The connected, sustainable and inclusive society – IoT implementation in a Swedish municipality

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Abstract. The Internet of Things (IoT) is expected to transform the way we live, work, and learn. Using IoT could thus be a game-changer for municipalities towards sustainability. The Swedish municipality of Södertälje strives to develop IoT concepts and use open data for a sustainable and inclusive society. The goal of this study was to explore how IoT can enable route optimization and placement planning for increased operational efficiency. The goal was also to enhance the knowledge of the environmental and social benefits of IoT systems in the waste collection system in Södertälje. The analysis is based on Life Cycle Assessment (LCA) and interviews. The results show a minor climate change impact for the IoT solutions in the overall smart waste collection system. The major climate impact contributor was instead associated with the trash bags used. Additionally, the study showed that the performance of the system relies on smart planning of the operations and the transportations.

1. Introduction

Internet of Things (IoT) is expected to transform the way we live, work, and learn [1]. As a term, IoT encapsulates a wide range of systems including hardware, software, and sensory equipment. The push towards sustainability and building smarter cities and societies has for many years engaged the public sector with IoT solutions [2]. However, we know little about the climate impact of IoT solutions and the practical operations of using IoT in the public sector. The Swedish municipality of Södertälje wants to develop IoT concepts and use open data for a sustainable and inclusive society. Their ambition is to drastically reduce climate impact and achieve net zero greenhouse gas emissions by 2030. Towards these goals, the waste disposal sector in Södertälje municipality plays a crucial role, and also implies a need for greater involvement and greater commitment from citizens and companies. To this end,

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a low-power Long Range Wide Area Network (LoRaWAN[1]) has been built in Södertälje to collect sensor data from IoT devices. LoRaWAN comprises a set of standards intended for machine-to-machine communication where battery-powered devices exchange very little data over an extended period of time. In practice, digitalizing the waste collection system in Södertälje entails attaching sensors to the top of the housing of existing litter bins scattered around the city centre. Each sensor periodically relays the volume of waste in the litter bin to a back-office system via a LoRaWAN network. Workers can then check the waste levels in each connected litter bin using an app in their smartphones – theoretically permitting them to only collect the trash when needed as opposed to following a fixed schedule based on guesswork.

The focus in this paper is 160 IoT litter bins capable of measuring filling degree. The municipality aims to enable route optimization, planning, better placement of litter bins, and reduced transportation and costs. The current study is a collaboration between Södertälje Municipality, Telge Recycling, RISE Research Institutes of Sweden and Umeå University, funded by Sweden's Innovation Agency (Vinnova). The study aimed to investigate how IoT-generated data can benefit the creation of both external civic value and internal organisational value in Södertälje municipality's transition to a sustainable city. The analysis is based on a Life Cycle Assessment (LCA) of the IoT litter bins and 12 interviews with participants with different roles in the overall Södertälje waste management organisation. In addition, an analysis was conducted on the municipalities' activities in relation to their ambitions of having a citizen dialogue. Based on these data, the paper reflects on possible gains for the municipality, specifically environmental, process, digitalization and social gains.

2. Environmental assessment of the IoT system in Södertälje

An LCA was conducted in Jan-Sept 2021 to evaluate the current situation in regard to the environmental performance of the IoT system in Södertälje, as well as the waste collection system with an IoT solution. The LCA study has been conducted following the ISO standards 14040-44:2006, which comprises four usual phases. First, the goal and scope were defined together with the Södertälje municipality, their IoT suppliers and project partners. The goals of the LCA study were: (1) To estimate the environmental impact of the **IoT system** and **waste collection system** (without IoT system) in Södertälje and find out the hotspots within the system in a life cycle perspective (2) To compare the current with the **future waste collection system** (including IoT system for planning and service). The system boundary comprises two different systems: IoT system and waste collection system. In the IoT system, the activities of the production of raw materials, manufacturing, use, end of life of electronics parts (sensors and gateways), internet network, and cloud services were evaluated. However, the users' devices (e.g. computer or mobiles) that are used for assessing data in the server were not considered as it is not the primary function of the devices. For the waste collection system, the activities, such as the transportation and plastic bags used, were studied. Since there is no change on the litter bins, as well as on handling the collected waste, these activities were not included. Two functional units were considered to correlate with the goal of the study: (a) one year of IoT system service, which consists of 160 sensors, 12 gateways, three units computer for cloud service, one unit computer for server, as well as the use of internet (b) one year of waste collection system service (with/without IoT system). The inventory analysis was conducted, and data were collected through numerous telephone meetings, email conversations, and literature review [3, 4, 5]. The impact category considered was climate change impact and the system has been modelled in SimaPro software using the Ecoinvent 3.5 database [6]. Lastly, an interpretation meeting was conducted to present the

[1] https://lora-alliance.org/about-lorawan/

LCA results to Södertälje municipality, their suppliers, as well as project partners and the inputs from the meeting were used for a scenario analysis to envision current and future scenarios.

2.1 The environmental assessment of the current system

The climate change impact of the IoT system solution in Södertälje was estimated to be about 120 kg CO_2eq per year, which mainly originates from the gateways (50%) and the sensors (27%) and the use of the internet (23%). However, the climate change impact of the current waste collection system in the city centre of Södertälje contributes with approx. 12 t CO_2eq per year, which mainly originates from the use of fossil-based plastic trash bags (96%) and the Hydrotreated Vegetable Oil (HVO) based transport (4%).

2.2 Scenario analysis for future smart waste collection system

To compare the current with the future waste collection system, scenario analysis was used. At the starting point of the study (scenario 1, Fig 1), the results are based on assumptions, where the transport fuel was based on diesel and the trash bags are made of 80% recycled low-density polyethylene (LDPE) and 20% fossil LDPE. Results showed that the transport and recycled plastic trash bags contributed a similar amount of CO_2 emissions (~50%), while the IoT system had insignificant impacts (3%). For the next step (scenario 2, Fig 1) of the study, the results are based on direct data of the current system. The results were based on HVO and fossil trash bags, which resulted in 11.5 t CO_2eq for fossil bags and 380 kg CO_2eq per year for transport and 120 kg CO_2eq extra for the IoT system. In the last step (scenario 3, Fig 1) of the study, the results are based on future assumptions, which includes using HVO fuel, but no trash bags for waste collection. This resulted in 120 kg CO_2eq for the IoT system and 380 kg CO_2eq for the transport and no emissions for trash bags.

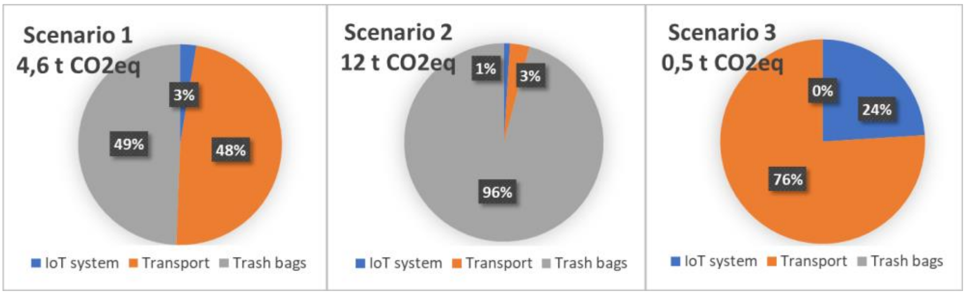

Fig. 1. Distribution of CO_2 eq in the pre-study (scenario 1), post-study (scenario 2), and future study (scenario 3).

For an improved environmental performance of the waste collection system, the future waste collection system needs to be better than the current system. That means, the future waste collection system needs to reduce the CO_2eq emissions. The reduction needs to be at least 120 kg CO_2eq to break-even the extra IoT system. For the IoT system to have an effect, at least 32% of the transport (km) or number of bins need to be reduced, to outweigh the extra CO_2eq from the IoT system. Södertälje has already reduced its climate change impact from transport (in 2016) by switching from diesel to HVO. For a network of 160 litter bins, this resulted in a reduction from 2.3 t CO_2eq to 380 kg CO_2eq (83% reduction), where only two tons of reduction is related to the fossil-free transport (i.e. 8.75 t CO_2eq for a possible future system with 700 litter bins). However, the results show that climate change impact can be even further reduced by removing fossil-based plastic trash bags by almost 12 t CO_2eq (50 t CO_2eq for 700).

3. Implementation of IoT: Connected litter bins in Södertälje

Additionally, an interview study consisting of 12 interviews was conducted during the spring of 2021 for the purpose of gauging the impact of the IoT-system on different professional groups across the municipality and also included questions regarding citizen dialogue. The interviews lasted an average of 45 minutes each, and targeted individuals across multiple departments and areas of expertise, including sustainability development, ecological strategy development, waste management, Geographical Information Systems (GIS), and communications coordination. Representatives from the supplier of sensory equipment for the connected litter bins were also interviewed. A semi-structured interview approach [7] was used where common themes were present in all interviews, but emphasised or de-emphasised based on the interviewees profession and background. All interviews were recorded, and extensive notes were taken by at least one researcher and reviewed by another researcher. Ongoing work with digitalisation and IoT systems in Södertälje are expected to reduce the environmental impacts from the waste collection system in the municipality. The environmental study provides the basis for findings under heading 3.1 and the interview study provides the basis for findings under heading 3.2.

3.1 Environmental benefits and lean management

The results from the LCA study shows that the IoT system plays a minor role in the overall environmental impact of the smart waste collection system. However, it also showed that the reduction in transport is *not* the most significant factor for environmental impact (regarding climate change). Transport is based on HVO and is already quite low (17% of diesel). Instead, the use of fossil-based plastic trash bags was the most important environmental impact. Meaning that it is better to avoid fossil-based bags or even change to a new litter bin that does not need bags. In the current study, the LCA helped to improve the sensor (product) development, since less plastic will be used in the next generation of the sensor. Additionally, the LCA provided knowledge that made it possible to learn more about the collection service, and it might also help in improving operation and lean management. As an example, the operation manager already generated ideas about improvements based on the LCA study, such as to have lunch and coffee breaks in the city centre to reduce transport, instead of driving back and forth to the station as is the current practice. However, it is concluded that the municipality needs to learn more about the collection system and how to integrate sensors in the daily routines. The lean benefit from the IoT system lies in improved operation and better planning of the waste collection system. The smart waste collection system can be assimilated to Product-Service Systems (PSS) that deliver values in the form of new services. The city of Södertälje wants to improve this service, deliver a “clean” and “social” city, and keep their personnel. Previous studies [e.g. 5] have shown environmental benefits of PSS and waste collections systems, such as 20% reduced climate impacts due to reduced transport. In the current study, the great benefits are found in time and cost reduction. IoT and its purported role in creating smart cities [2, 8] has the potential to facilitate the core tenets of lean management, i.e. efficient work processes and effective allocation of resources.

However, leanness in management does not translate into leanness in its planning and implementation. Connecting a litter bin by installing a sensor in the housing that is already in use is quick and easy. However, as this study shows, this approach may also bring problems with data quality. A possible alternative would be to completely redesign the litter bins with connectivity and digitalised work processes in mind, e.g. by having a housing and container that is less susceptible to outside interference and thus able to provide a more amenable environment to automated monitoring using sensors. However, engaging in new applications involves a learning journey. The aim of the smart waste collection system in Södertälje was to reduce the time spent on waste collection and the costs of transport. There was also a wish to learn more on how to include sensors in daily work. For this reason, Södertälje started with a simple system with temperature sensors and continued with a more complex system for the current waste collection system. Activities are however continuous involving new tests and refinement of sensors in litter bins and in the city in general.

3.2 Digitalised work processes and social benefits

The interview study shows that even at this early stage (i.e. a proof-of-concept), digitalisation of waste collection has facilitated learning on several levels. The suppliers that develop the sensors had to re-think the design twice during the last 12 months in order to 1) fit the environment, and 2) provide accurate data. The employees in waste collection had to both learn to work with a new tool (an app that relays data from sensors) and how to distribute their time using the tool. Employees tasked with emptying the litter bins have other duties as well, e.g. picking up litter in the streets and maintaining city greens. The latter duty implies that they still have to make their rounds to ensure that the area surrounding the litter bin is clean. Therefore, the need for transportation has been equivalent to that prior to the introduction of IoT litter bins. However, connected litter bins still have the potential to yield qualitative benefits, such as less time spent checking if a litter bin might need emptying and more time spent on cleaning the surrounding environment. This leads to gains such as a cleaner city and less traffic, as well as an operational management tool and Key Performance Indicators (KPIs) for management. This is important for the municipality as it makes the city attractive and impacts citizens' general impression and well-being. The connected litter bins were successful as a proof-of-concept, but are not yet ready to be fully integrated into the work processes of waste management. While the technology shows great promise, it is not yet fool-proof and can show faulty or misleading data. A common reason for this is that the top-mounted sensor sometimes registers the litter bin as full if the plastic bin liner is not properly inserted into its metal housing or if an empty/nearly empty bag is pushed to one side by a gust of wind. Even though connected equipment is sometimes referred to as “smart” products [8], sensors can sometimes be remarkably un-smart.

The interview study also focuses on how ongoing work with digitalisation and IoT systems in Södertälje can have social benefits, including citizen engagement for reaching sustainability goals. The interview study provided a current state of these processes and activities in Södertälje. According to “the Södertörn model” (http://sodertornsmodellen.com) five different types of activities exist in relation to citizen dialogue; 1) information, 2) consultation, 3) dialog, 4) collaboration, and 5) co-decision making. The analysis shows that Södertälje municipality reaches out to citizens in many ways and through a range of activities, with “information” and “consultation” being the more prevalent categories. Additionally, future events include more engaging elements of “dialogue” with citizens, e.g. in the form of a sustainability-themed hackathon during 2022. There is an awareness among interviewees of the need to include many different groups in this dialogue, but also of the challenges in terms of inclusion and a variety of spoken languages in the municipality. An opportunity for renewed focus on citizen dialogue in Södertälje can be found in the analysis, such as the opportunity of generating a clear strategy for citizen dialogue.

4. Conclusions and outlook

This paper presents an analysis of the current practices and situation in Södertälje municipality (as of spring 2021) with regard to implementation of IoT litter bins. Our focus areas have been on LCA, digitalization, and citizen dialogue. The analysis serves as a real life perspective on the details of an IoT implementation within the public sector. The results show that the reduction in climate impacts is not straightforward and not primarily related to transportation, but rather associated with the use of fossil fuel-based plastic trash bags. IoT generated data are a starting point for the creation of both external civic value and internal organisational value in Södertälje municipality's transition to a sustainable city. Despite low measured climate impact gains of the IoT solution the solution still appears to provide other values related to social sustainability, such as a cleaner city. Furthermore, the municipality's commitment and the process of learning about IoT opportunities act as a vehicle for initiating internal change processes in which they dig deeper into its impact and how different sensors and solutions could benefit the municipality and its citizens.

References

1. S. Kumar, P. Tiwari, M. Zymbler, Internet of Things is a revolutionary approach for future technology enhancement: a review. *J Big Data* ***6*** (1), 1-21 (2019)
2. O. Velsberg, K. Jonsson, U. H. Westergren, T. Saarikko, IoT Triggers: How municipalities are transforming to smarter cities through IoT use. *Scan J Inform Syst* ***33***(1), 17-64 (2021)
3. Y.L. Chiew, B. Brunklaus (2021). *Life cycle assessment of IoT solutions in Södertälje municipality – a smart waste collection system*. RISE report nr 2021:91
4. B. Brunklaus, Y.L. Chiew, A. Lundström, T. Mccarrick, H. Nilsson-Lindén, R. Rekonius, T. Saarikko, A. Sundberg, T. Thernström (2021). *Det inkluderande, hållbara och uppkopplade samhället: Nulägesanalys*. RISE, Umeå Universitet, Södertälje kommun, Telge Återvinning. RISE rapport 2021:89 ISBN 978-91-89385-79-5
5. T. Hoang, A. Lelah, F. Mathieux, D. Brissaud, V. Gimeno, Environmental Evaluation of Machine-to-Machine Services: the case of Glass Waste Collection, in *Proceeding of the 2nd CIRP IPS2 Conference*, Apr 2010, Linköping, Sweden (2010)
6. B.P. Weidema, C. Bauer, R. Hischier, C. Mutel, T. Nemecek, J. Reinhard, C.O. Vadenbo, G. Wernet G. (2013). *Overview and methodology. Data quality guideline for the ecoinvent database version 3*. Ecoinvent Report 1(v3). St. Gallen: The ecoinvent Centre
7. S. Kvale, S. Brinkmann, *Interviews: Learning the craft of qualitative research interviewing,* 2nd ed. Sage publications: Thousand Oaks, CA (2009)
8. T. Saarikko, U. Westergren, K. Jonsson (2020, January). Here, there, but not everywhere: Adoption and diffusion of IoT in Swedish municipalities, *in Proceedings of the 53rd Hawaii International Conference on System Sciences*, 7-10 January 2020, Maui, Hawaii, 2030-2039 (2020)