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1. Problem Statement

Incorrect waste sorting practices pose a significant barrier to the realization of a circular economy, which seeks to decouple the economy from resource depletion, environmental pollution, and carbon emissions by continually reusing, recycling, and regenerating resources (Ragossnig & Schneider, 2019; Eriksen et al, 2018a). By embracing a greater level of circularity, we have the potential to mitigate the effects of climate change and minimize the environmental impact as a result.

Contaminated waste streams complicate recycling operations, requiring additional sorting and cleaning processes (Jank et al., 2015). This results in longer processing times and higher costs. Moreover, the presence of non-recyclable or hazardous materials in recycling streams can render entire batches unusable, which leads to additional complexities in waste management and hinders the achievement of circularity (Eriksen et al, 2018b).

Improper waste sorting has consequences beyond economic implications for waste management companies, presenting significant ecological and social challenges for communities and the environment. Additional costs in the recycling phase are passed on to communities, increasing financial stress through higher service fees imposed by recycling companies. Environmentally, incorrect disposal of recyclable materials leads to unnecessary resource depletion and increased energy consumption. Furthermore, the contamination of biological waste streams leads to additional greenhouse gas emissions, primarily caused by microplastics (Misra & Pandey, 2005; Gautam et al, 2021; Shen et al, 2020).

Private households generate a substantial portion of municipal solid waste, comprising a diverse range of materials such as paper, plastic, glass, metal, and organic waste. Incorrect waste sorting in private households can be attributed to various factors, such as a lack of awareness, confusion about recycling guidelines, and inadequate access to information on proper waste disposal practices (Nagash et al., 2021).

Despite many efforts to promote proper waste disposal, the problem of incorrect waste sorting persists, resulting in contamination and hindering effective recycling and disposal processes. Current initiatives, such as widespread advertising campaigns or the manual inspection of waste bins accompanied by tailored household education, have proven to be ineffective, costly, or time-consuming.

To address this issue, an innovative solution is required to raise awareness about proper waste disposal practices. This solution should provide accessible information to residents and offer customized feedback to consumers in a scalable way, making it as easy as possible for private households to change their behaviors and improve waste sorting practices.

2. Methodology

During our collaboration with Infineon Technologies, our team embarked on an extensive investigation to gather valuable insights and feedback from various stakeholders in the waste management industry. In the initial stages of our research, we revisited the idea from the previous year's EuroTeq project, which focused on route optimization as a potential solution. However, through extensive discussions and feedback sessions with waste collection and recycling companies, we discovered that this solution did not create significant value for the companies we engaged with, and we expected the ecological impact of the solution to be limited. An interview with the Director of the District Company of Public Services in Bogota confirmed that there is very limited potential for demand-based route optimization solutions.
Based on this realization, we shifted our focus and began extensive research to get an overview of the waste collection and management industry and identify promising problem areas. In addition to the literature review, we reached out to ten companies responsible for waste collection and recycling in Germany. Within the given deadline, we successfully conducted five interviews with four different companies, allowing us to gain valuable firsthand information about their operations and challenges.
The interviews and feedback sessions provided valuable insights into the detrimental effects of contaminated waste streams and the importance of increasing customer awareness at the household level. We decided to focus on solutions to reduce waste contamination and improve waste segregation practices of private households and conducted further research by studying relevant academic papers and analyzing companies, previous concepts, and promising technologies to tackle the problem.
We focused on the initial stages of the recycling process and identified waste segregation at private household level as a major issue. The root cause of which were consumer’s mind behavior gap and communication gap. This led to increased costs for additional sorting and contamination of the ecosystem. Understanding these challenges was crucial for the development of an effective solution.
The primary objective was to uncover shared elements and understand the priorities and needs of municipalities in waste management initiatives. To evaluate the feasibility of our ideas and ensure compatibility with Infineon's current product portfolio, we organized a brainstorming session at the Makers Space in Munich with Infineon. During this session, we scrutinized our proposed concepts and their alignment with the available resources and technologies. Ideally, the key elements that emerged from this research and evaluation phase included the crucial need for the detailed records on a bin level, a comprehensive platform for collection, storage and analysis of the data for the optimization of the waste collection process and a user-friendly consumer-based application customized to provide users with a platform to get information about sorting, flagging notifications and to communicate directly with the waste management companies.
Throughout the project, we maintained regular meetings with our mentors from Infineon and the Technical University of Munich. These interactions played a vital role in ensuring continuous alignment and receiving valuable guidance and expertise from industry professionals. By incorporating their insights and expertise, we were able to refine our ideas, ensuring a robust and effective waste management solution. During the research phase of the project, it was identified that many waste management companies were concerned with the cost incurred by waste segregation at private household level. Our first step involved conducting a thorough analysis of the current municipal waste collection system. Additionally, discussions

with stakeholders and waste management experts were held to gather their valuable perspectives and requirements for the solution. To set the course for our project, we initially addressed several key questions that would guide our next steps:

1. What are the primary challenges faced by waste collection and recycling companies?
2. What existing solutions to the challenges in waste management are currently available, and how does our solution differentiate itself?
3. How can our solution effectively address the identified problem at its earliest stages and what positive impacts does it offer?
4. What are the minimum resources required for implementing our solution and what are their associated costs?
5. How can we ensure the feasibility and profitability of our solution?
6. How can municipal waste collection benefit from the innovation through integration of semiconductors and emerging technologies such as robotics, sensors, AI, IoT, Deep Learning, Quantum computing, and big data?
7. What are the environmental, social, economic, and governmental implications that arise from the implementation of the waste collection system, and how can these implications be addressed and managed in a sustainable manner?

Consideration of the environmental and social impacts was an integral part of our methodology. This project was designed so that it has low capital cost and material requirements during its initiation, to allow smaller communities to adopt our solution. To ensure successful implementation and scalability of our solution, we aimed at designing a modular solution that can be adapted to different legislation and technological equipment.

3. Final Concept

In this section the final concept is discussed, including the solution overview, the technological concept and the economic analysis.

3.1 Solution Overview

The solution was designed to integrate the various stakeholders over a single product and allow the multiple objectives of each one of these stakeholders to be pursued i.e., to have lower contamination rates for the companies and more friendly and direct information for the households. The research guided the project to the following purpose: to drive behavioral change directly at the polluting agent, the private households, to reduce pollution and improper sorting of waste. The solution is named “WasteWise”, a combination of software and hardware that enables the on-site flagging of polluting activities and notifies immediately the polluting agent over a user-friendly application. By incorporating this technology, private households and municipal waste management companies are directly connected to each other, through the digitalization of the waste collection process. Taking this into account it was determined that the waste collection companies are the target client, as these could be incentivized to pay for the product to perceive significant monetary savings.

The implementation considers the following aspects: Each waste bin under the supervision of our client, the waste management company, will be identified with a unique ID and linked to a community, this will be done by using Infineon NFC chips. Furthermore, our client will have access to a database that enables the storage of valuable information that helps understand the sorting or polluting behavior of the consumer. Finally, the app creates a channel of communication to the polluting agents, the households, such that tailor-made content can be delivered to correct the mind-gap behavior and adapt it to the most updated sorting, recycling and waste management guidelines particular for each user according to its location.

With this integrated approach that keeps technology at the core "WasteWise" has five pillars that make it resilient from regional and political fluctuations in the market:

i) Improved sorting at individual level
ii) efficient detection & flagging of pollution
iii) digitalization of records
iv) personalized and meaningful communication
v) Targeted campaigns and advertisements

The overview of the process is shown in Fig. (1) below.

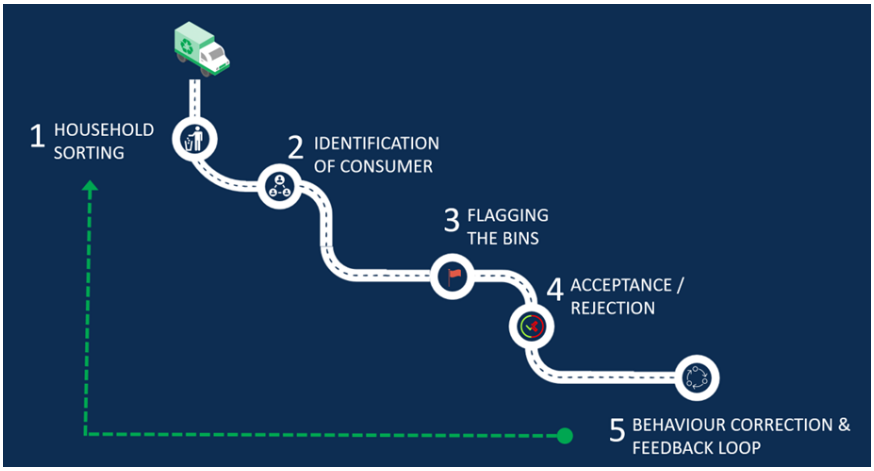

Figure 1: Product System Overview

3.2 Technological Concept

The final concept for digitalizing conventional waste sorting and narrowing the consumer mind behavior gap is depicted as in Fig. (2). It consists of two hardware and two software components which are NFC chips, scanners, Content Management System (CMS), and "WasteWise" mobile app. NFC chips will be installed on the lid or side of the waste bins designated to private households or communities who are being regarded as polluting agents. Thus, a unique ID will be assigned to each waste bin. Wearable scanners will be able to read the NFC chips and send the wireless signals to CMS. After the application of this model, waste collectors will first scan the NFC chip on the waste bin thus connecting the waste bin to our

CMS and allowing a seamless flow of information. Then they perform the sorting of the waste bin, and if they find contamination, they can directly flag the waste bin by merely touching the flagging option in the same scanner. The scanner will send the flagging signal to CMS. CMS will be able to capture, store, analyze the data and trigger notifications to our mobile app. Also, CMS will notify the waste collector about high-alert communities through historical tracking of previous findings for a more detailed sorting. A mobile application will be developed to provide a platform digitally connecting waste management companies to consumers who are the most important stakeholders in the whole chain. It will notify the consumers about waste collection schedules and flagging. It will contain tabs for information, education and community knowledge sharing. This will also unlock opportunities for all stakeholders for targeted campaigns and advertisements. Additionally, it will provide the companies with secure payment solutions for incentives and fines based upon consumer performance. Collected data can then be used by governments and NGOs as a foundation for legislation and policy making while targeting the most vulnerable regions. Data encryption was secured by using waste bin IDs in the flow of information instead of personal details of the users. This concept is open to new technological developments in the initial sorting of the bins by collectors. Thus, the innovations for contamination detection can be easily employed in future.

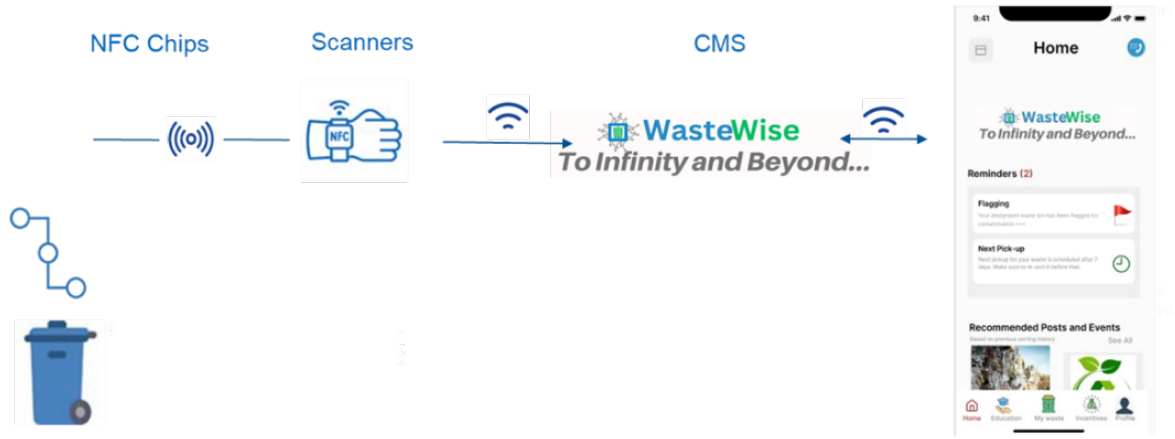

Figure 2: Concept for information flow

3.2.1 Hardware

NFC Chips

NFC, near field communication is a type of radio frequency technology allowing wireless flow of information at short distances. Initially, it was used for contactless payments, but it got rapid fame in its diverse applications across many fields. For instance, the potential use of NFC in the digitalization of the conventional library management system was emphasized previously (Singh, N. K., 2020). Similarly, the use of NFC technology combined with non-NFC devices in asset management was proposed for accurate recording of assets (Saraubon et al., 2019,). The application of NFC in resource management was investigated to avoid disinformation in wood blockchain (Shibano, K. et al, 2022). A cross-sectional survey of current strategies and

digitalization efforts of 130 German waste management companies was reported for the insights from public and private waste firms (Borchard, R. et al., 2022). They concluded that only 26% of those companies were using integrated NFC/RFID chips or barcodes for identification of their containers. Our NFC chips, developed by Infineon Technologies AG, consist of a spiral antenna enabling wireless communication of data through inductive coupling (Infineon Technologies AG. (2022) NFC Technology). In our model we employed Infineon secured NFC tags- NFC4TCXXX, contactless solution for authentication and identification. The internal circuit of an NFC diagram is depicted by Fig. (3):

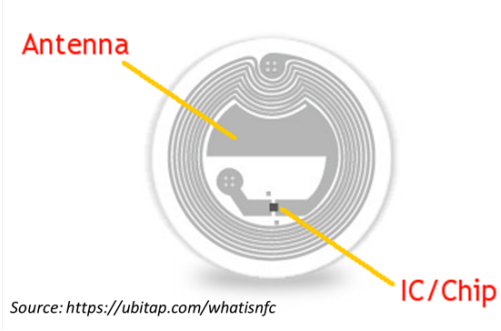

Figure 3: NFC Chip

Wearable Scanners

We aimed to use wearable scanners able to read NFC chips and communicate with the CMS through wireless signals. Keeping in mind the cost, a customized semi-smart watch with the specifications of NFC reading and connecting to CMS through long distance wireless signals was finalized as a wearable scanner.

Figure 4: Watch Scanner

3.2.2 Platform

Content Management System (CMS)

Our tailored cloud-based CMS, "WasteWise", would be able to capture, store, analyze, track the data and send triggering and scheduling notifications to consumers through our app. It will keep the historical records of flagging through real-time navigation of different communities. Based upon the analytics, it would be able to notify the waste collector about high alert areas to perform a more detailed sorting. The stored data can be accessed anytime. This collected

data can further be visualized and analyzed to withdraw conclusions to grade the performance of consumers. At this point, waste management companies can seek help from CMS to make decisions about their future strategies. They can also collaborate with the other stakeholders for targeted campaigns and advertisements in the areas where they are needed the most.

WasteWise
To Infinity and Beyond...

XYZ WMC					®WasteWise
Wbin ID	Time	Date	Location	Status	Intensity
XYZ123	4:55	30/05/2022	48.8, 12.58	Collected	Low
XYZ124	5:15	30/05/2022	48.9, 12.59	Flagged	High
XYZ125	5:35	30/05/2022	48.8, 12.59	Collected	Low
XYZ126	5:55	30/05/2022	48.9, 12.60	Collected	Low
XYZ127	6:15	30/05/2022	48.8, 12.60	Collected	Low
XYZ128	6:35	30/05/2022	48.9, 12.61	Flagged	High
XYZ129	6:55	30/05/2022	48.8, 12.61	Collected	Low

Figure 5: Content Management Sytem

Mobile Application

Our customized consumer based mobile application will provide a platform to connect the waste management companies to the most important stakeholders in the whole chain, consumers. Consumers would be notified about the schedules of waste collection and flagging through the notifications from this app. There will be tabs for information and education if someone lacks a basic understanding of sorting of waste. Additionally, it will provide a knowledge-sharing community platform where issues related to waste management can be discussed among individuals. Companies can use this platform for advertisement and campaigns in specific regions where it is needed. NGOs and policy makers can also use this for their own needs of awareness programs and seminars. There would be secure payment solutions for incentives and fines based on the performance of individuals. Through this app, people can easily access the chain of their waste thus making it more transparent. Mock for the proposed app can be seen in fig. 6:

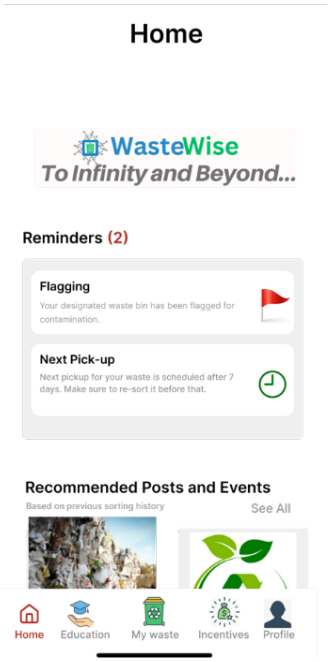

Figure 6: Mockup for the cosumer mobile application

3.3 Economic Analysis

An economic analysis was conducted to quantify the costs for building and implementing the content management system along with the associated hardware for a waste management center. The content management system is highly customizable and can be built based on the needs of each waste management center based on and meet the country's requirements, policies or behavior of the citizens and the targeted customer segment. For the calculations, certain assumptions have been made that are listed below:

- The average lifespan of NFC chips is 10 years.
- The average lifespan of the handheld scanners is between 3-5 years based on daily use.
- The 'Waste wizards' team will work on this project for the initial period without a salary, against equity in this company, until the company starts becoming profitable.

The costs are a representation of a combination of the above premises and information gathered from various use cases in the EU, research papers, company websites and other structures in Germany.

3.3.1 Cost Structure

For a realistic estimation, we have split the costs into fixed costs for investments and variable costs, depending on the size of the waste management company.
Fixed costs are driven by the costs of developing and building the content management system. The development of such a product can be modified to meet the needs of the waste management company, but for the minimum viable product, the functions across the system are expected to be similar for all waste management companies. Based on industry average, the cost for building such a system range from 10,000 € up to 100,000 €. A conservative estimate to build such a system to meet the average expected needs of the customer is 20,000 €. This also includes server and maintenance costs for the first year, as the data requirements are estimated to be within the price for the servers.

Variable costs mostly include the hardware i.e., the NFC chips and the handheld scanner, which depends on the purpose, quality, and manufacturer of the sensor. On average, each NFC chip can cost between 0.10-1€, depending on the scale and quantity requirements. Similarly, the handheld scanner can cost between 50-100 € per scanner. The quantity requirements will depend on the number of households and bins managed by the waste management company and the number of trucks required. Each truck will be given one handheld scanner.

As the content management system will be maintained and managed by the Waste Wizards, the compensation will depend on the success of the company. Each member is willing to work for the company against equity for the first year, until the company breaks even and successfully manages to churn out reasonable revenue and profit. Thereafter, once the product is a success, further compensation and salary will be estimated and calculated. All these costs are included in the estimate to build a content management system prototype (CMS).

As these are the only running costs to establish the technology, other costs like employee costs, office leasing costs, etc. are not included in this estimate. Along with this, the development of the CMS will be outsourced to a reputable development company in India, a software development hub, to minimize the costs.

3.3.2 Case Study: Straubing

Costs

For feasibility and testing, the calculations are based on deploying this product to the city of Straubing. The estimated population of Straubing is 50,000. The average household size in Germany is 2, thus the number of households in Straubing is estimated as 25,000. As the city is a mixture of apartment complexes and single-family homes, it was estimated that each bin is shared by 5 households. So, it was calculated that there are 5,000 bins that need to be collected in the city of Straubing, which means 5,000 NFC chips will be required. The price of the NFC chips was calculated at a conservative cost of 0.25 € per chip.

For collection, on an 8-hour shift, it is expected that each waste management employee can perform 200 scans/day. This is calculated based on the assumption that it takes between 1-2 minutes to check, scan, and collect the waste at every collection point, which includes driving time and other time spent for managing the operations. Based on this, 20 trucks will be required to collect all the waste in the city of Straubing, which means 20 scanners will be required. The price for each scanner is estimated to be around 75€.
Based on the above assumptions, the cost for the initial deployment of the technology is estimated as per table 7 below:

Production Cost				€ 22,750.00
Variable Costs				
Products	Price		Units	Total Price
NFC	€	0.25	5000	€ 1,250.00
Scanners	€	75.00	20	€ 1,500.00
Fixed Costs				
CMS development (Includes maintenance, server, employee costs)				€ 20,000.00

Table 1: Costs

Revenue Stream

The main criterion initially for the company is to offer an affordable solution to the customer. According to the interview we conducted with ZAW-Straubing, a waste management company in Straubing, they spend up to €300,000 per year additionally for rectifying the incorrect waste sorting. Of this, they spend €50,000 on manually sorting the waste. Although the solution provided by "WasteWise" will not completely solve this problem, it will help reduce these costs and the data will be useful for analytics.

Based on this, a one-time implementation fee of €1,000 will be charged to each waste management company. This fee is for comprehensively setting up the system across the waste management company and training the employees to use this system. Along with this a monthly subscription fee of €0.05 per household will be charged for all the households managed by the company. This will be charged by the waste management company directly to the households.

The hardware costs estimated above will be provided to the waste management companies at cost. These low prices for initial deployment are to incentivize the company to implement the CMS.

The revenue stream is show in table 8 below:

Revenue Stream (for Straubing)	€	18,750.00
Implementation Fee	€	1,000.00
Hardware-Costs	€	2,750.00
Yearly Subscription fee (All household)	€	15,000.00

Table 2: Revenue stream

Break Even Analysis

Based on the above calculation, the break-even point is estimated to be 26,207 households. As the business is expanded further to larger cities like Berlin (population: 3,275,000) or Munich (population 1,470,000), the revenue stream will continue to increase and will give room for further expansion of the operations while maintaining a healthy profit line.
The estimations for these are given in graph 9 below:

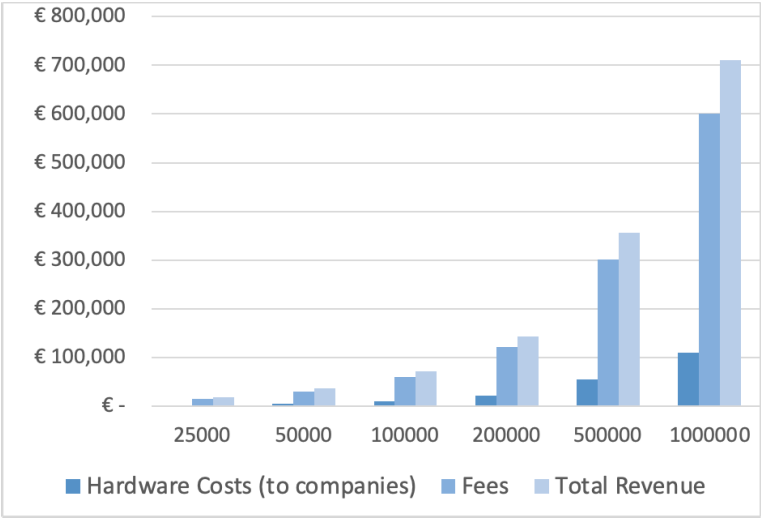

Table 3: Break-even Analysis

This graph shows the possible revenue based on household size. As the size of households managed by different waste management companies can differ, it is difficult to establish the revenue stream based on waste management companies.

Note: This represents a conservative estimate. As “WasteWise” continues to grow and expand, newer avenues for revenue and other costs which cannot be predicted now will come into the picture. Thus, a more detailed break-even analysis is not further investigated.

4 Outlook

The following section details the outlook for Waste Wizard. Section 4.1 explains the benefits and involvement of the different relevant stakeholders, thus making it a feasible solution to tackle current waste problems. Section 4.2 provides a vision for the future, the multi-staged go-to-market strategy is described, challenges are addressed, and solution strategies are proposed. Utilizing this information, the future vision can be mapped.

4.1 Stakeholders

Numerous different stakeholders are involved in the implementation of Waste Wizard. To develop a clear picture, they are all presented in detail. The general overview includes Waste Wizard itself, the technical stakeholders, the public and legislative stakeholders, the private households, and municipalities. By being involved, each stakeholder contributes to improved waste management practices, resulting in lower landfill rates.
Waste Wizard should emerge as a sustainable and lean startup. It must be guaranteed that the triple-bottom-line approach is the core value. Accordingly, environmental and social aspects are considered as equally or more important than economic aspects. Therefore, whilst Waste Wizard can ensure that the economic factors are used to invest in different technologies, these investments must contribute to closing resource loops, particularly in waste management. In part 3.3 of the economic analysis in the case study on Straubing, it is clearly stated that breaking even is already possible for a small town.
To achieve the ambitious goal of positively impacting the stakeholders and closing gaps in the circular economy, working closely with waste management companies is necessary. On one hand it is distinguished between waste collection companies that can directly use the solution “WasteWise” and feed data into the database. On the other hand, there are waste recycling companies that sort the collected waste in the second step and process the organic waste, for example. This subdivision is vital because there are regional differences. In some regions, both tasks are performed by one company, while in other areas, there are several companies. In summary, waste collection companies can save time with Waste Wizard and therefore increase their efficiency rates, which results in monetary benefits. While this holds true for waste collection companies, waste recycling companies can save money and obtain a higher markup on the resale of the material, for example, for biogas and garden soil, due to the higher quality of the biowaste (BMUV, 1998).
The social pillar includes municipalities and private households. Through flagging, private homes are made aware that they should separate their organic waste better. Thus, a data-based feedback loop is used to educate private individuals. The maxim is the privacy of garbage and is guaranteed by creating a unique ID, which is explained in more detail in section 1.2. This educational function is also in the interest of legislation and governance as laws are most effective if the population understands them (Boulanger & Bréchet, 2005).
The technical stakeholders include essential software and hardware providers. The required hardware includes NFC chips and scanners in the form of wearables, while the software includes content management systems, databases, and the application, original equipment manufacturers are contracted for this. Waste Wizard has a strong partner for the NFC chips, Infineon, our challenge partner and support provider. This partnership engenders benefits on both sides. Infineon can expand its product portfolio, and Waste Wizard has a reliable high-tech business partner that provides knowledge, hardware (NFC chips), as well as software in terms of data security.

The final pillar is the environmental pillar which contributes to the transition to a circular economy. This is achieved by improving the separation of organic waste with the help of Waste Wizard. As mentioned, the end-product biowaste has a significantly higher quality (Gautam & Agrawal, 2021; Hannah Ritchie & Max Roser, 2018). This makes the whole system more efficient and, especially in countries with more severe waste management problems than Germany, this also reduces landfill rates (Misra & Pandey, 2005; Gautam et al, 2021; Shen et al, 2020).
In conclusion, Waste Wizard is a multi-faceted approach that involves many stakeholders in the waste separation and disposal process. Waste Wizard can thus positively impact all stakeholders and promote sustainability in different areas. It is a small, albeit essential, piece of the puzzle in the circular economy.

4.2 Vision for the future

The objective of Waste Wizard is to mitigate the presence of plastic in bio-waste. To translate this vision into a tangible and implementable solution, developing a go-to-market strategy assumes critical significance. Therefore, the go-to-market strategy can be subdivided into three main steps (John Moore, 2020). The first step focuses on the market penetration in Germany, and the second focuses on Europe. The third step strives to leverage the positive impact of Waste Wizard globally and hence can be concluded as the expansion stage.
The first step of the go-to-market strategy involves the Waste Wizard pilot project. The focus here is on feasibility testing. A small town such as Straubing is suitable for this. Changes can be made here cost-effectively on a small scale. Break-even and profitability are of secondary importance here. If the pilot project is successful in improving waste collection and management in a small German town, it can be transferable to other companies within Germany. The second phase can be initiated once the German market is sufficiently saturated, vital partners have been identified, and the number of waste collection and management customers allow for a healthy profit.
The second phase aims to transfer the expertise from Germany to other cases. The European countries are particularly suitable for this. For example, Italy has similar legislation, nevertheless, it is poorly implemented. This leads to significantly higher landfill rates than in Germany. Accordingly, this results in a market and impact potential for Waste Wizard. The overarching goal is to revolutionize Europe’s waste management system and spread the applied approach of circularity throughout Europe. It would provide Waste Wizard with valuable market insight in addition to a) the feedback for feasibility and b) a solid financial base for further expansion. Especially in Europe, the leverage could be increased by making use of the current infrastructure and resources that are already available as the European Social Funds, the European Regional Development Funds, the European Agricultural Fund for Rural Development, and LIFE – Circular Economy and Quality of Life Biodiversity (European Commission, 1957a, 1957b, 2005, 2022).

Figure 7: The go-to-market strategy

The expansion stage follows successful market penetration in Europe. Global expansion focuses on other countries outside Europe with higher landfill rates. This international focus is purely impact driven. The main idea is to leverage the effect of lowering landfill rates for countries with significant landfill problems. Since Waste Wizard focuses on plastic segregation, it is highly relevant to keep the global picture in mind, to a great degree shifting attention to the countries that create the most plastic waste.

The quantification of the problem is presented in the graphic below. This shows visually where Waste Wizards can have the highest impact. Therefore, the priority is to apply the solution to the Philippines, then to Timor, and finally Sri Lanka. The map visually shows the per capita plastic waste entering the ocean in 2019. It serves as an annual estimate of plastic waste for each country. However, it is essential to note that this total figure does not include plastic waste exported to other countries, which poses a higher risk of ocean entry (Gautam & Agrawal, 2021; Hannah Ritchie & Max Roser, 2018).

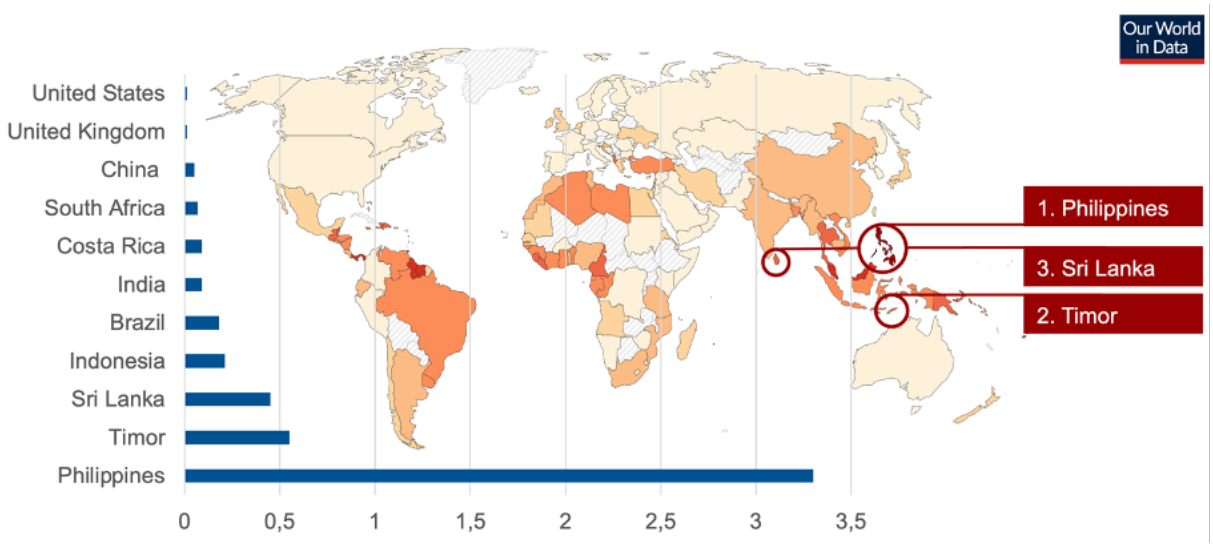

Figure 8: Author's adaptation from Hannah Ritchie & Max Roser, (2018). The global map of plastic waste emitted to the ocean per capita (in kg) by 2019

The approach suggested is covered by solutions that, by reaching phase three, will be used daily, therefore lowering environmental impact. The financial power gained in the previous phases provides the potential to apply Waste Wizard´s lean startup model and expertise in economically weaker regions. In conclusion, Waste Wizard´s solution uses and combines many existing technologies to create synergies. These are used to boost the global circular economy step by step and positively transform waste management on the global scale -leaving no waste behind.

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Appendix:

B) Business Model Canvas