TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

EVALUATION OF APPLICATION OF BLOCKCHAIN TECHNOLOGY IN MSW MANAGEMENT PRACTICES AND ITS POSSIBLE IMPLEMENTATION IN UNIVERSITY CURRICULA

PLOKIAHELA KASUTAMISE HINDAMINE OLMEJÄÄTMETE KÄITLEMISSÜSTEEMIS NING SELLE VÕIMALIK RAKENDAMINE ÜLIKOOLI ÕPPEKAVADES

MASTER THESIS

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DEPARTMENT OF CIVIL ENGINEERING AND ARCHITECTURE

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ABBREVIATIONS

AI	adaptive Intelligence
AREP	Amenagement, Recherche, Pole d'Echanges
BlockNet	Blockchain Network Online Education
BMW	biodegradable municipal waste
DAO	Decentralized Autonomous Organization
DLT	Distributed Ledger Technology
EMU	Estonia University of Life Sciences
EPR	Extended Producer Responsibility
ETH	Ethereum
EU	European Union
FL	Florida
GPS	Global Positioning System
ICT	Information and communications technology
IoT	The Internet of Things
IT	Information Technology
MoE	The Ministry of Environment of Estonia
MSW	Municipal Solid Wastes
NoSQL	Non-SQL
NWMP	National Waste management plan
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
p2p	Peer to Peer
QR	Quick Response
R&D	Research and Development
RCR	Recereum tokens
RFID	Remote readable radio identifiers tags
RIA	Estonian Information Systems Authority
SATA	Serial ATA
SNCF	Stations and Connections division
STDEV	Standard deviation
SwATEL	Swachh Adaptive Intelligence
SwBIN	Swachh Bins
SwIOT	Swachh Internet of Things
TalTech	Tallinn University of Technology
TLU	Tallinn University
TU	Tartu university
UID	Unique Identifier
WEEE	Waste from Electrical and Electronic Equipment
WFD	Waste Framework Directive
WiFi	Wireless Fidelity

1. INTRODUCTION

There are concurrent worldwide waste and resource problems that need more sustainable waste management strategies, such as redirecting waste streams that would otherwise be dumped or incinerated to be reused, recycled, or reclaimed (Velenturf and Purnell, 2017). Principles and goals such as "zero waste," "circular economy" (in which wastes and resources are prevented, reused, recycled, or recovered), and "resource efficiency" have been established to support such activities (*Taylor et al.,* 2020). The drive for reforms in waste governance to embrace some of these concepts and goals has led to the adoption of several laws and policies, including the European Commission's (2020) Circular Economy Action Plan, France's Anti-Waste and Circular Economy Law (2020), and the People's Republic of China's (2008) Circular Economy Promotion Law. The tracking and monitoring of waste is key to several of these. Tracking data is critical for adhering to current laws and policies. It also has the potential to inform regulations and policies that may prevent the garbage from being "wasted" through landfilling or incineration. However, tracking waste and monitoring their owners to collect this data is a difficult task. Complications may develop due to items breaking down into smaller components; existing rules, such as extended producer responsibility (which forces manufacturers to be accountable for subsequent wastes from their goods); and property abandonment via littering or fly-tipping. Hence, tracking garbage and monitoring its owners need more practical methods that are now routinely used (*Taylor et al.,* 2020).

Blockchain has enormous potential for promoting sustainable development and will fundamentally alter the present management paradigm (WEF, 2019). Many studies are being conducted to investigate the use of blockchains in environmental protection, such as enhancing solid waste management, rubbish categorization, and climate change mitigation (Howson, 2019; Bierbaum *et al.,* 2020). The use of blockchain in the waste management sector is one specific example of supply chain management, gaining popularity (Kouhizadeh and Sarkis, 2018; Saberi *et al.,* 2019). Current blockchain applications in waste management usually focus on payment or incentive facilitation, waste monitoring, and waste tracking (Taylor *et al.,* 2020). In the first example, a trash depositor is rewarded or compensated with a blockchain-secured digital token that can be redeemed for products or swapped for other currencies. The Plastic Bank uses blockchain rewards to encourage people to become plastic garbage collectors, particularly in underdeveloped nations, to reduce the quantity of plastic in the seas.

The accumulated waste is transported to collection sites, where it is weighed before payment is issued to the collector via a blockchain-based banking program. Blockchain's immutability and transparency deter fraudulent and corrupt behaviours. The inspection of garbage is usually done by hand. However, it might be automated in rare circumstances (Tomari *et al.,* 2017). There are more instances of blockchain payment or reward facilitation with and without social goals.

Problem statement

The worldwide resource and waste dilemmas demand and provide significant impetus for improved and more sustainable waste management. Resources and waste streams traditionally disposed of in landfills or incinerators are increasingly being reused, recycled, or reclaimed. Nonetheless, although various laws and regulations have been enacted for this goal, several recurring obstacles continue throughout initiatives to facilitate the necessary, widespread transitions to sustainable waste management. This study evaluates the application of Blockchain technology in MSW management practices and its possible implementation in university curricula "in Estonia.

Aim and Objective

The overall objective of this research is to evaluate the application of Blockchain technology in MSW management practices and its possible implementation in university curricula "

The research includes specific objectives:

- To investigate the university with the highest number of research and curricula related to Blockchain technology.
- To find out the SWM courses where blockchain technology can be integrated.
- To investigate the relevance of blockchain technology to MSW management.

Research questions

The following research questions were used to achieve the specific objectives.

RQ1. Which among the four universities have the highest research and curricula related to Blockchain technology?

RQ2. In which of the courses can blockchain technology be integrated into MSW management?

RQ3. How relevant is blockchain technology to MSW management?

Keywords: Municipal Solid Wastes, Blockchain technology, University curriculum, National Waste management plan, Master's thesis

2. LITERATURE REVIEW

2.1. Municipal solid waste management

According to the Estonian Waste Act (Waste Act, §2, 7), waste is defined as "any movable property or registered ship that the holder discards, intends to discard, or is required to discard". The modern concept of solid waste management emerged firstly in the United States in the 1890s. Around the end of the 20th century, an increasing number of American cities provided at least a basic level of waste collection and disposal service. By the 1930s, virtually all towns offered garbage collection services. The waste was disposed of in various ways, namely, landfills, incineration, and uncontrolled littering to the environment, including the ocean. The Post World War II period gave birth to a substantial escalation of the Waste management problems for two reasons: consumerism (overconsumption) and the rise of the chemical age, which, together, resulted in dramatic changes in waste volumes, composition, and toxicity (Karu et *al*., 2013).

Municipal solid waste (MSW) refers to waste generated in households and waste generated in trade, service provision, or elsewhere that is like waste generated in families due to its composition or properties (Waste Act, §2,7). In the EU's Landfill Directive, MSW is defined as household waste as well as other waste that is like household waste due to its nature or composition.

Today, worldwide urbanization is thought of as an unstoppable characteristic of global societal change. The amount of solid waste generated in the world is steadily increasing. Every government in the world is currently focusing on methods to approach the challenges posed by municipal solid waste management. The increase in population due to the industrial revolution in most cities of the world led to rapid growth or a high rate of urbanization, which led to an increase in the amount of waste produced or generated in those cities. World cities generate about 11.3 billion tons of waste per year (Tisserant *et al.,* 2017). The volume of municipal solid waste generated is expected to increase to 2.2 billion tons by 2025, increasing the per capita waste generation rate from 1.2 to 1.42kg per day in the next fifteen years (Tisserant *et al.,* 2017). Globally, wealthy regions generate large quantities of solid waste than less wealthy ones. However, some developing countries are among the top ten municipal reliable waste-producing countries, including Brazil, China, India, and Mexico. For instance, members of the Organization for Economic Co-operation and Development (OECD), a group of 34 industrialized nations, lead the world in municipal solid waste generation at nearly 1.6 million tonnes daily. Simultaneously, sub- Saharan Africa produces less than one-eighth

(1/8) as much 200,000tons daily (Tisserant *et al.,* 2017). In Africa, waste management problems are, however, not only brought about by the amount of waste accumulated in the cities but also the incapability of the governments and waste management authorities to keep up with the scope of the problem itself. Tanzania, for example, is faced with significant issues of solid waste management, with an estimation of 30-50% of waste being left uncollected. In Dar-es-salaam's capital city, estimates show that out of 3976 tons of solid waste generated each day, only 1440 tons are collected and sent to landfill for disposal. More so, approximately more than 70% of the daily waste generated is left near the houses, streets, markets, or drainage channels (Tisserant *et al.,* 2017).

Over the last decade, Estonia has successfully transformed its municipal waste management practices from landfilling to a high level of waste incineration. It has made progress in recycling, particularly in Tallinn, but is unlikely to reach European recycling targets (OECD, 2017). Gopalakrishnan & Radhakrishnan (2019), write up opine because of the frightening threat, that environment is the most sought-after issue for debate in worldwide forums. After global warming, which impacts the environment and serenity in Estonia, waste management is a critical problem. Governments and NGOs in Estonia have worked towards improved waste management solutions. Although technology nowadays forms part of solid waste management, technology in many countries is not a fundamental aspect of waste management. These authors have also shown that existing technology contributes only to manual intervention reduction by automating garbage collection and transfer. It also contributes to the disposal of useless garbage, recycles, and re-uses valuable waste by transforming it into raw resources. People are an essential element of the waste management cycle, and it is exceedingly impossible to achieve any technology-based solution without their cooperation. Today, the supportive technology in Estonia automatically monitors waste management cycles, records necessary actions, and react accordingly.

When Estonia transitioned to a market-based economy in the 1990s, a somewhat drastic turn toward privatization significantly impacted essential efforts to enhance urban solid waste management. The old municipal waste collection sector was almost fully privatized. Municipalities oversaw arranging MSW disposal and determining how the waste could be stored, but the collection was handled by private contractors hired through a competitive bidding process.

This strategy has the advantage of allowing for more rapid investment in collecting equipment and management. The disadvantage was that it was impossible to direct waste disposal toward recovery or know if residences were connected to a collection network. Municipalities have had fewer incentives to cooperate in trash disposal. Since

2000, there has been a persistent need to return cities to waste management to achieve better results (Fischer, 2013).

Estonia adopted a landfill charge for urban waste disposal in 1990. The tax was initially modest compared to other European landfill tax rates, but it steadily increased over time, eventually reaching EUR 30 per tonne by 2015 (ETC/SCP, 2012). The fee established incentives for waste diversion by prohibiting the landfilling of untreated waste. The first NWMP, which operated from 2002 to 2007, was primarily concerned with integrating national waste management with EU laws and transposing and implementing EU waste handling regulations (ETC/SCP, 2009). In addition, there was a significant emphasis on eliminating old landfills and building new ones. It also included plans for national waste networks and urban coordination systems. Although with financial assistance from the EU, incineration was deemed too costly (Fischer, 2013). The emphasis on eliminating old landfills and building new ones has been sufficient. Estonia had 221 landfills towards the end of the 1990s. It currently has five for non-hazardous waste (Castell-Rüdenhausen & Merta, 2016), and the new landfill size is enough.

Some progress has been achieved in establishing collaboration between the public and private sectors in MSW administration. Compared to the rest of the EU, city administrations in Estonia have far less control over the execution of waste management plans. A door-to-door waste collection service serves around 95% of the inhabitants, and 96% of communities have implemented a waste collection program that includes disposal stations or civic amenity sites. The waste management business is dominated mainly by the private sector (Castell-Rüdenhausen & Merta, 2016). There are additional concerns with waste ownership and severe commercial competition among private waste management providers (Moora, 2012). The last two NWMPs focused on increasing local government participation in waste management, but this cooperation remains inadequate and has not developed as projected. Several nations have no partnering arrangements at all.

Although other nations have built comparable systems, their overall involvement is small (Castell-Rüdenhausen & Merta, 2016). The third Estonian NWMP focuses on waste control, recycling, and recovery. The aim is to maximize biodegradable waste recycling and expand the network of recyclable collection points (BiPRO, 2014).

EPR is an environmental management technique in which a producer's obligation for a product is extended through the product's post-consumer life cycle. Farmers participate in EPR by collecting or returning discarded items for sorting and treatment. In Estonia, EPR initiatives for batteries, WEEE, packaging, end-of-life equipment, waste tires, and toxic waste plastic are in place. For the collecting of batteries, there are two producer responsibility groups (BiPRO, 2014). Producer responsibility organizations for WEEE collection include MTÜ EES-Ringlus (117 collection points), MTÜ Eesti Elektroonikaromu (90 collection locations), and Ekogaisma Eesti OÜ (collection of light bulbs at 131 collection locations) (BiPRO, 2014). There is no distinction made between industrial, consumer, and home packaging trash. A deposit corporation oversees the deposit refund mechanism for soda cans. Three producer responsibility groups organize the mechanism for other packaging waste. The home container collection network is undeveloped, with an insufficient number of collection stations. It is hard to gather all forms of packaging debris at each recycling location (BiPRO, 2014).

The Ministry of Environment of Estonia (MoE) oversees waste management policy and the translation of EU laws into national law and actual enforcement in Estonia. However, under the Waste Act, local governments are responsible for managing the collection, transportation, recovery, and disposal of municipal waste for their respective administrative region. According to the Waste Act, Estonia switched from a three-tiered (National, County, and Municipal) waste management structure to a two-tiered (National and Local) system in 2007 to give municipalities greater responsibilities and encourage municipalities to pool their resources to increase their financial and human capacity for effective solid waste management processes (MoE, 2007).

2.1.1. Organisation of Municipal Waste Collection in Estonia

Municipalities are responsible for waste management in Estonia., They organize the waste collection and separation. State municipalities have separate waste management plans that are district-specific and consider population growth and local capacity. Local waste management strategies are developed for specific time frames and consistent with the National Waste Management Strategy (2014-2020). (EC, 2014). According to the Waste Act, one of the most significant duties of local governments in terms of waste disposal is to coordinate urban waste disposal in their jurisdiction. A waste management company selected by the city by public procurement collects and transports urban household waste. A five-year deal is signed, and the organization has a monopoly to collect waste in a specific sector (waste collection areas are defined in the Waste Act). Typically, the company with the lowest waste disposal service fee wins the tender. Since the organized waste collection is required to cover (mixed) municipal waste produced in the city, the local authority can also expand the organized waste collection to other waste categories (Tallinn Environmental Agency, 2014).

In addition to the Waste Act, the Packaging Act governs waste management obligations, stating that municipal governments are responsible for organizing the disposal of packaging waste in their jurisdiction. The primary goal is for municipal governments to manage the implementation of a collection scheme (contracts with recovery organizations, presentation of standards for the packaging waste collection system, awareness-raising, and supervision) (Tallinn Environmental Agency, 2014).

In Estonia, the most popular method of collecting various forms of waste is by bringing points near residential areas. In addition, there is an expanded producer responsibility (EPR) deposit refund scheme, with return points mainly near/in nearby grocery stores. Door-to-door recycling and co-mingled collection schemes are becoming more widespread, but their use varies based on the local government's waste management plan; they are the chosen waste collection method for private housing estates/neighbourhoods. There is an increasing number of public amenity places for various forms of waste disposal (electronic waste, garden/green waste, building waste, and others). The collection schemes differ based on the demographic and population density in various geographical areas (EEWMP 2014, Annex 4, pp. 7-22).

Door-to-door recycling gathers residual waste from all houses, paper from 75% of homes, and bio-waste from 40% of homes. Only packaging waste (paper and cardboard, glass, and mixed packaging) is accepted at 95 percent of recyclable material collection stations. In comparison, the remaining 5 percent take all recyclable materials (including textiles and non-packaging paper). At civic amenities, bulky garbage, tires, garden trash, paper, metal scrap, waste electrical and mechanical equipment (WEEE), radioactive waste, bottles, and packaging debris are all allowed (Castell-Rüdenhausen & Merta, 2016). Others accept mixed waste but dumping it is too expensive. Civic amenity facilities are essential for the disposal of WEEE and hazardous garbage. The collection of packaging waste is organized by three producer responsibility organizations (not covered by the deposit-refund system). Most of the packaging trash is collected directly from enterprises and retail establishments. The collection station system is mostly utilized for storing domestic packaging garbage. In addition, a deposit-refund mechanism for beverage containers made of glass, plastic, or aluminium is in existence (BiPRO, 2014).

Monitoring compliance with the Waste Act's standards may be overseen by the Environmental Inspectorate and state councils or local government authorities. The highest penalty payment for non-compliance with a precept under the Substitutive Enforcement and Penalty Payment Act is 32,000 euros. The contract between the municipality and the supplier specifies the service payments. They are distinguished in distinct service packages, with the minimal package being required for the stated kind of construction, i.e., each waste holder must choose a package. Municipally combined collections aim to incorporate as many waste generators as feasible in the collection process. As a result, the cost of running fees has been greatly decreased. Households in certain areas spend approximately 1 € a month, whereas the national average is 4-6

€. These payments are made directly to the private service provider [EE MoE 2012]. The utility cost for apartment complexes is set at a specific rate.

2.1.2. Municipal solid waste regulations in Estonia

Estonia joined the European Union in 2004. As part of the country's aspirations for EU membership, the first nationwide waste management plan for 2003–2007 was focused on transposing EU waste laws (EEA, 2009). The Ministry of Environment created and implemented the NWMP, as well as all other waste management programs. Under the Ministry, permits are granted by an Environmental Board with six regional offices. Municipalities oversee garbage collection, transportation, and disposal (EEA, 2009; ETC/SCP, 2009). Estonia had a three-tiered waste management program until 2007. (national, state, and municipal). The EU Landfill Directive 99/31/EC, which was transposed into the Estonian legislation through the Waste Act (2004) and the Regulation of the Minister of Environment No. 38, sets out provisions covering the location of landfills and establishes more stringent technical and engineering requirements for aspects such as water control and leachate management, protection of soil and water and landfill gas (LFG) emissions control (Voronova *et al.,* 2011). The landfill directive also defines progressive targets for diversifying the biodegradable fraction of MSW away from landfills. In Estonia, all old landfills for depositing MSW were closed by 16 July 2009. After that date, only five new landfills that comply with the technical requirements of the EU landfill directive remained operational (Voronova *et al.,* 2011: Castell-Rüdenhausen & Merta, 2016)

The Estonian Waste Act, enacted in 2004, explicitly transposed the majority of the Waste Framework Directive (WFD). The Estonian Waste Act goes beyond the provisions of WFD Article 10 (2) by including supplementary specifications for "waste collection" in §14 (1). Referring to Article 11 (1) WFD, the requirements were not directly transposed into national law (Malinauskaite *et al.,* 2017). § 15 (7) states that "method for waste recovery could include one or more recovery operations," and recycling is among the waste recovery activities "through which waste materials are repurposed into commodities, materials, or substances, whether for the original or other purposes." Separate recycling responsibilities are directly tied to trash recovery (Malinauskaite et al., 2017). According to Article 11 (1) of the WFD, "by 2015, separate collection shall be developed for at least the following: paper, metal, plastic, and glass." However, § 31(3) requiring the organization of separate collection only entered into force on 01.01.2015. As a result, the goal of establishing at least separate collections for paper, metal, plastic, and glass by 2015 has not been completely realized. Article 22 of the

WFD is transposed with provisions in the bio-waste compost processing law, but it is discovered to deviate from the WFD criteria (Castell-Rüdenhausen & Merta, 2016: Malinauskaite *et al.,* 2017).

Furthermore, the Chancellor of Justice ensures the local and city regulation of general operation are in accordance with the constitution and laws of the Republic of Estonia (EE WMP, 2014). Local waste management policies shall have the following provisions (ETC/SCP, 2009):

- Waste transport development organized by a municipal authority within its administrative territory.
- Separate waste collection and storage and related deadlines for categories of waste are being established.
- Waste management financing.

In 2008, the second Estonian NWMP, covering the years 2008–2013, was approved. In terms of biodegradable urban waste (BMW), the second NWMP advocated separating biowaste from mixed MSW and separate garden waste collection in cities and, more significant, home composting in rural regions. It set targets for minimizing the quantity of biodegradable urban garbage dumped in landfills. In 2014, the third Estonian NWMP, covering the years 2014–2020, was authorized. The strategy's strategic goals are centred on the waste hierarchy, emphasizing waste reduction and trash diversion or recovery. The most significant issue discovered is boosting biodegradable waste recycling through more outstanding treatment capabilities and establishing a nationwide biodegradable waste storage and treatment network. Another focus is on the web of recyclables collection points, which must be reinforced and expanded (BiPRO, 2014).

Estonia now has two independent databases on urban waste. The Statistics Department of the Estonian Environmental Agency and the Ministry of Environment are now debating adjustments to the monthly submission of MSW data to Eurostat (EE WMP, 2014). A change in Estonian waste statistical data may need revising graphs and analysis.

Estonia established a landfill levy in the first half of 1990. The tax is imposed on all waste. However, the amount varies depending on the composition of the waste (ETC/SCP, 2012). Furthermore, the Environmental Charges Act establishes increased rates for environmental charges in certain circumstances. If a particular amount of waste is disposed of at a landfill, the costs climb. If the criteria are satisfied, each tonne of waste that exceeds the cap will be charged a premium ranging from five to 500 times the standard rate, depending on the kind (hazardousness) of the waste. The process dates to 1989 in the Soviet Union, when illegal (unlicensed) dumping was common, and the greater cost was a punishment rather than a charge. This period is responsible for all parts of present laws. Increased fees must also be levied when waste is disposed of in landfills that do not comply with the Landfill Directive's criteria (European

Commission, 2014). MSW landfill taxes rose from EUR 0.10–0.20 per tonne in 1996 to EUR 7.8 per tonne in 2006, EUR 10 in 2009, and EUR 12 in 2010, before rising by 20% per year to EUR 30 per tonne by 2015 (ETC/SCP, 2012). The tax is coupled with a prohibition on dumping untreated waste in landfills (EEA, 2009).

2.2. Blockchain technology fundamentals

Blockchain's inception is built on the blockchain, which serves as the shared ledger for bitcoin. Consider blockchain to be an operating system, like Microsoft Windows or macOS, with bitcoin being one of many applications that can be run on it (Ravindhar, 2020). Blockchain allows for the recording of bitcoin transactions in a shared ledger. Still, this shared ledger can record any transaction and track the progress of any asset, quantifiable, intangible, or digital. For example, blockchain enables securities to be settled in minutes instead of days. It may also be used to assist businesses in managing the movement of products and associated payments or allowing producers to exchange production logs with equipment manufacturers (OEMs) and regulators to prevent product recalls.

Blockchain technology, also known as distributed ledgers, is the fundamental technology that records the same information at multiple nodes and only adds information when the nodes reach consensus. New transactions may be inserted, but primary data cannot be deleted, allowing all nodes to trace the past. This removes reliance on a central player and the possibility of coercion or device collapse because all nodes have access to all knowledge (Ølnes, Ubacht, & Janssen, 2017). Beyond cryptocurrencies like bitcoin, blockchain technologies may have the potential to fundamentally change society, and we might witness right now the dawn of cryptographically secured trust-free transactions economy (Beck *et al.,* 2016). Another fundamental concept widely used in the blockchain is a Smart Property. This is mostly used to manage the ownership of a property or asset through smart contracts on the blockchain. The property may be distinct, such as a vehicle, home, or mobile, or non-physical, such as stock in a business. It should be noted that Bitcoin is not a currency in the traditional sense; rather, Bitcoin is more about regulating the ownership of assets. A blockchain dramatically lowers transaction costs by extensively reducing the need for intermediaries. This alters the forces involved in market transactions and reduces the middleman role in the business (Torres de Oliveira, 2017).

This future disruptiveness has also been dubbed by venture capitalist Marc Andreessen as the most critical discovery since the Internet's inception (Crosby *et al.,* 2015). Blockchain is a mathematically guaranteed cybersecurity technology that allows for the swift and reversible detection of changes in digital data and intelligent devices.

Blockchain technology allows for the rapid and error-free discovery of any modifications made to digital records, no matter how minor or who made them. While blockchain has recently become a hot subject, Estonia began researching the concept in 2008 – long before the Bitcoin white paper that coined the word "blockchain" was released. This technology was known as "hash-linked time-stamping" in Estonia at the time. Since 2012, Estonia has been using blockchain to encrypt national records, e-services, and smart devices in both the public and private sectors.

Estonia is a country with an extensive E-Government Development Index. According to the 2016 United Nations global E-Government Index, it is ranked 13th globally (Beck *et al.,* 2016). Estonia is also one of the most innovative countries globally, ranked 24th out of 128 countries surveyed in the 2017 Global Innovation Index report (United Nations, 2018). Since 2014, the topic of Blockchain innovation has gained significant popularity among private and public institutions in Estonia. The government of Estonia has announced several prototypes and concepts involving Blockchain technology. The name blockchain comes from the way transaction data is stored in blocks that are joined together to form a chain. The blockchain grows as the number of transactions increases. Within a separate network ruled by laws settled upon by network members, blocks document and validate the period and sequence of transactions, which are then logged into the blockchain (Ravindhar, 2020). Table 2.1 below shows some of the critical applications of blockchain technology in public administration in different countries.

Table 2. 1 Examples of the use of blockchain technology (Smerkis, 2019)

AREA OF APPLICATION	COUNTRY	DESCRIPTION
Taxes, land and documents	**USA, Georgia**	Some states' tax departments started work in collaboration with the BitPay company whose objectives are to collect taxes, driver's licenses, car numbers, and other documents in Bitcoin and Bitcoin Cash cryptocurrencies. The National Public Registry Agency has added blockchain options that allow you to find and receive information about real estate, cooperate with Bitfury, a leading manufacturer of mining equipment, purchase and sell land ownership rights and notarial certification of documents.
Digital currency platform **Peer-peer lending platforms**	**Estonia**	Crypterium is one of the blockchain company for digital currency exchange. CoinLoan is a blockchain company that is a p2p money lending platform AdHive is a blockchain company for advertising

Advertising companies		
Elections and voting	**USA, Denmark**	Voting in the blockchain was used during the municipal elections in West Virginia by the Danish Liberal Alliance party.
Business and finance	**Argentina, Russia, Malaysia**	The delivery of cargo from Argentina to Malaysia by HSBC and the Dutch ING Bank exemplifies how blockchain can be used in the banking sector. Banks used the R3 Corda platform to grant a letter of credit, avoiding the paperwork. Alfa-Bank and S7 made a similar agreement. The Ripple company, which is well-known in the blockchain industry, allows its customers to send money through its network. Inside the consortium, M.Video, AlfaBank, and Sberbank Factoring launched a blockchain-based factoring network based on Ethereum. This platform was used to check documents while keeping transaction details private. Megafon used blockchain technology to issue corporate bonds.
Smart contact	**Russia**	Smart contracts allow for the direct exchange of capital, securities, real estate, and other properties without middlemen. Users can create "smart contracts" on the Ethereum network. This can be achieved on any device that has the Ethereum program installed on it.

2.3. Application of blockchain technology in the municipal solid waste sector

Monitoring and tracking of waste have become essential and worth implementation. Tracking information on waste supports the policies and the real menace of the brought by the latter. The existing laws and policies lack enforcement measures. Therefore, they fail during their first phase of implementation. If appropriately actualized, the enormous landfilling and unworthy incineration would be addressed. However, it is relatively difficult to monitor and trace the waste owners, especially using the old waste collection and distribution model. The Estonian Government should set policies to monitor waste collection. Fly-tipping and littering should be tasked to the holders. As a result, monitoring and tracking of waste require a more sophisticated model of more practical and experimental operations than the current solutions being utilized.

Estonia employs blockchain technologies to ensure the accuracy of government data and processes. The Estonian Information Systems Authority (RIA) is a critical service provider for the Government, providing State Agencies' access to the blockchain network through the X-road infrastructure. Healthcare Registry, Property Registry, Business Registry, Succession Registry, Digital Court System, Surveillance/Tracking Information System, Official State Announcements, and State Gazette are among the state registries supported by blockchain technologies. Gopalakrishnan & Radhakrishnan

(2019) discuss the existing blockchain-based solutions for waste management in Estonia, namely.

Swachhcoin: Swachhcoin is a blockchain-based solution to micromanagement of wastes largely from households and industry, intending to transform them into valuable goods in an efficient and environmentally beneficial manner. Electricity, paper, steel, lumber, precious metals, and glass polymers are high value by products of trash processing. The swachhcoin ecosystem is a Decentralized Autonomous Organization (DAO) that governs itself autonomously based on established instructions in the Swachh Coin White Paper smart contracts. Swachhcoin uses several cutting-edge technologies to perform an iterative process cycle, allowing the system to be entirely autonomous, efficient, and productive. This iterative process cycle focuses on the data transferred between multiple ecosystem participants, analyzes these data, and provides real-time recommendations based on predictive algorithms. Some of the tools and technologies that are part of the swachhcoin ecosystem are listed below (Gopalakrishnan & Radhakrishnan, 2019).

SwATA (Swachh Big data): One of the problems in the waste management sector is data management and transparency. Tons of garbage is created, collected, transported, processed, and disposed of. There is an abundance of data that has been created equitably. SATA is a specialized program that gathers, saves, and analyzes data to make recommendations for different improvement tasks such as route optimization, maintenance cycles, and report production. The data created in a domain such as waste management is unstructured; SWATA employs a NoSQL-based method and a virtual data filter at the collection sites to produce highly structured data that the SWATA application can process. SATA employs the most advanced and reliable method called prescriptive analysis. Blockchain is used to provide data immutability (Gopalakrishnan & Radhakrishnan, 2019). SATA uses the most modern and dependable technology known as prescriptive analysis. Blockchain technology is utilized to give data immutability (Gopalakrishnan & Radhakrishnan, 2019).

SwATEL (Swachh Adaptive Intelligence): Water is regarded as the ecosystem's brain. This allows diverse equipment and machinery in the ecosystem to communicate and coordinate with one another, making them intelligent. SwATEL employs a tailored adaptable Intelligence (AI) technology to drive real-time judgments based on prior learning, much like humans. These decisions may result in physical or digital acts that are recorded on the blockchain. Deep learning and neural networks are two important areas of AI. SwIOT (Swachh Internet of Things): SwIOT is an abbreviation for "Swachh Internet of Things: The Internet of Things (IoT) helps regulate anything that is linked to the internet and has many stakeholders, numerous entities, collection and trucks, collection bins, treatment facilities, and landfill sites that are all interconnected to and managed by IoT-based networks in waste management (Gopalakrishnan & Radhakrishnan, 2019).

SwBIN (Swachh Bins): The waste management process would be improved if garbage was collected correctly and to the greatest extent possible. SwBIN is similar to our regular trash cans, but it has more sophisticated technological and appealing features such as automated lid shutting and opening, free WiFi services, and decentralized advertising. A Unique Identifier is issued to each waste generator (UID). SwBIN will identify the user with the QR representing the UID and measure characteristics such as the quantity and quality of trash dumped to compute the rewards points whenever trash is placed. These tokens are recorded on the blockchain. This incentive will be distributed to users in the form of Swachh Tokens. SwBIN will transmit the status of trash in the bin to waste service providers via the SwIOT. The Search Foundation wants to utilize advertising to recoup the expense of installing SwBIN across regions. Garbage is collected and transferred to waste collection/processing facilities (Gopalakrishnan & Radhakrishnan, 2019).

Recereum Recereum (Recereum Whitepaper online):

is a blockchain network that converts waste and recyclables into actual money. This blockchain allows individual consumers to communicate directly with the waste collection agency. Recereum blockchain compensates individual home users with Recereum tokens based on the cost savings achieved via appropriate garbage sorting. The recereum ecosystem is based on Ethereum, the most important public blockchain. The blockchain tracks the rewards (token transfers) from one account to another. As described in the Recereum whitepaper, the key uses are smart contracts, payments, and supply chain management (Gopalakrishnan & Radhakrishnan, 2019). Recereum tokens (RCR) are Ethereum-based tokens based on the ERC20 standard. Recereum will supply 7,999,000 RCR at an exchange rate of 1 ETH for 300 RCR, with 65 percent sold to the public. The Recereum blockchain technology might be connected with existing garbage collecting systems such as vending machines and battery collecting machines. Recereum primarily focuses on waste sorting and associated aspects of the waste management cycle. Plastic Bank (Online) is a blockchain-based application that monetizes individuals to reduce plastic flow into the ocean. This initiative's collected plastics are recovered and marketed as Social Plastic. These are Plastic Bank confirmed plastics that rewarded the collector with a premium as a reward. These awards are dispersed, validated, and kept utilizing Blockchain technology, which provides the most secure and reliable method of delivering a globally scalable social effect (Gopalakrishnan & Radhakrishnan, 2019).

The nations mentioned above' development and performance in MSW management can be attributed to incorporating various blockchain techniques into their waste management processes (Berg *et al.,* 2020).

3. METHODOLOGY

3.1. Screening University Curricula

The study included research questions investigating the application of blockchain technology in Estonia curricula by screening the related courses offered in the four Estonian largest public universities. This was to examine whether blockchain-related classes were provided in the curricula. This was triggered by the unpopularity and newness of the technology within the region. However, Estonia is digitalized country, which makes it easy to adopt blockchain technology in Municipal waste management. This study utilized an analytical approach to examine the curricula status in the universities. Descriptive analysis of the variables such as municipal waste management courses against the application of technology courses will be performed. The research gathered the information by screening four universities in Estonia: Tallinn University of Technology, Tallinn University, University of Tartu and, Estonian University of Life Sciences. The screening process was done by looking into waste management, circular economy and blockchain related courses in all four universities, where blockchain technology can be integrated into the waste management process. The study relied much on the previous studies and recordings to gather the most reliable data concerning municipal waste management and circular economy across the four universities. More information was gathered using Estonia Statistical Database (www.stat.ee), national ecosystem information portals, interviews and consultations with municipal waste management administrators, technological companies, waste processing enterprises, state research articles, and Eurostat database (https://ec.europa.eu/eurostat) universities websites and annual reports.

3.2. Sample size structure

The Estonian higher education system relies on four pillars:

- Private universities
- Public universities
- State professional **higher education** institutions
- Private **higher education** professional schools

These institutions offer diverse curricula courses and programmes: from IT and technical to theological and social. Applied technical courses, entrepreneurship, veterinary and natural sciences, aviation, health and medicine, and security courses are also offered widely in Estonia. The four most prominent public universities in Estonia were the primary subject of this study. They include Tallinn University of Technology (TalTech), Tallinn University (TLU), the University of Tartu (TU), and Estonia University of Life Sciences (EMU). The institutions were selected based on their natural Science and technical background. The assumption was that the universities could offer a wide range of courses, including circular economy, municipal solid waste management and IT topics. They also recorded to be the institutions with the most significant number of students in Estonia. As per the Estonian statistics office, the four universities hold 74% of the country's students in all the higher learning programmes: Bachelor's, Master's, Integrated Bachelor's and Master's, Professional higher educational studies, and Doctoral studies (Estonian Statistics 2021).

3.3. Metadata of higher Institutions

The validity and reliability of the study are guaranteed by providing the metadata for the four Universities. General information concerning the funding and budget, number of faculties, students, and staff as of 2019 academic year, staff cost as % of total expenses, level of student tuition fees for Bachelor and Master, study programs – university profile, strength in academic research, the profile of research, industry orientation of the University and university organisation are vital for the examination. Among the four screened universities, Taltech has a total of 4 faculties (School of Information Technologies, School of Engineering, School of Science, School of Business and Governance) + Estonian Maritime Academy, with 10 282 students (16,2% - international students) (TalTech, 2019a and TalTech, 2019b) and a total of 1 846 employees, including 987 as academic staff. Tallinn University has seven faculties (Baltic Film, Media and Arts School, Haapsalu College, School of Digital Technologies, School of Educational Sciences, School of Governance, Law and Society, School of Humanities, School of Natural Sciences and Health). A total of 6 993 enrolled students in 2019: (13 % - international students) and an employee count of 813, including 392 academic staff (Tallinn University, 2021). The University of Tartu has a total number of 13 395 (12,4 % - international students) students enrolled in 4 faculties (Faculty of Art and Humanities, Faculty of Social Sciences, Faculty of Medicine, Faculty of Science and Technology), with a total staff capacity of 985 members, 599 of whom have a doctorate (60,8 %) (University of Tartu, 2021). The fourth screened University (Estonian University of Life Sciences) has five faculties (Institute of Veterinary Medicine and Animal Sciences, Institute of Technology, Institute of Agricultural and Environmental

Sciences, Institute of Forestry and Rural Engineering, Institute of Economics and Social Sciences), 2 749 enrolled students in 2019 (about 10% - international students) and a staff capacity of 935, including 503 as academic staff (EMU, 2021). The complete metadata of four screened universities in Estonia can be found in appendix 1. The data presented in appendix 1 regards specific University as of 2019 and 2020 academic years.

3.4 Statistical assessment

The statistical assessment consists of data gathering and interpretation to reveal patterns and trends (Afghah, 2018). Statistical assessment in this study involves analysing the data collected through the screening process. The assessment is done using different data analysis methods. The process starts with summary statistics through excel, providing comparative data like total, mean and standard deviation, followed by defining the variables involved in the assessment. Correlation and regression analysis is done on SPSS to verify the degree of linearity and dependence between the variables described by the study. The student T-Test was also performed to determine if there is a significant difference between the means of all variable groups (waste management, circular economy and blockchain related courses offered by all four universities). The statistical analysis's overall aim was to describe and test the relationships between variables.

4. RESULTS, DISCUSSION AND CONCLUSIONS

Table 4.1 represents some of the courses found to offer units and modules related to MSW and circular economy within their scope. They were found to contain information regarding Circular economy attainment or municipal waste management. Some of the units are compulsory to some universities, while others are optional.

Table 4. 1. Courses that are related to MSW and Circular Economy in the 4 screened universities

Courses	**TalTech**	**TLU**	**TU**	**EMU**
Waste management courses (bachelor level)	1	2	2	1
Waste management courses (master's level)	3	0	1	4
Circular Economy courses (bachelor level)	4	4	5	5
Circular Economy courses (master's level)	3	6	1	2
Others	2	0	0	0
Total	**13**	**12**	**9**	**12**

Table 4.1 above shows that Taltech has the most waste management and circular economy-related courses (thirteen), followed by TLU and EMU with a total of twelve related courses each. In contrast, the University of Tartu has just nine courses related to these fields.

Application of blockchain technology in the four screened universities was found to be picking and advancing in the right direction. Being a new field, some institutions have embraced it and have developed programs that purely train students on different blockchain skills. Specific blockchain technology courses were incorporated in some of the universities, as shown in the table 4.2 below.

Table 4. 2. Courses that are related to blockchain technology in the 4 screened universities

Courses	**TalTech**	**TLU**	**TU**	**EMU**
Blockchain technology related courses (bachelor's level)	0	0	1	0
Blockchain technology related courses (master's level)	2	0	1	0
Others	1	0	0	0
Total	**3**	**0**	**2**	**0**

Table 4.2 above shows that Taltech and TU are the only two universities with blockchain-related courses. Taltach has the most courses (three), while TU has just two courses related to blockchain technology.

Tallinn University of technology was noted to offer some of the municipal Waste topics in the engineering school and to a minimal extent in the school of science. Generally, a comprehensive representation of waste management courses at Taltech was observed. Most of the circular economy and MSW courses were taught in the school of health and natural sciences. Fewer causes were found in the school of digital technology.

In the blockchain sector, two study curricula course was found related to the latter in the School of Information Technologies. Furthermore, the Taltech has ongoing projects in need to integrate digital solutions at the school of sciences. Taltech has a solid research group called Blockchain Technology Group. It is found in the school of informative technologies under the department of software science. It deals and responds to consensus algorithms, distributed applications, oracle problems, decentralized autonomous organizations, smart contracts, and blockchains.

Currently, the group is working on the Erasmus+ project, BLOCKS, whose objective is to provide the students, teachers, and business promoters with skills and knowledge regarding blockchain technology through the Industry 4.0 program. The project considers an appropriate setting to upgrade the adequacy of current courses given by the accomplices to allow for a crossing over of the holes in the abilities of non-tech business visionaries and different kinds of partners. The methodology is non-innovatively severe, as the object is to give a business-arranged type of information, material for a wide range of understudies and business visionaries. It also improves the partners' capacity to respond to a quick moving business world in which advantages and dangers of this specific innovation should be considered at each level, from the controller to the customer.

Some of the University's ongoing projects and especially on digital technology, include research on the effects of the coronavirus on the digital workforce in the school of humanities and the impact of technological renovation on the modern generation.
TLU's natural sciences and health school offer four courses on circular economy and two courses on waste management. Tallinn University does not have any Blockchain-related research curricula or courses. The School of Digital Technologies offers courses in computer science, informatics, and mathematics. The emphasis of academic and research activities at universities is on sustainable growth, especially cultural and linguistic aspects. Any study on combined digital and social solutions is being conducted mainly in digital Technologies and Educational Sciences/Humanities schools. Among the ongoing programs are: Establishing an interdisciplinary research group at Tallinn University called "Cities, Work, and Modern Platforms" to investigate the impact of the coronavirus pandemic on digital labour platforms in Tallinn (1.09.2020-31.08.2022)/School of Humanities. With a combined budget of 15 000 EUR, the Cross-Border Educational Innovation by Technology-Enhanced Research (1.07.2015-30.06.2020)/School of Digital Technologies and School of Educational Sciences. The total budget is 2 396 363 EUR (Horizon 2020 project)
DigiGen: The Effect of Technology Revolutions on the Modern Age (1.12.2019-30.11.2022)/ School of Governance, Law, and Society The total budget is 223 730 EUR (Horizon 2020 project) Tallinn University does not have any Blockchain-related research curricula or courses. The School of Digital Technologies offers courses in computer science, informatics, and mathematics.

At Tartu University, most of the courses related to solid waste management were offered in the school of environment, science, and technology. Both bachelor and masters' level offered the courses. The circular economy was found to be incorporated into business administration, biodiversity maintenance and biology to a minimal extent. A free online program was found, "Auditing Waste Management". This was accessible to all interested university students. Blockchain technology integration in the University curricula is good. Most of the information technology activities and learning are done at the faculty of Science and Technology. Technological advancements and training are primarily focused on information management and entrepreneurship. The several blockchain courses at the Institution are evident that the school has embraced the latter as one solution to social problems. With the MSW integration, the school has ongoing research proposals for digital solutions to be utilized in waste management. Other ongoing projects related to the coding theory and cryptographic protocols to create more sustainable solutions in blockchain, fault tolerance of widespread databases, and e-voting in computer science. Another project is the Blockchain Network Online Education (BlockNet).

The University of Tartu is working on a system inclined on RFID (remote readable radio identifiers tags) and GPS precision. This will essentially help track and monitor waste from the owners, collection distribution, and recycling in the country. The project commenced in September 2020 and is expected to be complete by August 2021 on a budget of 1256678 EUR. The University also has finished projects in the technology sector. They include Privacy-Enhancing Cryptography in Distributed Databases (privilege) and Blockchain competence for ICT experts (BLISS). Most of the blockchain publications were contributed by the Faculty of Science and Technology and Computer science.

At Estonia University of life Sciences, compulsory subjects on solid waste management were available at masters and bachelor levels. The courses were standard for all the students and emphasized environmental conservation and protection. Making the courses compulsory for all the students prove its worth in the economy. Environmental governance and adaptation to climate change are masters' curricula that dedicate some aspects to the circular economy and waste management. Other smaller extend of the circular economy and MSW management topics are offered in bio-economy and environmental conservation and management. No study course was found relating to blockchain technology in the University. The primary focus for research was on sustainable growth and natural resources. Biosystems Engineering was found to be performing several digital solution projects. An anticipated event might be related to blockchain technology and will be held on 7 May 2021 (International Conference Biosystems Engineering).

At Tallinn University of Technology (TalTech), there are several ongoing projects in circular economy and municipal solid waste management. The first project is in waste grinding technology and innovative products to support and improve the value of textile waste. This is being actualized in the school of engineering (TalTech, 2019). The same school is developing a climate-neutral green campus to enhance environmental conservation and facilitate the circular economy. The business school has developed and implemented a universal relationship with the partner countries by offering a Master Programme in Waste Management. For instance, some events on the smart city project were organized by the University in 2020. However, no recorded public conferences or event related to the circular economy or MSW management in 2020.

The incorporation and integration of blockchain technology in the University are good. There are four major independent courses offered in the University on the latter. Blockchain learning is mainly done in the School of informative Technologies and the School of engineering. There are several ongoing blockchain technologies in the

Institution. Numerous innovative Information Technology projects and solutions are being developed and integrated into MSW management. They include TalTech University school of engineering (2018 to 2021) are developing a blockchain application for learning institutions to deal with innovations and sharing of information and ideas between schools, teachers, and students on technological advancements. This is to be completed at a total budget of 58143 EUR.

The Department of Software Science at TalTech (2020- 2021) are creating a cheap and effective sensor answer that utilizes original data manufacturing method that involves machine learning and can be incorporated into the ProWare Service application node to make the solutions more affordable and reliable. This project aims to enable and facilitate the utilization of the Internet of Things, Smart City Intelligent deployment, and security of Technologies. The total budget is proposed to be 515000 EUR.

The Estonian higher education curricula are responding to the new technological innovations and possibilities. Modern problems have become resistive to traditional approaches. There is a dire need to incorporate sophisticated and available solutions for sustainable growth. The circular economy and actualization of Smart City need adequate preparation. MSW management and improvement of landfill situation require an urgent response. Estonia has shown significant commitment by incorporating and training human resources to solve waste dumping, incineration, and recycling.

The integration of the different courses across the faculties in the screened universities is evidence and a clear indication of blockchain's future in Estonia. The skilled workforce is likely to offer a better solution for the waste and sustainable energy options in the region. Some institutions like Tartu are offering free courses and units on blockchain technology at different levels. This is an excellent approach to market the program.

As indicated by the received answer from Tallinn Waste Recycling centre (https://tjt.ee/), the landfill trucks for a variety of MSW in Estonia are using GPS and the following programming, they are the most current and automated. No short courses of action on refuse repositories are used in Estonia for an immense extension since the proportion of MSW compartments, and the repeat of their depleting is exorbitantly high.

4.1. Statistical data analysis

Data analysis in this study looks at describing the data collected through the screening process, followed by defining the variables, verifying the relationships between variables, and finally testing hypothesis. The data description process is done through summary statistics in excel were the mean and standard deviation of the data set are gotten as shown in table 4.3 below.

Table 4. 3. Summary statistics of screened universities

Universities	Waste management courses	Circular Economy courses	Blockchain technology related courses	Total	Mean	STDEV
Taltech	5	8	3	16	5.3	2.5
TLU	2	10	0	12	4	5.3
TU	3	6	2	11	3.7	2.1
EMU	5	7	0	12	4	3.6

Table 4.3 above presence summary statistic data calculated through excel. The table gives the total waste management, circular economy and blockchain-related courses offered by all four universities as of 2019. Taltech has 16 courses related to all three fields, while TLU has a total of 12 courses. The University of Tartu and EMU have a total of 11 and 12, respectively. However, TLU and EMU do not have any blockchain-related course, so their total number of courses are waste management and circular economy-related courses. Therefore, Taltech and TU are the only two universities with courses related to all three fields. The table also gives the mean (average) course for all four universities. Taltech has a mean of approximately five courses, TLU has a mean of four courses, while TU and EMU have a mean of about 2 and 4 courses, respectively. Table 4.3 above also shows the results of standard deviation (STDEV), which measure the dispersion of a set of data from its mean. It measures the total variability of a distribution, the greater the dispersion or variability, the greater the standard deviation. The more significant will be the magnitude of the variation of the value from their mean (Lee *et al.,* 2015). Taltech has a standard deviation of 2.5 from the mean, while TLU, TU and EMU have standard deviations of 5.3, 2.1 and 3.6, respectively.

The metadata of all four universities collected has two sets of variables. The independent variables (predictors); the four universities, and the dependent variables are waste management, circular economy, and blockchain technology-related courses. This study adopts the four universities are the independent variables and the course as dependent variables because the universities do not depend on the courses. Instead, the course offered at a university depends mainly on the types of university or institution. Therefore, the variables are as follows.

- Independent variables (predictors): Taltech, TLU, TU and EMU.
- Dependent variables: waste management, circular economy and blockchain technology-related courses.

The four independent variables and three dependent variables were grouped into two variable groups (Universities and courses) by computing their means (Average). The calculated means were used in performing the correlation, regression, and T-Test (student test) analysis. Correlation analysis was done to verify the linear relationship between the variable groups, and regression was done to verify the dependency between the courses and the university. At the same time, a T-Test was done to test if there is a significant difference between the means of all variable groups' probability of the number of circular economy-related courses against waste management blockchain technology-related courses offered in all four universities. The result of the analysis is presented in table 4.4 below.

Table 4.4. Analysis results

Indicators	**Values**
R	0.743
R^2	0.552
P-value	0.001
T-Test (one-tail)	0.002

The correlation coefficient (R) of 0.743 between the two variable groups shows a strong positive linear relationship between the universities and courses offered. Which can be interpreted as; the number of waste management, circular economy and blockchain-related courses will increase if the number of such university increases (Tahereh, 2018: Smith, 2018). The R^2 value of 0.552 for the regression analysis between the two variable groups (universities and courses offered) shows a 55.2% dependency between the two variables groups, which means that 55.2% of this course depends on the type of university or institution offering them. The regression P-value of 0.001 shows that the relationship between the two variable groups is statistically significant; this means that there is a less than 1% probability that this result occurred by chance (Tahereh, 2018: Smith, 2018). The results of the student T-Test (0.002) shows that there is more than a 99% chance that universities of this nature (Taltech, TLU, TU and EMU) will offer more circular economy-related courses than waste management and blockchain-related courses.

4.2 Comparison of results regarding four screened university curricula on Blockchain

To compare the teaching of courses related to MSW and Circular Economy, the following traffic light system was prepared.

Table 4.5. Municipal Solid Waste training courses and subject in the 4 screened universities (traffic light system).

Name of the University	**Courses/ subjects related to MSW/Circular Economy**	**R&D**	**Events**
Tallinn University of technology	A minimum of 4 primary + 8 minor subjects were found to relate to Circular economy and or Municipal Solid Waste management	At least 2 ongoing projects on Waste management At least 10 publications on Waste Management were found	More than 3 in a duration of 2 years
Tallinn University	5 major + 6 minor subjects were related to MSW and Circular Economy	A minimum of 1 event per year At least 5 publications on Waste Management	More than 3 in a duration of 2 years
Tartu University	6 major + 11 minor subjects related to circular economy/Waste management were found	No ongoing project related to Waste Management Less than 3 publications	None`
Estonian University of life and sciences	6 major and 4 minor subjects related to MSW/Circular economy	At least 2 projects on MSW/Circular economy At least 3 publications	At least 2 in 1 year

KEY:
GOOD
BAD
NEUTRAL

Table 4.5 above compares the number of waste management and circular economy courses offered by the four-screened universities. The table also shows R&D projects and events related to waste management and circular economy in these four universities. Taltech has a minimum of four primary, and eight minor subjects were found related to Circular economy and or Municipal Solid Waste management. With at least two ongoing Waste management projects and ten publications on Waste Management. Taltech has more than three events in waste management within two years. Tallinn University has five major and six minor subjects related to MSW and Circular Economy, at least five publications on Waste Management, with a minimum of 1 project per year. Tallinn university also has more than three events within two years. The University of Tartu has six major and 11 minor subjects related to circular economy/Waste management. Less than three publications and zero events related to waste management and circular economy. In comparison, the Estonian University of life and sciences has six primary and four minor subjects related to MSW/Circular economy, at least two projects and three publications on MSW/Circular economy. They also have at least two events related to these fields within a year. The screened universities have integrated the technology in different capacities, and Respective teaching of the Blockchain technology courses across the 4 screened universities compares as follows.

Table 4.6. Traffic light system comparison on Application of Blockchain Technology in the 4 screened universities

Name of the University	Blockchain Courses	Development and Research	Events
Tallinn University of Technology	Min of 4 blockchain courses are offered + 4 minor subjects	Minimum of 3 blockchain projects and 9 publications	Min of 2 events on Smart Cities
Tallinn University	No course on Blockchain Technology was found	2 projects were ongoing in the school of digital technology	None for 2019 and 2020
University of Tartu	3 major courses + 4 minor	At least 2 projects on Cryptographic protocols and RFID	2 anticipated events for 2021
Estonian University of Life Sciences	No course on Blockchain was found	1 Research project in the school of Biosystems Engineering. No publication on blockchain was found	None

KEY:

GOOD

BAD

NEUTRAL

Table 4.6 above compares the number of blockchain-related course, R&D, and event offered by the four-screen universities. The results show that Taltech has a minimum of four major and four minor subjects related to blockchain technology, at least three blockchain projects and nine publications. Taltech also has a minimum of 2 events on Smart Cities. In comparison, Tallinn University has no blockchain-related courses, two ongoing projects, and zero events. On the other hand, the University of Tartu has three major and four minor courses related to blockchain technology, at least two projects on Cryptographic protocols and RFID and two anticipated events for 2021. Estonian University of Life Sciences has zero blockchain-related courses, zero publications and events, and one research project in Biosystems Engineering. Taltech and the University of Tartu have the most blockchain-related courses, R&D projects, and events.

4.3. Comparative results between Estonia and Germany

Germany has a relatively broader ecosystem of vigorous enterprises and companies in the field of blockchain compared to Estonia that is embracing blockchain technology in most of its sectors. Berlin and Tallinn are the centers of blockchain application in

Germany and Estonia, respectively. The German government identified the economic and technological life in the country. The Estonian government support and fund blockchain projects in most of the public and corporate sectors. In 2019, the German government embraced and implemented a national blockchain approach to guarantee their support and commitment to the utilization and invention of technological advancements. The strategy offers guidelines and the best way to fund blockchain projects. It also provides information on the potential application area of blockchain to the promoters. Both countries have incorporated blockchain technology, especially in the finance and commerce sectors. Digital currencies are one of the example applications in the finance sector.

Due to the extensive acceptance and implementation of blockchain capabilities in Germany, many institutions and organizations commenced providing professional skills and training on the technology. Frankfurt School Blockchain Centre is one of the major centers that offer training and competence in blockchain technology. It is a research epicenter that investigates the effects of blockchain expertise in different sectors. Distributed Ledger Technology (DLT) and digital assets are research subjects for enterprises and their commerce approaches. EIT Digital Professional School is another institution that offers training courses on block technology. Other schools in the country that offer blockchain courses include European Blockchain Association that provides professional techniques in DLT and blockchain expertise knowledge and skills.

For Estonia, Tallinn University of Technology has been a research center for blockchain technology in Estonia. However, the level of application and research in Estonia is lower compared to Germany. Germany has specialized research centers for blockchain, offering training on the latter on different dimensions. Through the ministry of education, the government of Germany monitor and support blockchain projects in a more significant way than in Estonia. Germany has a more sophisticated use of blockchain expertise in municipal waste management compared to Estonia. Tracking and monitoring waste technology are used in Germany and yet to be incorporated in Estonia.

Famous universities in Germany offer waste management courses and units to the students in environmental science, environmental management, and maintainable practices (Fehr *et al.,* 2020)). There are master's degrees and doctoral programs related to municipal waste and circular economy. Some of the universities that offer waste management courses include Wayne State University, Sierra College, University of Central Missouri, Santa Monica College, South-Western College, Rio Hondo College. However, the system is not quite popular, especially at the undergraduate level. Most of the waste management units have been offered as units within other courses such as environmental science and Mineral Engineering.

4.4. Recommendation

Recommending the possible implementation of blockchain technology in MSW management practices into the university's curricula requires background courses related to blockchain and MSW management. Nevertheless, recommendations can also be made to accommodate such fields of studies in universities that do not offer these courses. Based on courses offered by these universities, this study recommends as follows.

Taltech offers courses like introduction to Blockchain technology: Theory and Practice, Blockchain-based systems engineering and Waste Management at the bachelor level. These three courses provide a solid foundation for the possible integration of blockchain technology in MSW management practices. Therefore, blockchain technology should be integrated to.

- Recycling and Energy Recovery of Wood, Textile and Plastic Wastes.
- Theory and Equipment of Sludge and Wastes Treatment.
- Solid Waste Management

The school of information technologies at Tallinn university provides a base for the introduction of blockchain-related courses. Therefore, the study recommends introducing a new course at the bachelor's level titled: Introduction to blockchain MSW management.

The University of Tartu has solid waste management and blockchain technology background at both the bachelor's and master's level. This study recommends integrating blockchain technology into the course; Auditing waste management (master's level).

The Estonian University of Life Sciences has a solid waste management foundation at both the bachelor's and master's level. But the lack of courses related to blockchain technology makes it somewhat challenging to recommend integrating or introducing blockchain practice to MSW management in their curriculum. Nevertheless, through the institute of technology, EMU can add courses related to blockchain technology at the bachelor's level that might pave the way for blockchain integration to MSW studies at the university. In this light, the study recommends

- A new course at bachelor's level; Introduction of blockchain technology.
- The integration of blockchain technology into Waste management and circular economy at master's level.
- EMU can also introduce a new course at the master's level; Blockchain MSW management.

5. CONCLUSIONS

This research was carried out to evaluate the application of Blockchain technology in MSW management practices and its possible implementation in university curricula in Estonia. To navigate the objective of this study, the curriculum of four public universities in Estonia were screened. The research was structured into three specific objectives which lead to the formation of three research questions as stated in section 1 (introduction).

According to the results, Tallinn University of Technology and the University of Tartu have the most comprehensive Blockchain research and courses. These two universities feature a vast number of disciplines that are in some way or another relevant to the Blockchain concept. These universities also host active projects and events relating to Blockchain, Databases and Information Systems, and Cyber Security. The Institute of Computer Science, Information Security Research Group, at the University of Tartu, is primarily responsible for Blockchain technology research, emphasizing security risk management in blockchain applications, privacy management in intelligent transportation systems blockchain-based applications. The Blockchain Technology Group, which is part of the Department of Software Science/School of Informative Technologies at Tallinn University of Technology, conducts extensive Blockchain research. Furthermore, several Research Groups from the School of Engineering engage with smart cities, digitalization, IoT, and so on. There are no blockchain courses at Tallinn University or the Estonian University of Life Sciences. Tallinn University's computer science department is primarily concerned with digital solutions and their modern society and education applications. Estonian University of Life Sciences' academic and research focus is mainly on sustainable development and natural resources. Some digital solutions and research are focused solely on Biosystems Engineering.

The result also shows that blockchain technology can be integrated as into the universities curriculum as follows.

Tallinn University of Technology: Recycling and Energy Recovery of Wood, Textile and Plastic Wastes; Theory and Equipment of Sludge and Wastes Treatment; and Solid Waste Management

University of Tartu: Auditing waste management

Tallinn University and the Estonian University of Life Sciences both do not have solid background to accommodate the integration of blockchain technology into MSW management. However, the integration can be done in these two universities as follows.

Tallinn University: Introducing a new course at the bachelor's level titled: Introduction to blockchain MSW management.

Estonian University of Life Sciences: A new course at bachelor's level; Introduction of blockchain technology. The integration of blockchain technology into Waste management and circular economy at master's level. Introduce a new course at the master's level; Blockchain MSW management.

Furthermore, the application of blockchain within the waste management sector is highly essential. Effective waste management requires high-level monitoring and tracking of waste. Blockchain-based waste management will record timely data on the type of wastes collected and waste transfers. AREP, a subsidiary of SNCF (the French national railway company), does an example of this practice. They used blockchain technology to monitor the amount, type, and frequency of waste collected in train station waste bins to optimize waste collection. SNCF recorded the waste data and transfers in blockchain transactions using the digital identities of containers on train platforms (Taylor *et al.,* 2020). Blockchain waste management will also facilitate payment or rewards. An entity depositing waste is rewarded or paid with a blockchain-secured digital token, redeemed for goods, or exchanged for other currencies. The Plastic Bank uses such blockchain rewards to incentivize individuals to become plastic waste collectors, particularly in developing countries, to reduce the amount of plastic that ends up in the oceans. Therefore, blockchain technology is very relevant to MSW management.

SUMMARY

According to the Estonian Waste Act (Waste Act, §2, 7), waste is defined as "any movable property or registered ship that the holder discards, intends to discard, or is required to discard". The worldwide resource and waste dilemmas demand and provide significant impetus for improved and more sustainable waste management. Resources and waste streams traditionally disposed of in landfills or incinerators are increasingly reused, recycled, or reclaimed. Nonetheless, although various laws and regulations have been enacted for this goal, several recurring obstacles continue throughout initiatives to facilitate the necessary, widespread transitions to sustainable waste management. Monitoring and tracking of waste have become essential and worth implementation. Tracking information on waste supports policies and the real menace of all waste management related activities. The existing laws and policies lack enforcement measures. Therefore, it is appropriate to introduce a system that will help reinforce sustainable waste management. This study evaluates the application of Blockchain technology in MSW management practices and its possible implementation in university curricula ". In Estonian.

The study included research questions investigating the application of blockchain technology in Estonia curricula by screening the related courses offered in the four Estonian largest public universities; Tallinn University of Technology (TalTech), Tallinn University (TLU), the University of Tartu (TU), and Estonia University of Life Sciences (EMU). This was to examine whether blockchain-related classes were provided in the curricula. This was triggered by the unpopularity and newness of the technology within the region. However, Estonia is digitalized country, which makes it easy to adopt blockchain technology in Municipal waste management.

The validity and reliability of the study are guaranteed by providing the metadata for the four Universities. General information concerning the funding and budget, number of faculties, students, and staff as of 2019 academic year, staff cost as % of total expenses, level of student tuition fees for Bachelor and Master, study programs – university profile, strength in academic research, the profile of research, industry orientation of the University and university organization were examined.

According to the results, Tallinn University of Technology and the University of Tartu have the most comprehensive Blockchain research and courses. The application of blockchain within the waste management sector is highly essential. Effective waste management requires high-level monitoring and tracking of waste. Blockchain-based waste management will record timely data on the type of wastes collected and waste

transfers. This study also recommends implementing blockchain technology in MSW management practices into the University's curricula as follows.

Tallinn University of Technology: Recycling and Energy Recovery of Wood, Textile and Plastic Wastes; Theory and Equipment of Sludge and Wastes Treatment; and Solid Waste Management

University of Tartu: Auditing waste management

Tallinn University: Introducing a new course at the bachelor's level titled: Introduction to blockchain MSW management.

Estonian University of Life Sciences: A new course at bachelor's level; Introduction of blockchain technology. The integration of blockchain technology into Waste management and circular economy at master's level. Introduce a new course at the master's level; Blockchain MSW management.

Keywords: Municipal Solid Wastes, Blockchain technology, University curriculum, National Waste management plan.

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APPENDICES

Appendix 1. Metadata of four screened universities in Estonia

Name of institution:	**1. Tallinn University of Technology**
Meta data	
Funding and budget	• Public university https://www.taltech.ee/en/ • Consolidated budget for 2019 (planned): 111.4 mln € (TalTech, 2019a)
Number of faculties	**4** (School of Information Technologies, School of Engineering, School of Science, School of Business and Governance) + Estonian Maritime Academy
Students and staff	• Number of enrolled students in 2019: **10 282** (16,2% - international students) (TalTech, 2019b and TalTech, 2019c) • Number of students enrolled in faculty running the MSW curriculum (10.11.2019): ✓ School of Information Technologies: 2952 ✓ School of Engineering: 3349 ✓ School of Science: 474 ✓ School of Business and Governance: 2767 ✓ Estonian Maritime Academy: 740 (PS: no courses offering MSW/Circular Economy topics) • Total number of employees: **1 846**, including **987** as academic staff. • In total: **140 professors and 216 lectures** (TalTech, 2020d). Thereof: ✓ School of Information Technologies: 35 professors, 35 lecturers ✓ School of Engineering: 46 professors, 81 lecturers ✓ School of Science: 26 professors, 14 lecturers ✓ School of Business and Governance: 29 professors, 54 lecturers ✓ Estonian Maritime Academy: 4 professors, 32 lecturers • Academic staff with a doctorate degree in %: 985 academic staff, with a doctorate degree: 599 (60,8%)
Staff cost as % of total costs	54,5% (58,2 mln €)
Level of student tuition fees for Bachelor and Master	Tuition fees at TalTech differ from English-taught and Estonian-taught programs and vary depending on the curriculum. From 2017/2018, tuition fees for **1 ECTS** for Bachelor and Master students admitted to TalTech for Estonian-taught programs who study part-time or in paid studies are as follows: ✓ School of Information Technologies: **40 EUR** ✓ School of Engineering: **40 EUR** ✓ School of Science: **40 EUR** ✓ School of Business and Governance: for Bachelor and applied higher education – **45 EUR**; for Master – **50 EUR** ✓ Estonian Maritime Academy: **40 EUR** Bachelor and Master students admitted to TalTech for English-taught programmes who study full-time pay a semester fee independent of the amount of ECTS announced beginning in 2019/2020: ✓ School of Information Technologies: **3000 EUR** ✓ School of Engineering: **1640 EUR**

	✓ School of Science: **1650 EUR** ✓ School of Business and Governance: from **1150 EUR** to **2500 EUR** (depending on programme) Tuition fees are reasonable, given that the average gross wage in Estonia in 2019 was 1 407 EUR (Estonian Statistics, 2020)
Study programs – university profile	• Number of study programs offered in total in 2019-2020: **79** **Bachelor:** 19 **Master:** 38 **Doctorate:** 9 Integrated studies: 4 (4 - School of Engineering) Applied Higher Education: 9
Strength in academic research – stronger or weaker?	Strong academic research: • 1289 scientific publications were published in 2019 from TalTech academic staff • External funding through R&D project agreements: 17,4 million € (participation in foreign programs, international agreements)
Profile of research	TalTech's waste management research is mostly centered on the oil shale sector – reusing oil shale ash to reduce GHG pollution or wastewater treatment technologies. The main waste-related projects, for example, Horizon 2020 project "CLEAN clinKER processing by Calcium looping process (CLEANKER)" and EIT KIC network "FLy Ash to useful MinErals (FLAME)").
Industry orientation of the university – high or low	TalTech places a strong emphasis on industry. The TalTech Development Plan 2020 emphasizes the university's close collaboration with the private and public sectors. The aim is to be an involved investor for Estonian businesses, involving them in TalTech research and development. TalTech works closely with Tehnopol, a research and business campus for cutting-edge technology firms. Tehnopol Startup Incubator works with the best advisors from TalTech and beyond to help technology-based companies grow their companies, reach export markets, and secure investments (https://www.tehnopol.ee/en/). TalTech has also founded the Innovation and Business Center (MECTORY) (https://taltech.ee/en/mektory). In 2019, the value of industry/business deals totaled 10.6 million EUR. Contracts for both domestic and international firms are included (TalTech, 2019b). Since there are so many, it is very difficult to carry out research projects in close collaboration with industry. The School of Engineering has the most programs in collaboration with industry. Numerous bachelor's and master's theses was published in collaboration with business. There are no industry-sponsored study programs at TalTech; nevertheless, several private industry firms are members of the TalTech Development Fund, which financially funds young promising students, academic professors, and lecturers.
University organisation	TalTech has the Environmental Strategy 2015-2020, but not the *Sustainability Strategy*. In TalTech Development Plan 2020 is mentioned that *«…university aim is to be an advisory partner of Estonia country in solving technological, economic and social problems».* Nevertheless, the sustainability part is not directly mentioned in the university's mission.
Name of institution:	**2. Tallinn University**
Meta data	
Funding and budget	• Public university https://www.tlu.ee/en • Consolidated budget for 2019 (planned): 41.9 mln € (TLU, 2019)

Number of faculties	**7** (Baltic Film, Media and Arts School, Haapsalu College, School of Digital Technologies, School of Educational Sciences, School of Governance, Law and Society, School of Humanities, School of Natural Sciences and Health)
Students and staff	• Number of enrolled students in 2019: **6 993** (13 % - international students) • Number of students enrolled in faculty running the MSW curriculum: ✓ Baltic Film, Media and Arts School: 853 ✓ Haapsalu College: 235 ✓ School of Digital Technologies: 713 ✓ School of Educational Sciences: 1397 ✓ School of Governance, Law and Society: 1418 ✓ School of Humanities: 1239 ✓ School of Natural Sciences and Health: 1138 • Total number of employees: **813**, including **392** academic staff. • In total: **46.8 professors and 135.05 lectures**. • The percentage of academic staff with a doctorate degree out of the 392 academic staff, is 59 %
Staff cost as % of total costs	63,69 %
Level of student tuition fees for Bachelor and Master	• Tuition fees at TLU differ from English-taught and Estonian-taught programs and vary depending on the curriculum. • Beginning in 2020/2021, tuition rates for 1 ECTS for Bachelor and Master students admitted to TLU for Estonian-taught programs who study part-time or in paying studies will be as follows: ✓ Baltic Film, Media and Arts School: **54-100 EUR** ✓ Haapsalu College: **40 EUR** ✓ School of Digital Technologies: **40-44 EUR** ✓ School of Educational Sciences: **40-46 EUR** ✓ School of Governance, Law and Society: **40-69 EUR** ✓ School of Humanities: **30-49 EUR** ✓ School of Natural Sciences and Health: **43-46 EUR** • Beginning in 2020/2021, full-time Bachelor and Master students admitted to TLU for English-taught programs will pay a semester fee regardless of the number of ECTS announced as follows: ✓ Baltic Film, Media and Arts School: **1900 – 2000 EUR** ✓ School of Digital Technologies: **1250 – 1875 EUR** ✓ School of Educational Sciences: **2250 EUR** ✓ School of Governance, Law and Society: **1628-2200 EUR** ✓ School of Humanities: **913 – 1650 EUR** ✓ School of Natural Sciences and Health: **1500 EUR** The tuition fees can be considered as affordable, since the average gross wage in 2019 in Estonia was **1 407** EUR (Estonian Statistics, 2020)
Study programs – university profile	• Number of study programs offered in total in 2019: **116** **Bachelor:** 38 **Master:** 59 **Doctorate:** 14 Applied Higher Education: 5
Strength in academic	Strong academic research:

research – stronger or weaker?	• 1226 scientific publications were published in 2019 from TLU academic staff (TLU, 2019) • In 2019 21,1% of TLU budget income was from international research projects (TLU, 2019)
Profile of research	In general, TLU research focuses on various aspects of **sustainability**. The most important research projects at TLU in 2019 have little to do with substance circulation, logistics, supply chain, or the Circular Economy in general.
Industry orientation of the university – high or low	TLU has a strong industry/business focus in general. In 2016, it was one of six founders of the ADAPTER website, which provides easy access to the best of Estonian R&D for both businesses and organisations (www.adapter.ee/en/). The platform serves as a link between the industrial and educational sectors, providing various teaching, consultancy, and R&D opportunities. TLU offers a variety of practical educational programs, including collaboration with European industry firms.
University organisation	The subject of sustainability is well incorporated into the Tallinn University Development Plan 2020-2022 and is also highlighted as a separate priority area of the TLU Development Plan. TLU is known as the "green university," and it hosts several seminars and campaigns promoting a healthy lifestyle. The sustainability aspect is explicitly stated in the university's mission. TLU's mission is to be a pioneer in developing healthy lifestyles in Estonia and to fully incorporate sustainable growth concepts on university campuses and beyond. In addition, an academic vacancy for Vice-Rector for Sustainable Development was established at TLU Rectorate in 2020.
Name of institution:	**3. University of Tartu**
Meta data	
Funding and budget	• Public university https://www.ut.ee/en/welcome • Consolidated budget for 2021 (planned): 199.5 mln €
Number of faculties	**4** (Faculty of Art and Humanities, Faculty of Social Sciences, Faculty of Medicine, Faculty of Science and Technology)
Students and staff	• Total number of students enrolled in 2019: 13 395 (12,4 percent - international students). • Students enrolled in faculty teaching the MSW program (2019): • Science and Technology Faculty (3174 students) • Total number of employees: 3635, of which 1920 are academics. ✓ There are 208 professors and 255 lectures in all. ✓ There are 40 professors and 85 lecturers in the Faculty of Art and Humanities. ✓ 46 professors and 60 lecturers in the Faculty of Social Sciences. ✓ 48 professors and 69 lecturers in the Faculty of Medicine; and, ✓ 74 professors and 41 lecturers in the Faculty of Science and Technology. • Academic workers with a doctorate in percentage: There are 985 university staff members, 599 of whom have a doctorate degree (60,8 percent)
Staff cost as % of total costs	52% (92,2 mln €)
Level of student tuition fees for Bachelor and Master	Tuition costs at the University of Tartu differ for English-taught which Estonian-taught programs and vary depending on the curriculum. For full-time students, all Estonian-taught degree programs are free. And if you fail to fulfill the nominal study load requirement, should you have to begin paying the tuition fee. A full-time student can complete 30 ECTS per semester and 60 ECTS per academic year. The payment threshold is 6 ECTS: if you complete 24 ECTS before the end of the

	semester, you are not required to pay. However, at the conclusion of the second term, you must have earned 54 ECTS: credit points are measured cumulatively every course. Tuition fees for 1 ECTS for Bachelor and Master students admitted to University of Tartu for Estonian-taught programmes who study part-time or in paying studies in 2021/2022 are as follows: ✓ Faculty of Art and Humanities: bachelor **40 EUR** per ECTS and master programme **45 EUR** per 1 ECTS. ✓ Faculty of Social Sciences: bachelor **40 EUR** per ECTS and master programme **45 EUR** per 1 ECTS. ✓ Faculty of Medicine: **50 EUR** (both bachelor and master programmes) ✓ Faculty of Science and Technology: bachelor **45 EUR**, master **50 EUR**. Bachelor and Master students admitted to the University of Tartu for English-taught programmes who study full-time pay a semester fee regardless of the amount of ECTS announced beginning in 2020/2021: ✓ Faculty of Art and Humanities: semester fee **2000 EUR** (1 ECTS is 80EUR). ✓ Faculty of Social Sciences: semester fee **(1900 EUR)** bachelor 76 EUR per 1ECTS and master programme 76 EUR per 1 ECTS. ✓ Faculty of Medicine: semester fee **(6000 EUR),** 200 EUR per 1 ECTS ✓ Faculty of Science and Technology: semester fee **(2500 EUR)** bachelor -100 EUR per 1 ECTS, master – 100EUR per 1 ECTS. The tuition fees can be considered as affordable, since the average gross wage in 2019 in Estonia was **1 407** EUR (Estonian Statistics, 2020)
Study programs – university profile	• Number of study programs offered in total in 2019: **144** **Bachelor:** 44 (14 - Faculty of Art and Humanities, 14 - Faculty of Social Sciences, 6 Faculty of Medicine, 10- Faculty of Science and Technology) **Master:** 65 (14 - Faculty of Art and Humanities, 25 - Faculty of Social Sciences, 4 Faculty of Medicine, 22 - Faculty of Science and Technology) **Doctorate:** 35 (8 - Faculty of Art and Humanities, 7 - Faculty of Social Sciences, 4 Faculty of Medicine, 16 - Faculty of Science and Technology)
Strength in academic research – stronger or weaker?	Strong academic research: • In 2019, the University of Tartu published 2834 research publications, with 1983 of them being high-level publications. • In 2019, there are 412 R&D programs, 28 of which are Horizon 2020 projects. In 2019, the overall funding amount in the R&D market is 69 712 443 EUR.
Profile of research	Several projects related to the circular economy are currently underway at the University of Tartu. One is related to the social sciences and the green economy, while others are related to wastewater treatment research (4 projects) at the Faculty of Science and Technology. Currently active waste sector initiatives are mostly concerned with industrial waste disposal (2 projects).
Industry orientation of the university – high or low	In 2019, the number of business contracts at the University of Tartu is 18 503 889 EUR, which includes contracts for supplies to other funders (6 285 098 EUR), contracts with businesses (4 800 205 EUR), and financing scheme contracts for a company as a partner. The University of Tartu has founded the Centre for Entrepreneurship and Innovation. Network between companies and universities: Adapter-

	ADAPTER is a network of Estonian universities and research and development organizations that provides businesses and organizations with a fast and secure access to the research and development ecosystem (adapter.ee/en/). The list of spin-off companies is available on the university's website – whose companies want to strengthen their ties with the university to grow their businesses (by the end of 2019, 54 enterprises)
University organisation	The University of Tartu has no proven sustainability policy. There were no sustainability metrics assessed and included in the annual report.
Name of institution:	**4. Estonian University of Life Sciences**
Meta data	
Funding and budget	• Public university https://www.emu.ee/en/ • Consolidated budget for 2021 (planned): 34.1 mln €
Number of faculties	**5** (Institute of Veterinary Medicine and Animal Sciences, Institute of Technology, Institute of Agricultural and Environmental Sciences, Institute of Forestry and Rural Engineering, Institute of Economics and Social Sciences)
Students and staff	• Number of enrolled students in 2019: **2 749** (about 10% - international students). • Number of students enrolled in faculty running the MSW curriculum: ✓ Institute of Agricultural and Environmental Sciences: 750 students • Total number of employees: **935,** including **503** academic staff. • In total: **39 professors and 168 lectures**. • The percentage of academic staff with a doctorate degree amongst the 985 academic staff is 599 (60,8%)
Staff cost as % of total costs	70% (19,8 mln €)
Level of student tuition fees for Bachelor and Master	It is free to begin studies at the university in full-time Estonian-language curricula. There is a charge for part-time work and learning in an English-language program. Tuition payments in the first study year are charged in three installments: the first (200 EUR) before arrival in Estonia, the second by September 15, and the third by February 15. Tuition payments are charged in two installments in subsequent study years, one for each term (Autumn and Spring). ✓ Veterinarian studies based on integrated B.A. and M.A. programmes – semester fee **(4400 EUR),** price per credit point 145 EUR. ✓ Landscape Architecture M.A. programme Immatriculated before 2018/2019 study year - semester fee **(1050 EUR),** price per credit point 35 EUR. ✓ Landscape Architecture M.A. programme Immatriculated starting from 2018/2019 study year - semester fee **(1200 EUR),** price per credit point 40 EUR. ✓ Agri-Food Business Management M.A. programme – semester fee : EU students: **1260 EUR** ✓ Non-EU: **1500 EUR**, EU students: 42 and Non-EU: 50. The price of one credit is 40 euros for students enrolled in Estonian-language curricula (except for doctoral curricula) who have a duty to refund research expenses under the Estonian University of Life Sciences' protocol for repayment of study expenses. The semester tuition charge for graduate students studying part-time is 50 euros. The tuition fees can be considered as affordable, since the average gross wage in 2019 in Estonia was **1 407** EUR (Estonian Statistics, 2020)

Study programs – university profile	• Number of study programs offered in total in 2019: **44** **Bachelor:** 18 (4-Institute of Veterinary Medicine and Animal Sciences, 2-Institute of Technology, 6-Institute of Agricultural and Environmental Sciences, 5-Institute of Forestry and Rural Engineering, 2- Institute of Economics and Social Sciences) **Seasonal study bachelor**: 2 (1- Institute of Economics and Social Sciences, 1- Institute of Technology) **Master:** 5 (3-Institute of Agricultural and Environmental Sciences, 1-Institute of Forestry and Rural Engineering, 1- Institute of Economics and Social Sciences) **Seasonal study master:** 14 (2-Institute of Veterinary Medicine and Animal Sciences, 3-Institute of Technology, 5-Institute of Agricultural and Environmental Sciences, 2-Institute of Forestry and Rural Engineering, 2- Institute of Economics and Social Sciences) **Doctoral study:** 5 (1-Institute of Veterinary Medicine and Animal Sciences, 1-Institute of Technology, 1-Institute of Agricultural and Environmental Sciences, 1-Institute of Forestry and Rural Engineering, 1- Institute of Economics and Social Sciences)
Strength in academic research – stronger or weaker?	Strong strenght in academic research: • In 2019, the Estonian University of Life Sciences published 647 scientific level papers, 362 of which were high level publications. • 145 new R&D contracts were awarded in 2019. In 2019, the overall financing amount in the R&D sector is 13 million EUR.
Profile of research	Several waste-related programs are currently underway at Estonian University of Life Sciences. There are two programs in the Institute of Veterinary Medicine and Animal Sciences that are mostly concerned with medical waste. Three projects at the Institute of Technology are related to manufacturing processes and biomass. 1 project at the Institute of Agricultural and Environmental Sciences dealing with phosphorus reduction in catchment lake systems. Four current programs are based on the circular economy, with a particular emphasis on the bioeconomy.
Industry orientation of the university – high or low	Estonian R&D partnerships and EU strategic funds accounted for 38% of R&D sales in 2019 (46%) in 2018, R&D international agreements accounted for 16% (18% in 2018), and base financing accounted for 23%. (16 percent in 2018). Network between companies and universities: Adapter- ADAPTER is a network of Estonian universities and research and development organizations that provides businesses and organizations with a fast and secure access to the research and development ecosystem (adapter.ee/en/). Strong collaboration in the organization of internships for students with various Estonian enterprises.
University organisation	The Estonian University of Life Sciences has become a member of the Green University Initiative. They established the Green University concepts and implemented the Green University strategy based on the University's mission and vision. Green tips and waste disposal instructions are available on the website.