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Publication date

2023

Document Version

Final published version

Published in

EUROSIM CONGRESS 2023

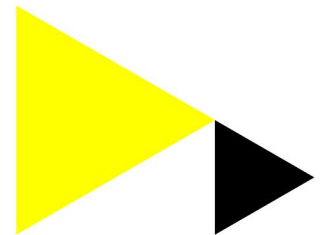
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Citation for published version (APA):

Lange, K. P. H., Kerssens, S. I. M., Korevaar, G., & Warnier, M. (2023). An Agent-Based Model for exploring behaviour change policies for improving waste separation at SMEs. In *EUROSIM CONGRESS 2023* (pp. 1-5)

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An Agent-Based Model for exploring behaviour change policies for improving waste separation at SMEs

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Abstract. Waste separation at companies is considered a priority to achieve a circular and sustainable society. This research explores behaviour change policies for separating the organic fraction of municipal solid waste (OFMSW) at Small and Medium Enterprises (SMEs), particularly in cities. At SMEs, co-workers are responsible for waste disposal. Therefore, their behavioural intention towards pro-environmental action plays a major role. In this study, we have used agent-based modelling and simulation to explore the waste behaviour of the actors in the system. The models were co-created in participatory workshops, surveys and interviews with stakeholders, domain experts and relevant actors. Additionally, we co-created and tested practical social and technical interventions with the model. We used the collaborative modelling method Lange reported to conceptualise, implement, test and validate the models. Five policies that affect waste separation behaviour were included in the model. The model and simulation results were cross-validated with the help of a literature study. The results were validated through experts and historical data to sketch a generalisable idea of networks with similar characteristics. These results indicate that combinations of behaviour profiles and certain policy interventions correlate with waste separation rates. In addition, individual waste separation policies are often limitedly capable of changing the behaviour in the system. The study also shows that the intention of co-workers concerning environmental behaviour can significantly impact waste separation rates. Future work will include the role of households, policies supporting separating multiple waste types, and the effect of waste separation on various R-strategies.

Keywords: Circular Economy, Waste management, Behaviour Change Policies, Value-Believe-Norm Theory, Agent-Based Modelling.

1 Introduction

This research contributes to improving policies for separating the organic fraction of municipal solid waste (OFMSW) at Small and Medium Enterprises (SMEs) in cities, such as offices, shops and service providers. OFMSW separation is considered a top priority to achieve a circular and sustainable society [1, 2]. Post-collection separation of OFMSW is not feasible due to the complex composition and fluctuating quality [3].

Therefore, OFMSW often ends up in landfills, resulting in GHG emissions [4]. Governments and waste processors are looking for policies to motivate urban SMEs to improve their waste separation behaviour. However, policymaking is challenging for these actors since the disposal of waste at SMEs is carried out by employees. Therefore, this study focuses on behaviour change policies for waste separation.

There are various types of co-workers at companies disposing of waste. Co-workers adapt their behaviour continuously, influenced by the working environment, events over time and self-evaluation of their actions [5]. Therefore, we examined waste separation at SMEs from a Socio-Technical Complex Adaptive System (STCAS) perspective. Together with professionals and experts, we co-created an agent-based model representing the waste separation behaviour of co-workers to test the effect of five policies at a business park located at a former shipyard in Amsterdam, The Netherlands.

2 Methods

A conceptual and agent-based model of the system and the environment were set up through participatory workshops, surveys and interviews with stakeholders, domain experts and relevant actors. We used the method Lange [6] reported to conceptualise, implement, test and validate the models. Together with our case participants, five policies that affect waste separation behaviour were included in the model. We gathered empirical data in three steps. First, we identified the narrative of commercial waste separation and collection. We then identified the key factors and relevant policies for increasing organic waste separation rates. Third, we collected and validated data regarding the actor's values, beliefs and norms. We also co-created practical social and technical interventions within the domain of separated waste collection. The gathered empirical data and interventions were then used to construct our ABM and simulate the effect of the co-created interventions on waste separation rates. The model and simulation results were cross-validated with the help of a literature study.

Here we provide a brief description of our case study. The NDSM-wharf area is a former shipyard that lies north of the IJ river. Between the twenties and eighties of the 20th century, it was one of the largest shipyard areas in the world. Nowadays, the shipyards have moved out of the city, and the area is redeveloped into a business park with a focus on cultural activities, thus becoming a home port for small offices [7]. The area consists of approximately 400 companies, which are mainly SMEs. Within the area, two organisations are actively serving the interests of the companies: an area management foundation and energy cooperation. The foundation programmes and directs all activities on the NDSM wharf. One of their main concerns is how to support waste separation to facilitate the Circular Economy goals of the municipality of Amsterdam [8]. For increasing waste separation rates, the municipality has officially provided the NDSM wharf with a legal breeding ground status for innovation, allowing the foundation to experiment with new ideas for the Circular Economy and diminishing the legal obstacles to doing so. The energy cooperation comprises approximately 60 companies

in the area, which aims to promote renewable energy, and in line with this, the concept of the Circular Economy. This cooperation aimed to explore possibilities of using separated organic waste to produce biogas, which made it a suitable case for our study.

3 Model

The model consists of five types of agents representing company co-workers. Each agent follows three steps. (1) It produces OFMSW; (2) It determines whether this organic waste must be stored in a special bin for organic waste or put in the residual waste bin; (3) And it puts the waste from the bin either in a separate organic waste street container or the residual waste container for collection by the processor.

The amount of waste separated in the model depends on the agents' behavioural intention, which is affected by itself and physical factors, such as street container distance and hygiene levels. Pro-environmental behaviour is crucial for successful sustainable waste management [9]. Environmental policies are intended to increase pro-environmental behaviour in the future. In future situations, people cannot refer to habits; Therefore, behavioural intention best explains future behaviour [10]. Several theories have been used to explain pro-environmental behaviour. The two most important are the Theory of Planned Behaviour (TPB) [11] and the Value-Belief-Norm theory (VBN) [12, 13]. TPB is widely used by scholars and has also been used to study the topic of waste separation [14]. Nevertheless, TPB has its limitations. TPB does not describe behaviour that is not out of personal choice or preference or requires resources and skills [15]. Waste separation heavily relies on knowledge and awareness [16]. Ruepert et al. [17] found that general environmental considerations affect the personal pro-environmental norms and behaviour of professionals at work. Therefore, recycling and waste separation are highly normative behaviours [18]. Moreover, Whitmarsh et al. [19] state that TPB does not properly explain recycling activities at work and recommend performing more research on applying the VBN model in this context. Hence, to model the behaviour of each co-worker's values, beliefs and norms during the separation and disposal of OFMSW, we have used the VBN Theory [12].

The five policies that were modelled and simulated are described as follows. The *feedback* policy simulates the effect of personal feedback on co-workers' awareness of consequences and the ascription of responsibility, thereby positively influencing the percentage of correctly separated OFMSW. The *facilitation policy* introduces facilitator agents that create links with waste-generating agents to improve waste separation rates through actionable support temporarily. The *on-demand policy* no longer uses a scheme to empty the street containers; rather, it will measure the quantity of waste in this container and collect the waste accordingly, resulting in higher waste separation rates through cleaner street containers. The *newsletter policy* is based on research by Rideout [20] that shows knowledge is forgotten after a while. The distributed newsletter refreshes the memory of agents, thereby avoiding knowledge losses and improving waste separation rates. The *street container interaction policy* simulates information on

correct waste separation on the container design: it is assumed that with a proper informative design, the difficulty of disposal reduces by 80% and will therefore be less of a barrier to separating waste.

4 Results and discussion

The model's simulation results are validated through experts and historical data to sketch a generalisable idea of networks with similar characteristics. These results reveal that combinations of behaviour profiles and certain policy interventions correlate with waste separation rates. Individual waste separation policies are often limitedly capable of changing the behaviour in the system. Rather, integrating simple information-sharing and communication policies can significantly increase the waste sortation rate. More expensive interventions, such as container interface redesign or on-demand emptying, yield relatively small contributions. The preliminary study results also indicate that initial behavioural profiles of co-workers can significantly impact the percentage of separated organic waste, warranting the inclusion of actor behaviour in waste management models.

5 Conclusion and future work

This study contributes to a better understanding of how policies can support co-workers' pro-environmental behaviour for organic waste separation rates at SMEs. It proposes that policy implementation depends on the actors' values, beliefs and norms. In combination with relevant policies to these network types, a societal benefit can be realised through recovering valuable organic resources and improving the processing of residual waste streams. Thus, the study shows policymakers how to stimulate the circular transition by actively engaging co-workers' waste separation behaviour at SMEs. Future work will include integrating consumer behaviour involving household waste, policies supporting separating multiple waste types, and the effect of waste separation behaviour on various reuse and recycle strategies such as those proposed by Potting et al. [21].

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