CBI4I Final Report

Detecting Lithium-Ion Batteries in Waste Transfer Stations

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Research Report: Understanding the problem

Our challenge: Infrastructure and Industrialization

The purpose of the CBI4AI program is to tackle a problem related to one of the Sustainable Development Goals (SDGs) by the means of a challenge-based project focused on AI and creativity. The SDGs are a collection of 17 global goals set by the United Nations in 2015[1]. They cover social and economic development issues including poverty, hunger, health, education, climate change, gender, equality, water, sanitation, energy, urbanisation, environment and social justice.

In our case, we focused on SDG number 9, Infrastructure and Industrialization. The purpose of this SDG is to build resilient infrastructure, promote sustainable industrialization and foster innovation. Inclusive and sustainable industrialization, together with innovation and infrastructure, can unleash dynamic and competitive economic forces that generate employment and income. These play a very important role in introducing and promoting new technologies, facilitating international trade and enabling the efficient use of resources.

Understanding the challenge

Initially, it became apparent that we lacked knowledge and experience concerning practical sustainability problems in industries and infrastructure. Therefore, during the first weeks of the course, each of us separately researched topics related to these. At this point we were not thinking about any solution, we were mainly focusing on gaining some base knowledge.

After some research we realised that the Covid-19 pandemic has revealed the urgent need for resilient infrastructure, as in many countries, critical infrastructures remain far from adequate, despite the exponential economic growth and development that some of these countries have experienced in the past years.

However, we concluded that this domain was extremely broad, hence we had to granularize the areas where we wanted to focus, or else we could spend too much time trying to understand all the details of such a big sustainable development goal. Mostly, our attention shifted towards problems that are growing in nature; Challenges that might be present already but not yet to a scale that they garner the attention they need, although that in the future they might pose severe dangers.

[1] "THE 17 GOALS - Sustainable Development Goals - the United Nations." https://sdgs.un.org/goals. Accessed 20 Jun. 2022.

Brainstorming problems

We started brainstorming problems, however, the way we did it was different than usual. Each of us was given some post-its, and we had five minutes to write a problem we thought was related to the industry and infrastructure domain. After the five minutes expired, we gave our post-it to the person on our right, and then they had to continue iterating on the problem that we had defined.

This way, after twenty-five minutes, we have five post-its and each of them was filled with different comments elaborated by all the members of the group regarding a single problem. This turned out to be very useful, as it enabled each problem to be analysed from different points of view. For instance, some of the problems stated were related to:

- Improper recycling of heavy metals.
- Food wastage.
- Poor supply chain tracking in the clothing industry.
- Optimization of ship containers.
- Etc.

Thanks to the initial research performed during the first weeks, together with this activity, we selected some problems to focus on. This was very useful, as it avoided us getting lost in the vast amount of problems that can be found in the infrastructure industry.

To reach a consensus regarding what exact problem we wanted to focus on, we did another group activity. We pasted all the post-its to a whiteboard and started discussing together which of them we thought were more relevant. Each of us had the opportunity to present and reflect on ideas from others.

This process resulted in the selection of two domains, food wastage and recycling of heavy metals. We spent a few weeks deciding which one we wanted to select, as both had very interesting challenges to tackle.

However, we finally decided to focus on the recycling of heavy metals, particularly, the recycling of ion-based batteries. We thought that, as the number of devices containing ion-based will exponentially grow in the future, and knowing that the recycling of these devices is very low, we could tackle a very important problem with a high impact on the future.[2][3]

[2] "Global lithium-ion battery capacity to rise five-fold by 2030 - Wood ...." 22 Mar. 2022, https://www.woodmac.com/press-releases/global-lithium-ion-battery-capacity-to-rise-five-fold-by-2030/ . Accessed 20 Jun. 2022.
[3] "Solving Battery Production Growth Challenges - Emerson ...." 14 Mar. 2022, https://www.emersonautomationexperts.com/2022/sustainability/solving-battery-production-growth-challenges/. Accessed 20 Jun. 2022.

Nevertheless, recycling is also a huge industry itself, so we had to repeat and iterate on the process to find a niche inside this industry that we could focus on, allowing us to have a higher chance at actual impact.

Waste industry

The waste industry represents the last step in the lifetime pipeline of all products. It is in charge of discarding or recycling the things that are no longer useful or could be transformed into new products. After researching this industry, we discovered that waste is processed as follows:

- When people decide to throw away a product, it ends up in the garbage can, which is picked up by the garbage truck.
- The garbage trucks proceed to transport all waste to the waste transfer stations, which act as a hub for garbage.
- The garbage is then classified and transported to different places according to its type, for instance, landfills, waste-to-energy plants or recycling centres.

But, how could we link the waste industry with the recycling of ion-based batteries? We discovered that when ion-based batteries (which can be found as batteries, or inside any electronic device), are improperly discarded, ignoring using the best practices, these can generate serious problems: Because of a various possibilities these batteries can get damaged or encounter liquids in the bin thus causing chemical leakage, fires or even explosions as a result from short-circuit.[4][5]

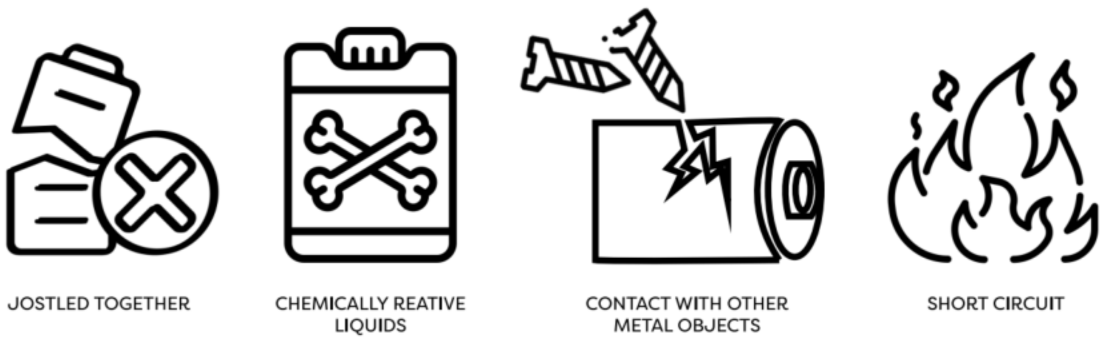

Figure: Effects of improperly discarding batteries

[4] "An Analysis of Lithium-ion Battery Fires in Waste Management and ...." 10 Jul. 2021, https://www.epa.gov/system/files/documents/2021-08/lithium-ion-battery-report-update-7.01_508.pdf. Accessed 20 Jun. 2022.

[5] "Environmental impacts, pollution sources and pathways of spent ...." 13 Oct. 2021, https://pubs.rsc.org/en/content/articlehtml/2021/ee/d1ee00691f. Accessed 20 Jun. 2022.

Conceptual development: Finding a solution

Problem statement

Lithium-ion-based batteries (LIBs) that have ended up in the wrong bin, are not sufficiently detected and segregated, which causes an increasing amount of fires and explosions in recycling centres and landfills, negatively impacting the environment and human health and safety.[6][7]

This problem is more serious than it might appear to be at first. For instance:

- In a European country like Austria:
  - Almost 1000 tonnes of ion-based lithium batteries end up in the wrong garbage.
- In the UK:
  - There are 201 fires on average in waste plants produced by improperly discarded ion-based lithium batteries.
- In the US:
  - There have been more than 240 waste fires across 64 facilities in 28 different states.
  - There have been more than 25 fires in landfills in the last for years, requiring approximately 8.5 million $ in restoration.

So we ended up realising that the improper discarding of batteries can cause multiple problems, some of them being very serious, especially fires in landfills or waste transfer stations. The consequences derived from fires can impact all 3 dimensions of sustainability:

Figure: Three dimensions of sustainability

[6] "An Analysis of Lithium-ion Battery Fires in Waste Management and ...." 10 Jul. 2021, https://www.epa.gov/system/files/documents/2021-08/lithium-ion-battery-report-update-7.01_508.pdf. Accessed 20 Jun. 2022.

[7] "Environmental impacts, pollution sources and pathways of spent ...." 13 Oct. 2021, https://pubs.rsc.org/en/content/articlehtml/2021/ee/d1ee00691f. Accessed 20 Jun. 2022.

- **Ecological**: Waste fires can have direct and indirect consequences on the environment. For instance, fires can directly affect the land or even have long-term negative consequences, such as the leakage of polluting chemicals into the soil.[8]
- **Economical**: Incidents with waste can derive from very high monetary amounts required for recovery and also affect the waste industry.[9]
- **Social**: Fires can directly affect villages or workers in the stations, and even can cause indirect effects on people surrounding the areas, such as pollution, contamination, soil pollution, etc. Moreover, the health of workers within the industry is directly put at risk, potentially coming into contact with these fires and/or explosions. [10]

Ideation phase

Once we had found the exact problem we wanted to focus on, we had to start with the ideation phase. As the problem evolves around improperly discarded batteries, our first and most intuitive approach was to ideate some kind of system which was able to detect and extract these batteries in the waste bags.

However, the first dilemma was: where can we implement this system? We had different ideas at first:

- **In the garbage cans**: We thought that, as this is the first point in the pipeline of waste disposal, it could be a good point to develop a device which could detect batteries. However, as there are probably millions of garbage cans, we would require millions of devices as well as the infrastructure to deploy and control all of them. Moreover, these batteries could be detected, but how could they be extracted? We would need thousands of workers. This option was not viable.
- **In the garbage trucks:** Another approach was the garbage trucks, as each of these can daily pick up garbage from thousands of cans, hence it could be more scalable. However, we had problems visualising a cheap and affordable system that could be implemented in the trucks. Deployment of an intelligent system would be complicated.
- **In waste transfer stations:** We realised waste transfer stations act as a hub for waste, as all garbage from cans is dumped by the trucks in these stations, before transportation to other places like landfills or recycling facilities. Moreover, implementing a system in these stations would be scalable and easier than with the other two approaches.

[8] "An Analysis of Lithium-ion Battery Fires in Waste Management and ...." 10 Jul. 2021, https://www.epa.gov/system/files/documents/2021-08/lithium-ion-battery-report-update-7.01_508.pdf. Accessed 20 Jun. 2022.
[9] "An Analysis of Lithium-ion Battery Fires in Waste Management and ...." 10 Jul. 2021, https://www.epa.gov/system/files/documents/2021-08/lithium-ion-battery-report-update-7.01_508.pdf. Accessed 20 Jun. 2022.
[10] "An Analysis of Lithium-ion Battery Fires in Waste Management and ...." 10 Jul. 2021, https://www.epa.gov/system/files/documents/2021-08/lithium-ion-battery-report-update-7.01_508.pdf. Accessed 20 Jun. 2022.

Validating the Problem

Next to various online academic sources explaining the problem, personal contact with experts to validate our perception of the challenge was needed. Therefore, a various group of people were contacted: Waste Agency Workers, Environmentalist, Battery Production Companies, Battery Recycling Companies and TeraHertz-sensor Production Companies (for the solution, presented later). Most connections were rather brief, but conforming to our vision on the problem. However, one stood out as exceptionally informative and interesting: A phone call was organised with Maria López Blanch from the Circular Economy Area of the Department of Climate Action, Food and Rural Agenda of the Waste Agency of Catalonia. She gave us inside information about the problems present in the Catalonian waste management system, confirming our beliefs as well as presenting some of the broader problems such as the general lack of innovation of any kind in battery management in Spain as well as the lack of awareness world-wide in this ever-growing industry. She made clear that the potential risks with the inevitable battery production growth cannot be understated and that solving it would not only prevent disaster, it would help the circular economy, further positively impacting both the climate and social endeavours.

Linking with Attract Technologies

The problem calls for a battery detection system. Currently, such systems exist based on X-ray imaging supported by AI, reaching detection and classification rates of about 91 %. [11] This would allow for a first iteration of our project: A X-ray camera on the roof of a transfer station, selectively imaging the garbage present in the space. This, together with general cameras for more detailed spatial data, would make up the input for an AI-based system, detecting where between the garbage, the improperly discarded batteries are. The software would send this spatial information to the local workers to indicate where to find the respective garbage bags, for example in the form of a heat sensor, displayed in augmented reality glasses. Note that the X-ray images would have to be taken in a selective and controlled manner, because of the well known health concerns posed by X-ray radiation.

This is where Terahertz (Thz) imaging technology comes into play. Radiation in this spectrum has the unique ability to penetrate a variety of materials (including plastic), which enables imaging of the material's internal structure. THz radiation enables non-ionizing and contactless inspection of various materials for in-line supervision of industrial processes. In the THz range, metals have a skin depth in the nanometer range and, therefore, they are highly reflective.[12] Thus the internal structure would most likely not be visible, as batteries are often cased in Ni-coated steel, which limits the capabilities compared to X-ray Transmission (XRT) which is sensitive to the internal structure of an object.[13] However, an AI could be trained to detect, based on shape recognition, which metal objects potentially contain batteries or are batteries themselves, thus broadening the scope of target objects.

[11] "Detection and recognition of batteries on X-Ray images of waste ...." https://www.sciencedirect.com/science/article/abs/pii/S0921344920305619. Accessed 20 Jun. 2022.
[12] "Terahertz Detection of Wavelength-Size Metal Particles in ...." 11 Dec. 2015, https://ieeexplore.ieee.org/document/7353225. Accessed 20 Jun. 2022.
[13] "Detection and recognition of batteries on X-Ray images of waste ...." https://www.sciencedirect.com/science/article/pii/S0921344920305619. Accessed 20 Jun. 2022.

However, this would restrict the solution to waste that should not contain metal, such as the green waste and plastic waste. One of the emerging concepts in generating more accurate, cheaper and smaller sensors bases itself on graphite. The ATTRACT program has a project looking into this called GRANT.[14] It aims to develop technology that leads to optimised, affordable and industrialised TeraHertz sensors, based on graphene and plasmonics. The project description clearly states its possible use in future detector systems: "*These light and small cameras will be then assembled and interfaced together with portable and energy efficient THz sources to realise portable and integrated THz inspection systems. Indeed, opposite to the imaging system operating with near infrared and visible light, THz natural sources are too weak to be used for imaging. The so conceived light, portable and autonomous THz inspection systems will equip unmanned vehicles and drones enabling a low cost and effective monitoring in many different fields, from large infrastructure such as bridges, railways, buildings to the status of cultivated field and the maturation of crops, with a significant impact on the society wealth and safety.*"

Although TeraHertz seems like not the ideal option, it is warranted that more research has to be performed in this field. There might be some underlying properties of batteries that help TeraHertz detection and classification that are not yet explored. When proposing the idea to a company specialised in making TeraHertz imaging systems, it was noted that: "We can hardly say that applications associated with NDT inspection of items consisting specifically of your combination of materials (Lithium inside batteries) have been sufficiently studied by our experts. ... The devil is always in the details. Needless to say, each application may have its own peculiarities, each material has its own transmission ratio and behaves differently in THz light i.e. has its unique absorption index, thickness (the most critical dimension), internal structure/configuration and many other aspects that may be critical for successful inspection."

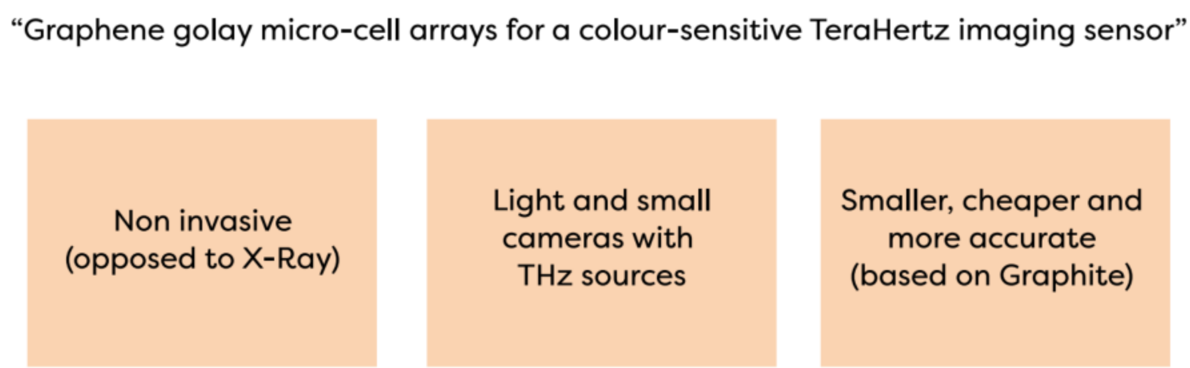

Figure: Advantages of THz imaging/sensing.

[14] "Graphene golay micro-cell arrays for a colour-sensitive TeraHertz ...." https://phase1.attract-eu.com/showroom/project/graphene-golay-micro-cell-arrays-for-a-color-sensitive-terahertz-imaging-sensor-grant/. Accessed 20 Jun. 2022.

The final idea/solution

Explanation

Our final idea was to develop an intelligent detection system based on computer vision (AI), cameras and sensors to detect garbage bags containing improperly discarded lithium-based batteries in waste transfer stations.

The following diagram illustrates how our system works:

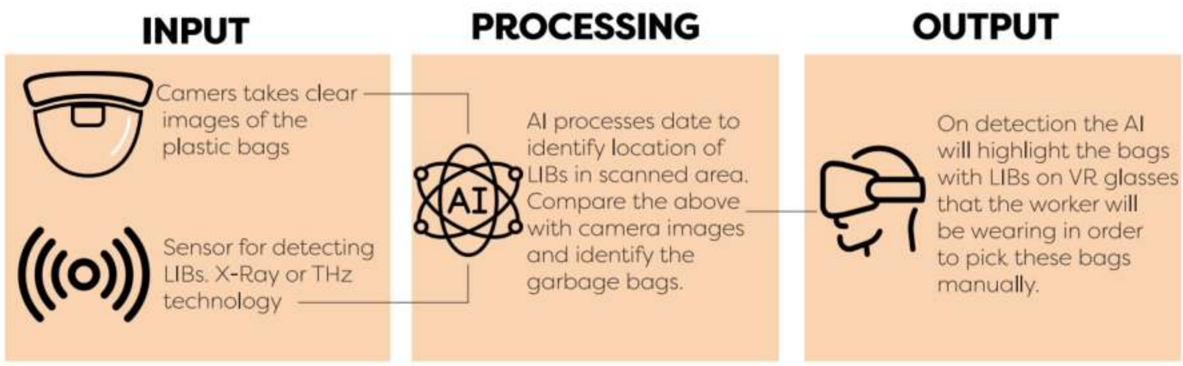

Figure: System pipeline.

As it can be seen, we have divided the process into three blocks:

- **Input**: Data from the environment is obtained through cameras and sensors. This includes images related to the physical disposition of bags and input data obtained from the THz sensing/imaging.
- **Processing:** The input data, images and senses, is leveraged together with an AI system to identify the exact location of the batteries in the waste bags.
- **Output:** When detecting the LIBs, the AI will highlight them in an augmented reality system. This will be possible thanks to the collection of input data related to the actual physical disposition of bags.

As explained before, this system would be implemented in waste transfer stations, as these act as a hub for all the collected garbage. This way, we could avoid LIBs ending up in landfills or other waste facilities and causing any harm. Hence, by tackling the problem in waste transfer stations, we avoid it to happen in all the subsequent locations.

Figure: Implementation of the system in waste transfer stations.

Our idea is not only scalable, as it needs to be only implemented in waste transfer stations, but it is also effective. Leveraging THz sensing/imaging with AI, we are able to detect batteries improperly discarded and these can be easily extracted thanks to the augmented reality representation of the space. Moreover, it is all done in a non-invasive way for the station workers, as these technologies are not harmful to human life (as opposed to X-ray-based systems).

Design elements

We created an augmented reality simulation of how our system would actually work:

Figure: Prior to scanning.

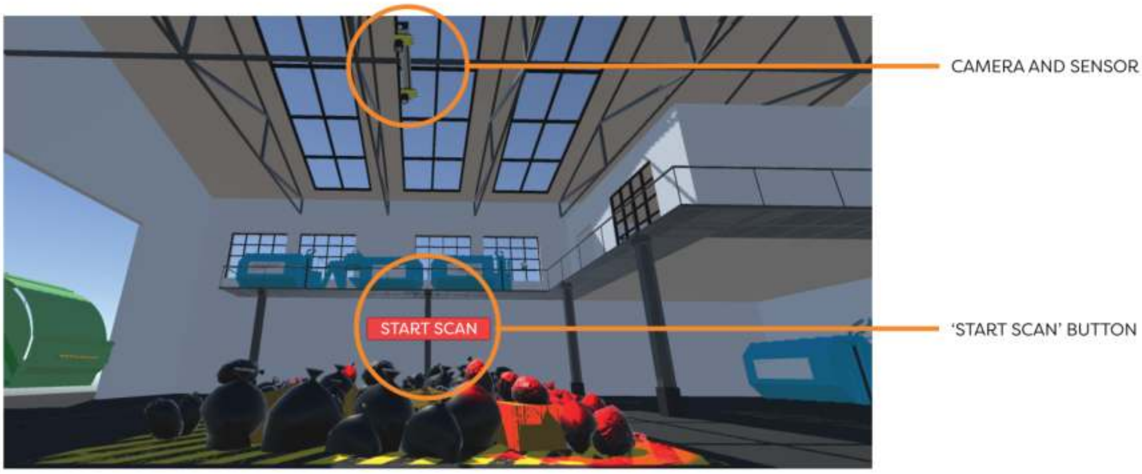

Figure: Implementation of the system in the waste transfer station.

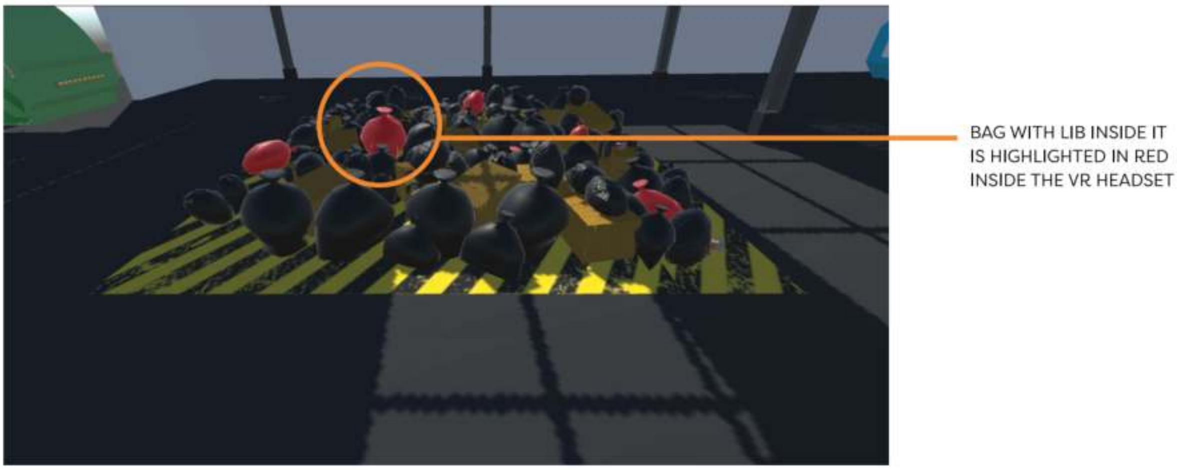

Figure: Highlighting the waste bags containing LIBs.

We actually presented our prototype on demo day, enabling our classmates and professors to experience how the actual system would work. By using the VR glasses, they could experience the same as a waste transfer station worker would when extracting the batteries:

Figure: Prototype on demo day.

Impact Model and Map

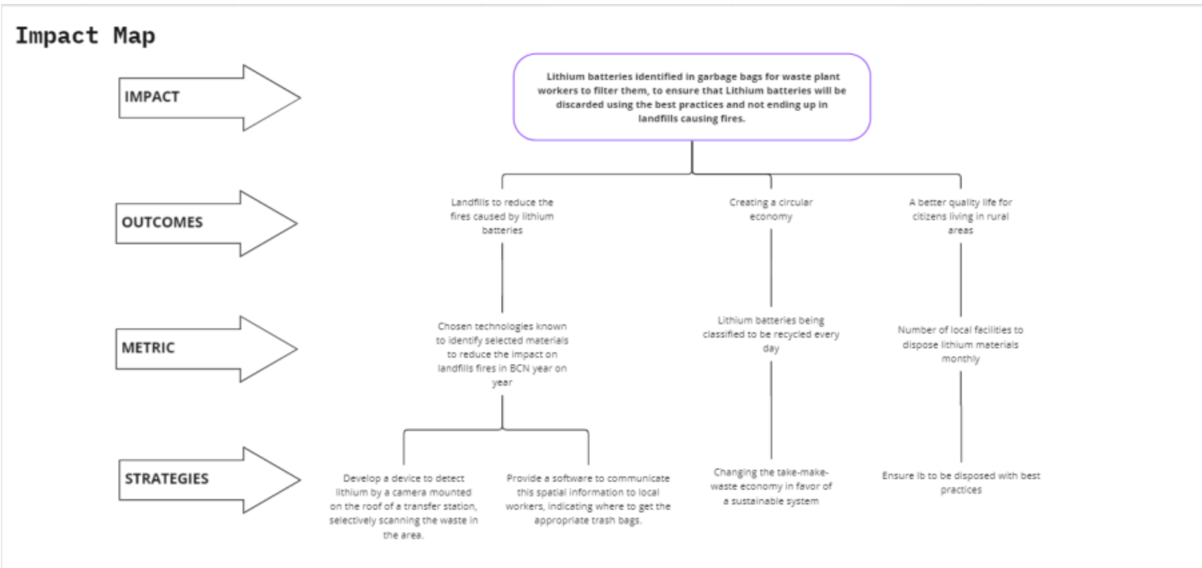

Figure: Impact Map

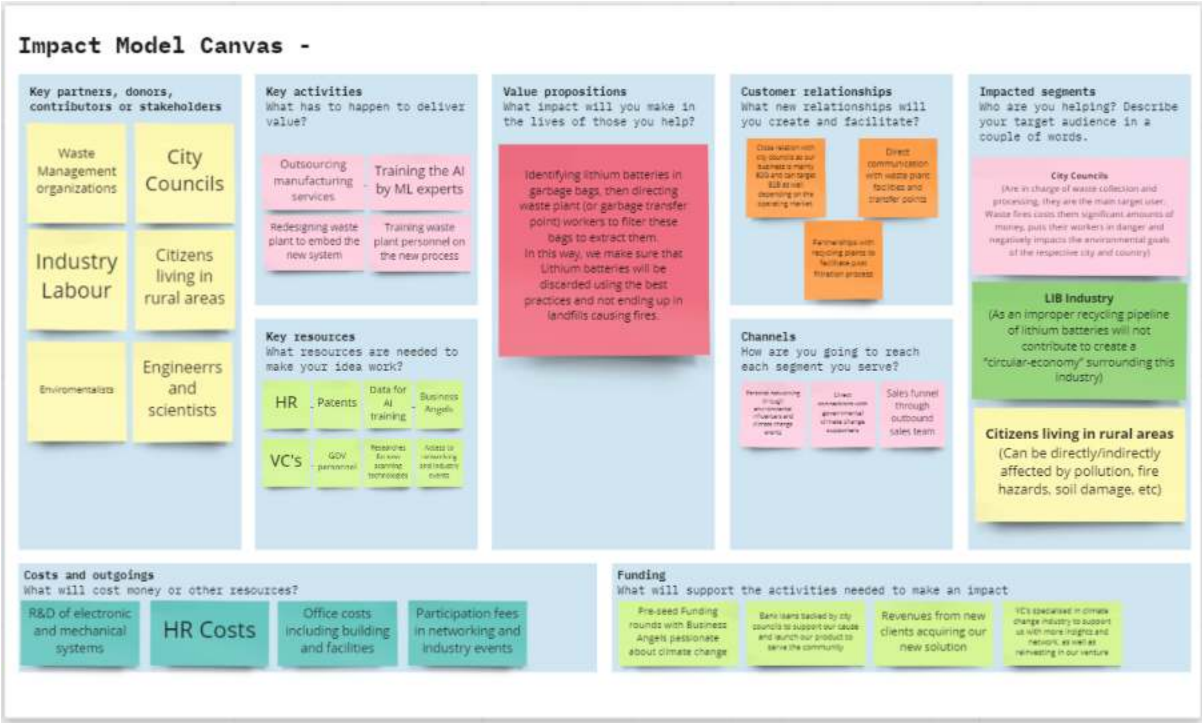

Figure: Impact Model Canvas

<u>Conclusion</u>

We were challenged to explore AI-based sustainable innovation in the context of SDG number 9: Industry, innovation and infrastructure. After extensive research and validation, we came up with the following concrete problem statement: *Lithium-ion-based batteries (LIBs) that have ended up in the wrong bin, are not sufficiently detected and segregated, which causes an increasing amount of fires and explosions in recycling centres and landfills, negatively impacting the environment and human health and safety.*

In order to help solve this problem present in the waste industry, a solution is proposed to develop an intelligent detection system based on computer vision (AI), cameras and sensors to detect garbage bags containing improperly discarded lithium-based batteries in waste transfer stations. Technology would be based on TeraHertz Sensors, on which further research is needed. ATTRACT might play an important role in this as several projects consider the topic of TeraHertz technology, with as most fitting and exciting the GRANT one, developing affordable and optimised Graphene-based TeraHertz Sensors.