark yet still trails behind numerous EU counterparts. In the healthcare sector, significant challenges persist: 40 % of respondents in Latvia in 2024 associated hospitals with a high risk of corruption, compared to only 27 % across Europe [27]. Among the reasons for this, experts mention insufficient financial resources lacking in the health sector for an extended period of time, which encourages practices such as informal payments to medical personnel [28], [29]. Public procurement also

poses corruption risks, with major hospitals frequently awarding contracts to a select group of suppliers, raising concerns regarding transparency and possible conflicts of interest [29]. This issue is particularly significant in the context of iHCW management, where handling and treatment are costly and the values of contract are typically high. In an effort to address these risks, the National Health Service has implemented internal control system guidelines for outpatient providers, in accordance with KNAB's principles, although the rollout has been inconsistent [30]. Furthermore, some hospitals, recognizing that anti-corruption programs are important for building their reputation, have recently obtained certification under "ISO 37001:2025 – Anti-Bribery Management Systems" [30], including the Riga Maternity Hospital on 23 November 2023 and the Riga 1st Hospital on 6 June 2025.

Insights from our research reveal that hospitals, as government- or municipality-funded entities, typically excel and show clear formalized commitments to combating corruption, although practical implementation of these measures is often limited. Private companies involved in HCW transportation, treatment and landfilling exhibit more diverse outcomes: those connected with trade organizations (e.g., the Latvian Chamber of Commerce and Industry) demonstrate stronger commitments and collaborate with both internal and external oversight. Likewise, the RDF-based energy recovery company in Estonia – part of an international waste management group – also shows superior performance in this category. It is worth noting that Estonia received a CPI score of 76 points in 2024, making it the leader among the three Baltic countries [27].

3.5.4. Category "Local community", subcategory "Local employment" (aggregated weighted score – 58 %)

According to the standards of S-LCA and the guidelines set by UNEP/SETAC, local employment pertains to the jobs generated for individuals residing in the specific region where the product is manufactured, processed or distributed. This aims to ensure that the value chain of the product benefits the local community by offering stable, equitable and accessible job opportunities, thus capturing the social impacts on local economies and livelihoods while aiding in poverty alleviation, skill enhancement and sustainable development. When applying the researched methodology, the authors have defined local employment as persons originating from the same cultural region, namely the western, eastern, southern, northern regions and the capital – Kurzeme, Latgale, Zemgale, Vidzeme and Riga. None of the analysed supply chain actors (hospitals, transportation and treatment companies, landfills and energy recovery companies) have incorporated such requirements into their contractual frameworks, which we assume is likely representative of the majority of other, healthcare- and waste management- unrelated supply chain actors in the country, as well as in Estonia, where the RDF energy recovery company is located. The inclusion of this requirement in the context of Latvia and Estonia is somewhat problematic due to the small size and limited population of these countries, which also restricts the number of available employees.

The lowest score for this subcategory was observed among hospitals. Latvia is grappling with considerable challenges regarding the employment of healthcare personnel, especially in its rural regions. The healthcare system is facing a deficit of doctors and medical practitioners, including assistant physicians and nurses. In 2021, the number of physicians in Latvia was slightly below the EU average, standing at 3.4 per 1000 population, while the density of nurses was 4.2 per 1000 population, which is less than half of the EU average of 8.5 per 1000 population [32]. To tackle these challenges, the Government of Latvia has put into action several strategies, including the "Healthcare Workforce Development Strategy 2025–2029", which seeks to enhance working conditions, implement innovative approaches to medical education and cultivate new professions and roles aligned with labour market

demands [33]. Furthermore, the Ministry of Health has launched incentive programs designed to motivate medical professionals to practice in rural regions. These initiatives provide one-time bonuses equivalent to five months' salary, alongside additional payments for family members and, in certain cases, municipal housing assistance [34]. Nonetheless, these measures have drawn fewer medical practitioners than expected. The employment landscape for healthcare personnel in Latvia is further complicated by an aging workforce. As of 2023, more than 8000 medical professionals were between the ages of 60 and 64, whereas the number of younger professionals under 29 was just below 7000 [35]. This demographic disparity raises alarms about the viability of the healthcare workforce in the future. The persistent shortage of medical staff in Latvia is closely tied to uncompetitive salaries, which are among the lowest in the EU. In Latvia, healthcare salaries are typically lower than the national average. The Latvian Health and Social Care Workers' Trade Union has advocated for a 13.5 % salary increase for 2026 to tackle the ensuing staffing crisis [36]. Nevertheless, the government has yet to enforce any substantial wage increases, resulting in high turnover rates as professionals pursue better-paying jobs in the private sector or overseas. Numerous young healthcare workers, after obtaining a state-subsidized or fee-based medical degree, also leave the country in pursuit of higher salaries, further intensifying workforce shortages [37]. This predicament particularly impacts rural regions and contributes to a lack of qualified medical personnel. To alleviate this issue, regional hospitals often depend on physicians from larger cities, primarily Riga, who dedicate a few days each week to working in regional healthcare facilities.

4. CONCLUSION

The significance of S-LCA in supply chains is increasingly emphasized through companies' participation in sustainability rankings and the adoption of corporate sustainability standards. While S-LCA remains in the developmental stage from a methodological perspective, various guideline frameworks – such as the CSRD reporting framework, UNEP/SETAC's S-LCA Guidelines also integrated in ISO 14075:2024, and the environmental LCA principles defined in ISO 14044 – are effectively adapted to assess social factors.

The results of the S-LCA conducted for the iHCW supply chain have identified key social hotspots that should be addressed when planning the transition of iHCW to circular economy principles. However, certain limitations in the interpretation of these results must also be considered. Firstly, the interview-based S-LCA of the iHCW supply chain is "company-specific" and should be analysed within the context of the entire supply chain rather than through a comparative assessment. If one of the supply chain actors (a company) is replaced with another that has different social and environmental practices, the S-LCA results will inevitably change. Secondly, the S-LCA results within iHCW generation, treatment and end-of-life stages demonstrate performance which is above average (60 % and above). The social responsibility of the hospitals in the field of HCW management is not the highest priority for hospitals. The level of inclusion of social responsibility principles depends on the hospital's class (university, regional): larger hospitals have more top-level management personnel and diverse management mechanisms in place (incl. social and environmental standards, public information campaigns, etc.). While waste management companies dealing with iHCW are socially responsible (mainly due to national requirements set to take part in tendering procedures), the dialogue with the community and awareness raising specifically on iHCW topics needs to be improved.

The social hotspots within the iHCW management supply chain, where the lowest performance is indicated, are linked with poverty alleviation actions and corruption, awareness and educational activities for children, as well as a focus on local employment. This connection is largely influenced by the fact that these issues are not actively discussed

across the entire country in various sectors. Therefore, similar performance in these subcategories is also anticipated in other fields unrelated to iHCW.

Further research on the S-LCA of iHCW would be valuable, particularly in more circular supply chains where HCW is treated effectively and utilized as a valuable resource in product manufacturing. In-depth studies and the development of linkages could promote greater societal acceptance of using iHCW in new waste recovered products, facilitating its application more broadly.

ACKNOWLEDGEMENTS

This research is funded by the Latvian Council of Science, project "Public health and environmental pollution prevention through circular economy approaches in health care waste management (Panacea)", project No. lzp-2020/1-0299.

ANNEX

Zenodo link: https://zenodo.org/records/17140162

REFERENCES

[1] Reibling N., Ariaans M., Wendt C. Worlds of Healthcare: A Healthcare System Typology of OECD Countries. *Health Policy (New York)* 2019:123(7):611–620. https://doi.org/10.1016/j.healthpol.2019.05.001

[2] Dri M., Canfora P., Antonopoulos I., Gaudillat P. Best Environmental Management Practice for the Waste Management Sector, *Publications Office of the European Union*, 2018. https://doi.org/10.2760/50247

[3] Ministry of Environmental Protection and Regional Development, "Healthcare waste". [Online]. [Accessed 11.12.2023]. Available: https://www.varam.gov.lv/lv/veselibas-aprupes-atkritumi

[4] World Health Organization. Overview of technologies for the treatment of infectious and sharp waste from health care facilities. 2019. [Online]. [Accessed 11.12.2023]. Available: https://www.who.int/publications/i/item/9789241516228

[5] United Nations Environment Programme. Compendium of Technologies for the Treatment/Destruction of Healthcare Waste, 2012. [Online]. [Accessed 11.12.2023]. Available: https://wedocs.unep.org/20.500.11822/8628

[6] Li C. *et al.* Bridging the Energy Benefit and POPs Emission Risk from Waste Incineration. *The Innovation* 2021:2(1):100075. https://doi.org/10.1016/j.xinn.2020.100075

[7] Zlaugotne B., Pubule J., Gusca J., Kalnins S. N. Quantitative and Qualitative Assessment of Healthcare Waste and Resource Potential Assessment. *Environmental and Climate Technologies* 2022:26(1):64–74. https://doi.org/10.2478/rtuect-2022-0006

[8] Korhonen J., Honkasalo A., Seppälä J. Circular Economy: The Concept and its Limitations. *Ecological Economics* 2018:143:37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

[9] Luthin A., Traverso M., Crawford R. H. Assessing the social life cycle impacts of circular economy. *Journal of Clean Production* 2023:386:135725. https://doi.org/10.1016/j.jclepro.2022.135725

[10] European Parliament. Directive (EU) 2022/2464 as regards corporate sustainability reporting, amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. *Official Journal of the European Union* 2022: L 322/15

[11] Bouillass G., Blanc I., Perez-Lopez P. Step-by-step social life cycle assessment framework: a participatory approach for the identification and prioritization of impact subcategories applied to mobility scenarios. *The International Journal of Life Cycle Assessment* 2021:26:2408–2435. https://doi.org/10.1007/s11367-021-01988-w

[12] Arcese G., Lucchetti M. C., Merli R. Social life cycle assessment as a management tool: Methodology for application in tourism. *Sustainability (Switzerland)* 2013:5(8):3275–3287. https://doi.org/10.3390/su5083275

[13] United Nations Environment Programme. Guidelines for Social Life Cycle Assessment of Products and Organisations. [Online]. [Accessed 20.06.2023]. Available: https://www.lifecycleinitiative.org/library/guidelines-for-social-life-cycle-assessment-of-products-and-organisations-2020/

[14] United Nations Environment Programme. Guidelines for Social Life Cycle Assessment of Products. United Nations Environment Programme, 2009. [Online]. [Accessed 20.06.2023]. https://www.unep.org/resources/report/guidelines-social-life-cycle-assessment-products

[15] International Organization for Standardization, ISO 14075:2024 Environmental management – Principles and framework for social life cycle assessment. 2024. [Online]. [Accessed 20.06.2023]. https://www.iso.org/standard/61118.html
[16] Paoli R., Pechsiri J. S., Souza A., Romagnoli F. Social Life Cycle Assessment for Wild Harvesting and Cultivation of *F. Lumbricalis* Red Macroalgae. *CONECT International Scientific Conference of Environmental and Climate Technologies*. Riga, May 14–16, 2025. https://doi.org/10.7250/CONECT.2025.076
[17] Messmann L., Köhler S., Antimisaris K., Fieber R., Thorenz A., Tuma A. Indicator-based environmental and social sustainability assessment of hospitals: A literature review. *Journal of Cleaner Production* 2024:466:142721. https://doi.org/10.1016/j.jclepro.2024.142721
[18] Jones A. *et al.* Investigating the Spatial Relationship between Social Vulnerability and Healthcare Facility Distribution in Nassau County, New York. *International Journal of Environmental Research and Public Health* 2023:20(5):4353. https://doi.org/10.3390/ijerph20054353
[19] Chang D.-S., Wang W.-S., Wang R. Identifying Critical Factors of Sustainable Healthcare Institutions' Indicators Under Taiwan's National Health Insurance System. *Social Indicators Research* 2018:140(1):287–307. https://doi.org/10.1007/s11205-017-1761-7
[20] Tuan N. Q. *et al.* Prevalence and Factors Associated with Psychological Problems of Healthcare Workforce in Vietnam: Findings from COVID-19 Hotspots in the National Second Wave. *Healthcare* 2021:9(6). https://doi.org/10.3390/healthcare9060718
[21] Zhao X., Klemeš J. J., Saxon M., You F. How sustainable are the biodegradable medical gowns via environmental and social life cycle assessment? *Journal of Cleaner Production* 2022:380:135153. https://doi.org/10.1016/j.jclepro.2022.135153
[22] Shaikh S., Thomas K., Zuhair S., Magalini F. A cost-benefit analysis of the downstream impacts of e-waste recycling in Pakistan. *Waste Management* 2020:118:302–312. https://doi.org/10.1016/j.wasman.2020.08.039
[23] Turcott Cervantes D. E., López Martínez A., Cuartas Hernández M., Lobo García de Cortázar A. Using indicators as a tool to evaluate municipal solid waste management: A critical review. *Waste Management* 2018:80:51–63. https://doi.org/10.1016/j.wasman.2018.08.046
[24] Rametsteiner E., Pülzl H., Alkan-Olsson J., Frederiksen P. Sustainability indicator development-science or political negotiation? *Ecological Indicators* 2011:11(1):61–70. https://doi.org/10.1016/j.ecolind.2009.06.009
[25] Bulgarian National Audit Office, State Audit Office of the Republic of Croatia, State Audit Office of Hungary, State Audit Office of the Republic of Latvia, and Supreme Audit Office of the Slovak Republic, Joint report on measures taken in poverty alleviation, 2021.
[26] European Anti Poverty Network Latvia, Poverty Watch Report, 2022.
[27] Transparency International, Corruption Perceptions Index. [Online]. [Accessed 06.05.2025]. Available: https://www.transparency.org/en/cpi/2024
[28] Providus. Corruption in the health sector: challenges and examples of good practice in Latvia. 2015.
[29] Organisation for Economic Co-operation and Development, "Anti-Corruption Trends in Eastern Europe and Central Asia", 2025. [Online]. [Accessed 09.05.2025]. Available: https://www.oecd.org/en/publications/anti-corruption-trends-in-eastern-europe-and-central-asia_69c92037-en/full-report/component-3.html?utm_source=chatgpt.com
[30] ZiemelisE., Zvaigzne A., Silina L. Effectiveness assessment of the internal control system at national institutions in the area of conflict of interest and corruption in Latvia. *Journal of Regional Economic and Social Development* 2024:16:172–187. https://doi.org/10.17770/jresd2024vol16.8276
[31] International Organization for Standardization, ISO 37001:2025 Anti-bribery management systems – Requirements with guidance for use. 2025.
[32] Behmane D. A new initiative (2024–2029) aims to attract health professionals to work in the public sector. *Policy Analysis* 2023.
[33] Cabinet of Ministers of Latvia, Cabinet Order No. 1194 About the plan Health Workforce Development Strategy 2025-2029, 2024.
[34] European Labour Authority and S. A. and I. Directorate-General for Employment, Three ways EU health and social organisations attract and retain staff, 2024.
[35] Lukjanska S. Fears of future skills and labour shortages in Latvian healthcare sector. [Online]. [Accessed 20.08.2025]. Available: https://eng.lsm.lv/article/society/health/11.04.2025-fears-of-future-skills-and-labour-shortages-in-latvian-healthcare-sector.a595148/?utm_source=chatgpt.com
[36] Zirnite A. Health and Social Care Employees' Union expects Health Ministry to raise medical staff's salaries by at least 13.5%, LETA. [Online]. [Accessed 26.08.2025]. Available: https://leta.lv/eng/home/important/7EE770F1-3733-4BD1-B624-F52E12110009/
[37] Jirgensons G. EU Health Policy and the Healthcare Labour Market in Latvia: The Out-Migration of Healthcare Practitioners. *Studia Europejskie – Studies in European Affairs* 2024:149–163. https://doi.org/10.33067/SE.1.2024.8