UNIVERSITY OF GOTHENBURG

Household Waste Segregation:
Lessons from Poland

Author: Alexander Stelmach

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Supervisor: Pernilla Nordqvist

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ABSTRACT

One of the problems facing the world in the twenty-first century is the management of municipal waste, a problem where the household plays a key role in the process through its interaction with the municipal waste management system. How this interaction works is dependant not only on the design of the municipal waste management system, but also on the individual households. This study introduces the topic of household waste segregation, and finds that there is a lack of research with regard to how the various parameters of the dwelling affect the rate of waste segregation in households. To address this lack of research, a review of previous studies from a variety of disciplinary fields was made, based on which a survey study was conducted through social media. The study which was performed in Poland had a total of 50 local respondents. To better understand the scale and importance of the underlying processes, a mixed methods approach was taken, where both qualitative and quantitative data were put through a three-step quantitative analysis to provide different perspectives. The first two steps analysed the correlations between various pairs of variables through a bivariate analysis and explored the relationships between various obstacles to household waste segregation as reported by the householders. Whilst this was enough to provide a limited understanding of the data, to understand the overall importance of these various factors in relationship to one another, a third step utilising a non-linear multivariate analysis was performed using a multilayer perceptron procedure which utilises machine learning to create a predictive model. The results indicate that the most important factor that influences household waste segregation is the willingness to exert effort, which can overcome obstacles faced in the process. The most frequent of these obstacles which was specified by 46% of the respondents is the availability of space at home to perform the segregation of waste, followed by the recyclability of waste which had 18%. The spatial factors ranked highly with regard to the householders' rate of segregation, with the number of rooms per person ranking as the most important after the willingness to exert effort. In conclusion, the data in this study indicates that the most efficient ways to improve the rate of waste segregation among householders is through increasing the incentive to segregate waste, combined with the simplification of the recycling process through means that take into account the effort and space required, such as a reduction of categories into which waste needs to be segregated.

Contents

1 Introduction

The relations between humans and the environment have increased vastly in complexity over the past century (Stahel, 2016, pp. 9–10), human ecology is the interdisciplinary field that deals with these issues from a system wide perspective by combining research, whether it be from the field of sociology, toxicology, or any other ology. A perspective that is necessary, as approaches taken from one single disciplinary field which only focuses on a small part of the human condition, often not only fail to grasp the broader problem that they try to solve, but may also create more difficulties elsewhere. This insight is not new in the field of human ecology, and was even described in the original introductory statement of the journal Human Ecology, along with a wide range of issues still being dealt with half a century later across the whole of academia (Lay, 1972). There are many environmental problems in the twenty-first century that are related to the relations between mankind and the environment, these include: population growth, famine, habitat loss, biodiversity loss, unsustainable fisheries, climatic change, alternative energy, air pollution, fresh water conservation, municipal waste, human waste, chemical pollutants, and public participation in sustainable development (Gillespie, 2018, Chapter 9). Out of these, municipal waste is one of the problems that impacts on both the health of local communities and the global climate (Smith et al., 2001), and is also important in addressing many of the other problems as will be discussed later in this introduction. A specifically challenging issue when it comes to municipal waste, is the waste generated by households, because of the large quantity of different materials that people dispose of at home (Rousta & Bolton, 2019). In approaching the challenge of analysing the circumstances that lead to this diverse waste being generated, some insight may be gained from a UN definition of the role of the household when it comes to the human condition:

> *"The household, defined as a group of persons who make common provision of food, shelter and other essentials for living, is a fundamental socioeconomic unit in human societies. Households are the centres of demographic, social and economic processes. Decisions about childbearing, education, health care, consumption, labour force participation, migration and savings occur primarily at the household level. Understanding the trends and patterns of household size and composition can thus inform efforts towards the achievement of the 2030 Agenda for Sustainable Development." (UN, 2017)*

With this definition, households are therefore a type of social structure that is at the centre of many processes, where waste segregation is one of the important processes for reducing environmental impact as it is instrumental in extracting higher quality materials from municipal waste (Miliute-Plepiene et al., 2016). Furthermore, given that municipal waste is one of the great environmental challenges in this century (Gillespie, 2018, Chapter 9), understanding the various factors that affect

the waste segregation behaviour of households is essential for promoting recycling behaviour and policy address the negative impacts of waste. This chapter provides a concise summary of: the relevant background as to how the world is dealing with the problem of waste; developments that make a better understanding of the role of households more important; and the specific focus of this study.

1.1 Background

1.1.1 The Global Situation

As a response to the urgent global environmental challenges, and building upon earlier efforts, in 2015 the United Nations introduced plan called the 2030 Agenda for Sustainable Development (UN, 2015). While the agenda focuses on a broad spectrum of Sustainable Development Goals (SDGs)[1], they do address to some extent the environmental problems facing humanity (Gillespie, 2018, Chapter 9). The twelfth goal being of particular interest to this study as it relates to the creation of sustainable consumption and production patterns, including targets for waste reduction and recycling (UN, 2015). From a global perspective this is also relevant as the material demands of these consumption and production patterns have been drivers of problems which many of the other goals aim to address, such as the need to address inequality among countries or the promotion of healthy lives (UN, 2015), with developed nations driving global inequality through trade agreements and excessive exploitation of natural resources (Banerjee, 2003). One of the symptoms of this exploitative consumption of natural resources is the generation of large amounts of waste by households and the economies that these households support. This waste has until recently indiscriminately been exported abroad, a situation that changed in 2018 when China imposed strict limits on the importation of poorly segregated waste (Hook & Reed, 2018). More recent media attention has been focusing on how, with China no longer accepting any further waste imports as of 2021, neighbouring countries have also been introducing measures to crack down on the problem of waste imports, increasing the need for exporting countries to deal with their own waste (Nguyen, 2020). This is a large change in a world where globally in 2005, waste generation was at 13 gigatonnes annually, of which only 4 gigatonnes got recycled into new materials or downcycled into lower grade materials. While that may seem like a considerable fraction of materials being recycled, systemwide across the whole economy that amount of recycling corresponds to only 6 percent when accounting for all the materials processed, including those going towards the generation of energy (Haas et al., 2015, pp. 769–770). With the global economy running at up to 94 percent material inefficiency, there ought to be ample space to improve the status quo.

[1] The SDGs are a set of 17 goals at the heart of the 2030 Agenda for Sustainable Development. The goals are built on previous global efforts, and represent an urgent call to action by all countries to address the social and environmental challenges faced by the world (UN, 2018).

Achieving such improvement is no trivial matter, as more globalized systems require more effort in overcoming various lock-in challenges presented by the economic infrastructures involved (Corvellec et al., 2012, p. 33). There is however hope when a large economy such as the European Union (EU) makes a more localised coordinated effort in addressing the global waste problem.

1.1.2 A European Approach

The strongest effort to date by the EU with regard to the 2030 SDGs and beyond, is the 2019 European Green Deal that by 2050 aims at achieving climate neutrality whereby emissions of greenhouse gasses would be at net-zero (OECD, 2020, p. 23). The broader agenda for achieving this ambitious goal is outlined in the subsequent Circular Economy Action Plan (CEAP). This action plan takes a system wide approach to reducing the environmental impact of the economy by outlining how waste ought to be dealt with, but also enabling the recycling of materials so that they can be reused (European Commission, 2020), an approach that fits into the Circular Economy (CE) framework which will be discussed later (see: 2.2.1). There are, however, some conflicts between shorter term goals such as reduction of waste that is buried in the ground via the 10% landfill limit for municipal waste by 2030 (EC, 2019), and the ambition of climate neutrality by 2050. This is the case when the landfill reduction is achieved by incineration, where municipal waste is burnt for some combination of disposal and energy recovery. This process, apart from destroying the waste materials, is also associated with high levels of greenhouse gas emissions, and infrastructure lock-in through the investment or the integration into the municipal energy system by which local governments become dependent on incineration (Corvellec et al., 2012; Saner et al., 2011). The CEAP approaches this issue in part by aiming to facilitate economic instruments like incineration taxes, and in part through a decoupling of economic growth from waste generation where more consumption in the economy would not cause more waste (European Commission, 2020). Such market conditions need to be taken into account to make the necessary infrastructure investments possible (van Voorst & Schoenthal, 1992). There are however reasons for why incineration may seem like a convenient solution in the present, as due to the scale of the waste problem, even the European Commission acknowledges that this decoupling would require considerable effort from households and the whole value chain in general (European Commission, 2020, p. 12). Member states will now have to make sure that the effort is taken, with the European Commission banning the export of waste to poorer nations from the 1st of January 2021 (Johnson, 2020). To help guide the process the CEAP covers a great many aspects of how this can be achieved in the value chain, including product design, packaging, ownership, and use. When it comes to households, support is focused on the waste collection systems with which householders interact. (European Commission, 2020, p. 13). These systems exist outside of the dwellings [living spaces] that

householders occupy. With the effort necessary on behalf of the households having been acknowledged, the interaction between these municipal recycling systems and how various households experience recycling within the confines of the dwelling becomes relevant in the quest to promote recycling. Especially as these experiences might change in conjunction with broader demographic developments where the number of single households is growing at a rapid rate (EC, 2020).

1.1.3 Household Perspective

While there have been many studies concerned with various factors affecting household participation in recycling, a collection of which will be presented further down, most seem far more focused on less direct socio-economic factors such as income and education, rather than on the technical factors of the dwelling that directly affect the household. While both socio-economic and technical factors affect the living conditions of householders, looking through the wrong lens can lead studies to miss significant information that may prove useful for policy makers in achieving regional waste management targets. A specific example of this lack of focus on technical factors can be seen in a broader international study conducted by the OECD[2] about encouraging environmentally friendly behaviour in households, where the size of the dwelling was not found to correlate with waste generation (OECD, 2014, p. 225). The study based its findings on a survey where the scale started at $50m^2$, which means that it fully ignores smaller dwellings (OECD, 2014, p. 265). This is a significant omission if one considers the smallest households consisting of only one person living alone in an urban area, as the average area per person for whole countries can be under fifty square meters, with Poland, Lithuania, Estonia, Latvia, and Romania being examples of this within the EU (Eurostat, 2012). This is even more problematic given that by the year 2050, urbanization is expected to reach 83.7% in the EU from the current level of 74.9% (United Nations: Department of Economic and Social Affairs, 2018). Single households are also becoming far more common among all adults, with the sharpest increase during the period of 2010-2019 being among men aged 55-64 where single households increased 47.7%. This can be seen in the figure below that illustrates the percentual change in household composition by demographic over the past decade, and that the growth of single households has been the greatest for the majority of the demographic groups presented (EC, 2020, p. 4).

[2] The Organisation for Economic Co-operation and Development (OECD, 2014)

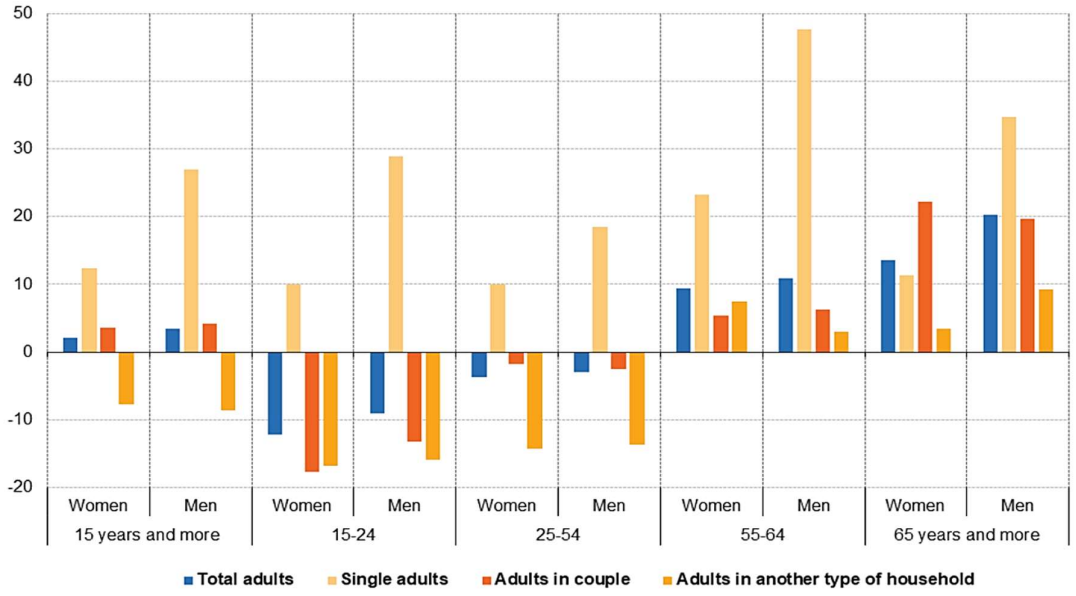

Figure 1: Growth rates of the adult population by type of households, sex and age, EU-27, 2010-2019 (%) (EC, 2020, p. 4)

Understanding how living conditions affect recycling behaviours becomes important in gaining insights into what can be done to promote waste segregation from a households perspective, at a time when demographic developments are leading to a shortage of adequate housing despite a slowdown in population growth (Eurostat, 2018).

1.1.4 The Case of Poland

To better understand the challenges faced by households due to inadequate housing, a good candidate for this small study would need to meet the right regional metrics. In the EU there is a measurement of the overcrowding rate, that is household dwellings not having an adequate amount of rooms relative to the composition of the household, this takes into account that certain cases such as couples or younger children can share a room (Eurostat, 2014). Out of all the nations where this rate is in excess of 32% across the various degrees of urbanisation: rural, towns/suburban, and cities/urban (Eurostat, 2018, pp. 57–58), Poland with its 37.8 million inhabitants is the most populous (Worldometer, 2020). This means that it has a large share of the more overcrowded households in the EU, and ought to provide a good example of how the technical aspects of housing affect the waste segregation rate of households in cases where there is a lack of adequate housing. Figure below shows a comparison of the overcrowding rate in Poland with the rest of Europe.

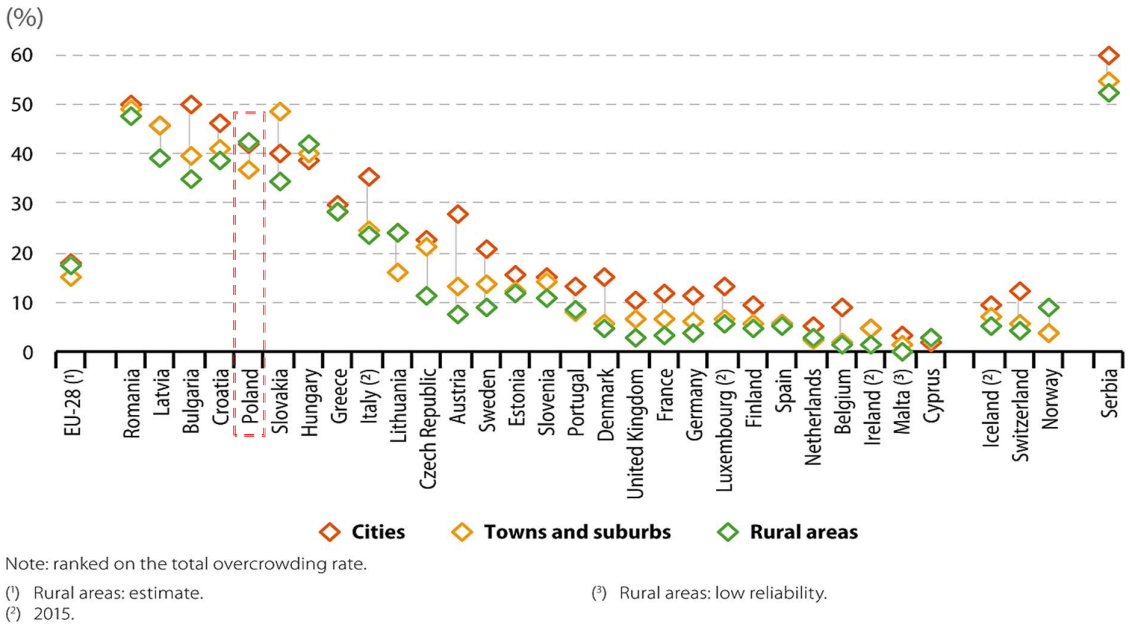

Figure 2 Overcrowding rate by degree of urbanisation, 2016 data (Eurostat, 2018, p. 58)

There are other relevant statistics too, such as that the Polish national average dwelling space per capita is only 27.8 m^2 (Adamczyk et al., 2018), considerably lower than the latest available data for the European average of 42.56 m^2 (EC, 2011), a figure that can be assumed to be even lower in more urbanised areas where space is at a premium. Other factors such as Poland's central European location and variables such as recycling categories being controlled for by national standards (Ministerstwo Klimatu i Środowiska, 2020), also help make Poland a good location for studying the effects that denser housing has on recycling in a European context. Therefore, this study will focus on Poland rather than on a broader geo-political area, where the recycling standards and languages vary, as that would require a more comprehensive study than is realistic in this case. The relatively high level of overcrowding across the various degrees of urbanisation in Poland also means that further delimitation to a smaller area or city seems unnecessary in this case, as the odds of a given household being less than adequate by the European definition of overcrowding are quite high no matter whether it is in a rural or urban setting, if anything the differences between households may provide some interesting insights.

1.2 Focus of this Study

1.2.1 Problem Statement and Purpose

There is a lack of research into how various dwelling related factors such as living space and number of rooms correlate with recycling behaviour of householders. Understanding these relationships could provide insights into the challenges that households face with regard to waste segregation, and how policymakers can deal with these challenges as the composition of households' changes over the next

30 years. Changes that will have to be dealt with as Europe moves towards climate neutrality with the European Green Deal.

1.2.2 Research Questions

Based on what has been discussed so far, filling the gap that exists in current research will require both quantitative data that provides measurements of the householders dwelling conditions, and qualitative data that expresses the householder opinions and attitudes towards recycling. Together with a thorough review of previous research and theoretical work to provide context, this approach should allow two questions to be answered:

> **RQ1**: How strong, if any, is the relationship between a households' rate of waste segregation and various spatial factors that relate to the dwelling?
>
> **RQ2**: What obstacles in sorting waste do households face in relation to their dwelling, and how can they be mitigated?

By answering these questions, and putting the findings gained into a theoretical perspective that works with the current efforts being undertaken by the UN and the EU, insights could be gained about the greatest challenges affecting the waste segregation behaviour of households and how they can be addressed.

1.2.3 Delimitation

While it would be extremely interesting to explore the full scope of factors that can affect a household's behaviour, this study will focus on comparing the technical and spatial aspects of households as they relate to recycling behaviour, not differences between demographic groups as the anticipated sample size is limited given the time and resources available. It will further only focus on households in Poland, since that reduces the number of potential variables of which a selection was discussed earlier in this introduction. While these choices do limit the generalisability of this study, it ought to provide an insight into what factors households are having a difficulty with when dealing with waste segregation.

2 Theory

As has been discussed in the introduction, the field of human ecology is interdisciplinary and this paper focuses on the subject of household waste segregation as it fits into the broader theoretical framework that defines this behaviour in a global context. This chapter will review previous research that has been concerned with the subject of household waste segregation, offer a description of the circular economy framework which binds the subject of recycling as it is being pursued within the EU, and provide some theoretical underpinnings which can be used to determine a suitable approach in the research of this topic. This latter part will go into the theoretical underpinnings of the methodology used in this study, describing how the theory will be combined to explore the topic of household waste segregation through a quantitative analysis that takes a mixed methods approach by utilising qualitative data.

2.1 Previous Research

Earlier research offers a great deal of insight into what is known about the waste segregation behaviours of householders, and this insight can help focus the study on what areas of research require greater attention so as to avoid taking a too generalised approach as seen in the study discussed earlier [see: 1.1.3]. A good approach to summarizing this research can be found in a meta-analysis of 63 empirical studies that looked at the determinants of recycling behaviour among householders. In that meta-analysis the authors defined variables based on the examined studies, and whether or not the studies found household recycling behaviour dependant on these variables. In the analysis, these variables were defined in four theoretical groups. Without going too far into the specific variables yet, the four groups and some of the key findings can be summarised as follows (Miafodzyeva & Brandt, 2013), with additional input from other research where necessary:

> **Socio-Demographic**: A mostly ambiguous yet also the most commonly investigated group of variables, often called socio-economic by many of the studies in the meta-analysis and in the introduction of this study. In the meta-analysis this group included *age, gender, income, dwelling type,* and *education* (Miafodzyeva & Brandt, 2013, p. 224). Out of these, *dwelling type* was the only variable for which the analysed studies unambiguously showed a correlation with recycling behaviour, with the explanation that single-family dwellings have more storage space and a generally higher environmental concern among homeowners. However in addition to being uncontroversial in that studies agree that it is of significance, this variable has not been examined in a significant number of studies (Miafodzyeva & Brandt, 2013, p. 225), which at least based on this meta-analysis confirms that there is a lack of focus in the research on factors

that concern the living conditions of householders, as has been discussed in the introduction (see: 1.1.3).

Technical-Organisational: This group contained what the analysed material referred to as technology, organisational systems, or material structures. With the key idea being that these variables reflect two opposing sides where *"For the [waste] collector, more central collection points seem more attractive and economically efficient. For householders, a closer [to home] collection point means less effort and is more convenient"* (Miafodzyeva & Brandt, 2013, p. 225). Here the meta-analysis had three variables that included: *kerbside* [waste collection being adjacent to the building], *convenience* [which covered a broad range of aspects from how frequently waste was collected, to the ease of use and design of the recycling scheme/infrastructure], and *unit pricing* [various schemes where householders pay by the volume or weight of their waste]. Among these variables *convenience* and *kerbside* were found to unambiguously correlate to recycling behaviour, even though the latter was not present in a significant number of studies. And *unit pricing* through which households that segregate waste would pay less was found to be ambiguous, with the conclusion that *"People report being motivated by money, yet they do not always act in accordance with this claim"* (Miafodzyeva & Brandt, 2013, pp. 226–227)..

The importance of this technical-organisational group of variables can be highlighted with a more recent French study, where after surveying 593 respondents it was found that an important variable is the presence of recycling bins in the building. For every 1% increase in the availability of individual sorting containers, the probability of adopting waste sorting behaviour increased 27.7%. The same study noted that older buildings and buildings in town centres are especially problematic in lacking dedicated spaces for recycling bins (Kirakozian, 2015, pp. 1491–1492). This confirms earlier interior design research from the United States, where convenience and access to the recycling storage area was deemed to be of high importance, and perceived lack of space at home being deemed a major obstacle (inconvenience barrier) to recycling behaviour (Macy & Thompson, 2003, p. 23). While Macy & Thompson (2003) showed the importance of residential design implications and convenience, there is understandably a lack of insight into the denser urban setting given that it was predominantly larger dwellings that were researched, with most respondents having a garage. Another more general geographic matter that affects Technical-Organisational research like Macy & Thompson (2003) is the fact that it was conducted in the United States, where living alone in a 39 m^2 apartment is considered cramped enough to be published in the New York Times (Hill,

2013), this makes the residential design implications of that study harder to translate into the European setting where space is at a higher premium (see:1.1.4).

Socio-Psychological: The largest group of variables, and a group that can be largely described as normative in that it relates to variables which define how households ought to deal with waste either from an individual or societal perspective. Variables in this group included: *social norms*, *legal norms*, *past behaviour*, *information and knowledge*, *moral norms*, *general environmental conc*ern, and *personal effort*. The studies which looked at these variables have mostly found them to correlate with recycling behaviour, although only *information and knowledge* was found to have consensus among the analysed studies. *Personal effort*, *past behaviour*, and *legal norms* were variables that were not looked at by a significant number of the studies (Miafodzyeva & Brandt, 2013, pp. 227–229).

Study-Specific Variables: Here Miafodzyeva & Brandt (2013) included a selection of interesting variables which were rarely studied and therefore not included in their quantitative meta-analysis. However, these variables deserved a mention as the studies that did look at them found that there was a correlation with recycling behaviour. Mentioned variables included: *population density, political allegiance, religious identity and ethnicity, sense of community, new immigrants, amount of household waste generated,* and *shopping behaviour.* Overall, this group of variables demonstrates the complexity of the subject and that to truly get a good understanding of household waste segregation would require a very extensive study (Miafodzyeva & Brandt, 2013, p. 230).

Miafodzyeve & Brandt (2013) continued their meta-analysis with the creation of a *model of householders' recycling behaviour*, where they mapped out the relationships between variables. This was done with the acknowledgement that given the complexity of the interrelationships between variables is such, that neither their model nor any of the previous studies can account for the effect of the interactions between variables. So while certain variables can help predict recycling behaviour, they do not act alone, and "*Factors such as the inconvenience barrier, lack of information and lack of positive personal values that reduce the extent of the personal effort can be overwhelming and recycling behaviour may not be performed"* (Miafodzyeva & Brandt, 2013, p. 232). To better address these interactions a more interdisciplinary approach is necessary, and as this very extensive analysis concluded, *"variables from these groups are frequently studied separately and it is difficult to identify the interrelationships between them and complete the picture of recycling behaviour. There is a need for future investigations combining these groups of variables"* (Miafodzyeva & Brandt, 2013, p. 233).

The present study is well positioned to address the need for combining these groups of variables, as spatial factors that relate to the dwelling relate to all of these groups. The same can be said of obstacles to recycling which may be related to these spatial factors. Specific variables that relate to space, as has been shown by this review, would include: *dwelling type*, *kerbside*/*adjacency*, *convenience*, *personal effort*, and *population density*. These variables span all the groups and have all been found to affect the recycling behaviour of householders, therefore the present study while being focused on spatial factors addresses the need of combining various theoretical groups that previous research indicates are in need of further inquiry.

A search for more recent studies did not provide any additional results that would fill the research void. While other studies using the interdisciplinary approach of Miafodzyeva and Brandt (2013) do exist, the tendency seems to be case studies with the same breadth of trying to model the groups fully rather than select a specific theme that spans all the groups (Miliute-Plepiene et al., 2016), therefore this literature review has not been successful in finding any previous studies that more closely explore the spatial factors affecting householders within the dwelling. Something that can be understood by the fact that studies often look at specific variables from within a given discipline (Miafodzyeva & Brandt, 2013), which can fail to grasp a broader problem (Lay, 1972). This as studies in a fashion similar to Miliute-Plepiene et al. (2016) often seem to have a broader social focus, alternatively like Kirakozian (2015) or Macy & Thompson (2003) do not take into account the smaller technicalities that relate to the dwelling itself while going into specific availability of recycling facilities. Therefore, it seems safe to assume that the middle ground of general spatial factors such as the number of rooms or dwelling space/density, is not an area that has been thoroughly explored within the context of recycling behaviour and even a limited study such as this one ought to yield some interesting insights.

2.2 Concepts and Research Approach

2.2.1 Circular Economy

When it comes to household waste segregation, circular economy (CE) provides a broad theoretical landscape within which this topic can be situated. Whether seen as a concept, theory, or a framework, CE has been defined in a variety of ways which generally agree, that the goal in a circular economy is to create an economic system that replaces the 'end-of-life' concept for materials used in products, with systems that instead cycle these materials back into production, distribution, and consumption processes (Kirchherr et al., 2018). While materials in nature are subjected to circular flows by default, for mankind the driver of these processes is scarcity and economics (Stahel & MacArthur, 2019). To fully understand the context of how the European Union is working to transform the economic system into a circular economy, the various areas of where and how the flow of materials needs to be

developed ought to be illustrated as it relates to the consumer. For households a key area is the segregation of waste so that materials can be brought back into what is for the most part a linear industrial economy. On a day-to-day basis this is especially true for packaging materials used for distribution of consumables (bottles, cans, jars cartons, etc.), with Europeans generating 173kg of packaging waste per capita in 2017 (European Commission, 2020, p. 8). The role of household waste segregation can be seen in the illustration below where ideally materials are fed back into the manufacturing process after they are recycled according to governmental guidelines, such as those that exist in Poland where households are required to sort waste into five categories: *product* [plastics and metals], *paper and cardboard*, *glass*, *biological waste* [compostable], and *mixed municipal waste*. (Ministerstwo Klimatu i Środowiska, 2020).

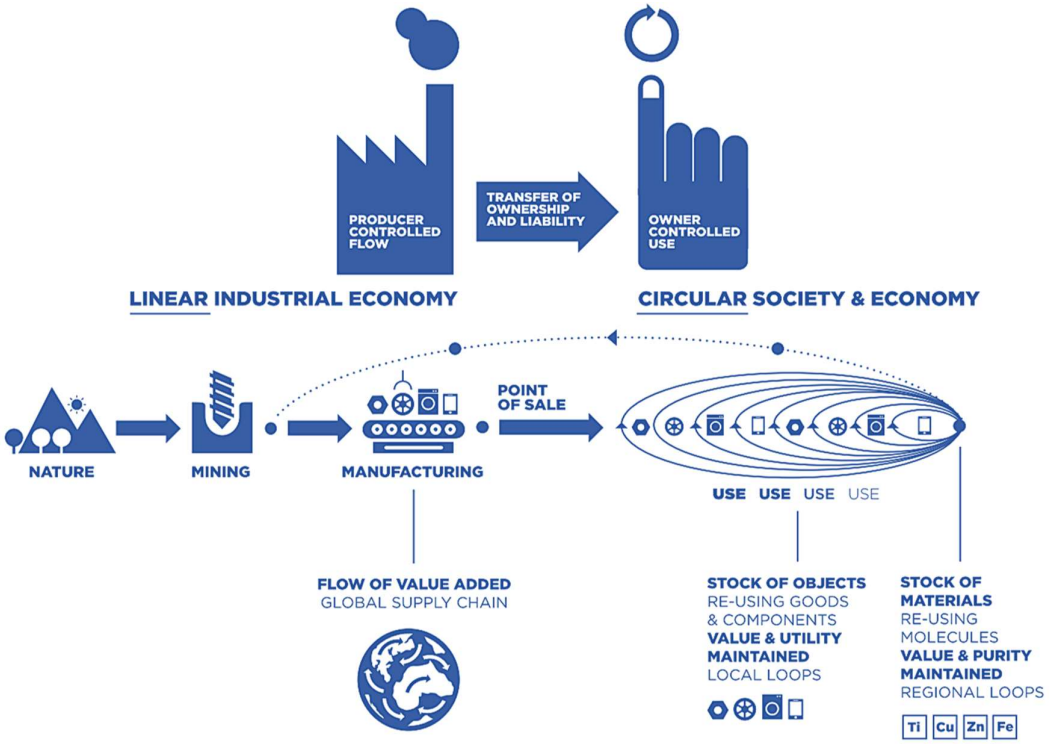

Figure 3 The characteristics of the linear industrial economy, and the circular society and economy (Stahel & MacArthur, 2019, p. 17)

To facilitate this process that places a considerable burden on householders to segregate waste at home, and to ensure that by 2030 it is economically viable to reuse or recycle all packaging on the EU market, the European Commission will reinforce the mandatory requirements for packaging to reduce overpackaging and increase recyclability (European Commission, 2020, p. 8). And while this transformation does help to some extent, there is still a transfer of ownership and liability that frees the producers from responsibility as illustrated above. A problem with this transference of ownership is that if recycling behaviour is to be regulated according to the Polluter Pays Principle (PPP), then as

the consumer becomes the owner, they also take on the liability for the responsible disposal of that product, while not giving producers any incentive to ensure that such a responsible disposal is realistic (Stahel & MacArthur, 2019). To address this issue, regulation is being explored to incentivise product-as-a-service so that manufacturers keep the responsibility over the product (European Commission, 2020, p. 4; Stahel & MacArthur, 2019, p. 64), while this could transform the way the economy handles everything from appliances to clothing, there could even be a case to let manufacturers or distributers maintain ownership of reusable packaging used in consumables like the once common milk bottles (Stahel, 2016). This kind of transformation incentivises economic actors to create reverse logistics flows as illustrated below, giving consumers clear directions of what to do with specific products once they have been used as these products are effectively rented and the company (fleet manager) has an interest in making sure that products are returned.

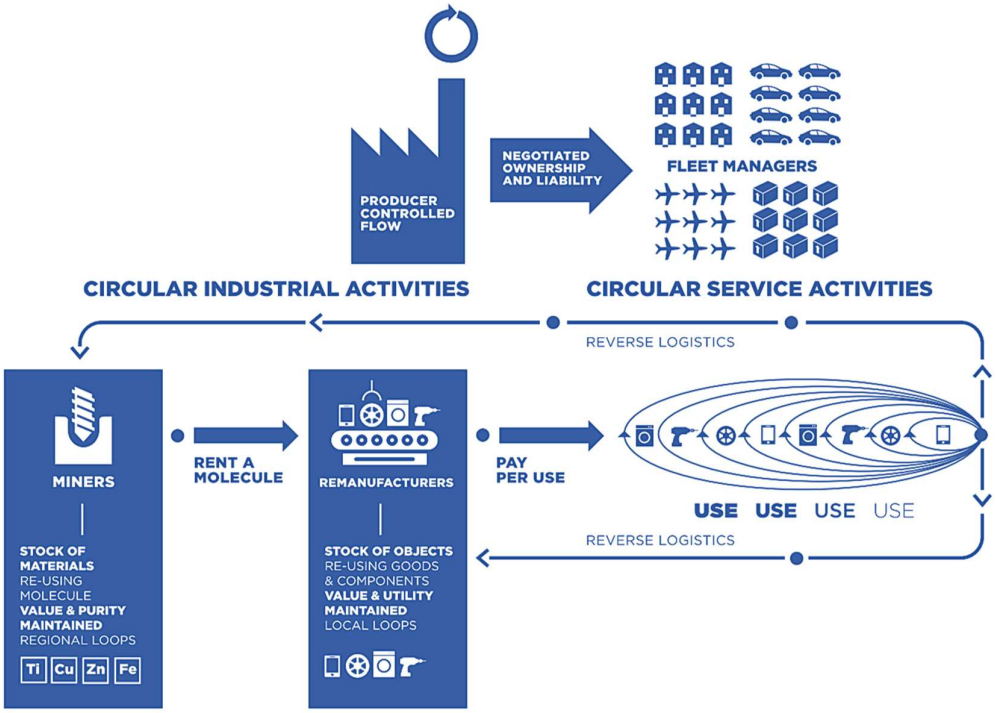

Figure 4 The Performance Economy (Stahel & MacArthur, 2019, p. 70)

The circular Performance Economy model illustrated above goes further than the traditional rental service in that it creates a whole ecosystem. It is not only the rental company (fleet manager) that would be renting the product to the user, instead they are also renting the product from the manufacturer who is renting the materials necessary to make the product from the supplier/miner. This is in part possible with the developments in information technology, which can help track resources throughout their use cycle and maintain a closed loop (Stahel & MacArthur, 2019, Chapter 8).

This circular Performance Economy model provides a clear illustration of the aspects that the European Circular Economy Action Plan seeks to address (European Commission, 2020, p. 4). Although the broader circular economy, sometimes more broadly and possibly more aptly referred to as Green Economy (GE), has also being criticised as it focuses on driving the solutions to environmental issues through the manipulation of market prices rather than tackling inequality and consumerism head-on (Demaria & Kothari, 2017, pp. 2590–2592). While this critique of its potential sustainability is understandable as it does not directly seek to stop the use of new virgin resources, CE still is very ambitious in its aim to drastically reduce and phase out resource use in ways that often require advanced technologies and infrastructures to substitute natural processes (Vlasov & Vincze, 2019, p. 261). As these technologies develop they have the potential to revolutionise incentive programmes and household waste segregation, although the technology will have to mature so that legislative and ethical issues surrounding the privacy and sharing of user data are worked out (Stahel & MacArthur, 2019, Chapter 8). Whether this approach will ultimately be successful is yet to be seen, but that the EU is working within this framework is however not surprising given the global situation discussed in the introduction, and the effort that would be required to transform the current system. A system that is fuelled by the consumption of natural resources (Marks, 2015; Marten, 2001).

2.2.2 The Principle of Least Effort

The great many choices that have led the world to adopt circular economy as the way forward towards sustainability, these can be understood through the values that maintain the status quo of economic growth, or they can be understood through the effort necessary to overcome those values and adopt an alternative framework such as degrowth which aims to break the political and cultural status quo on which these choices are based (Asara et al., 2015). Similarly, the effort required by a household to start segregating the waste it generates can help understand the challenges households face and what measures may be necessary to mitigate them. It can be said in general that changing previous behaviours, the overcoming obstacles and forming new habits, requires considerable effort and that this effort needs to be taken under consideration (Zipf, 1949, p. 11).

Human behaviour can generally be quantified in terms of effort, which when describing the principle of least effort would mean that an entity will tend to choose the most convenient, least taxing method, and exert effort until minimally agreeable results are achieved in solving both immediate problems and probable future problems (Zipf, 1949). While it is by no means new, this deterministic model of human behaviour has been tested mathematically in many different human settings (Bierbaum, 1990), therefore it ought to provide some guidance in this study by allowing for a better understanding of human behaviour. Specifically, as in the review of previous studies, effort seems to be more central to

household recycling behaviour than the unit pricing which following the polluter pays principle would be the first choice to regulate the behaviour of householders in the circular economy framework. Following this line of reasoning, understanding the obstacles faced and efforts necessary by householders ought to provide for a clear understanding of what expectations can be reasonably placed upon them, and aid in the resolution of the previously mentioned Technological-Organisational conflict between waste producer and collector that needs to be addressed in the creation of a functional recycling system.

2.2.3 Data-Driven Exploratory Research

So far, this paper has examined the problem that there is a lack of research on the topic of how various aspects of the dwelling affect household recycling behaviour, and why this research is important considering that it is the households who have the burden of segregating the waste. Also presented was the disjunction between how behavioural changes are motivated in the circular economy framework with unit pricing which previous research has proven ineffective, versus how behaviours can better be understood through the principle of least effort. While one approach to addressing this problem would be to examine a large number of households in a variety of dwelling configurations and objectively measure the work that they perform to segregate waste. Such a purely quantitative approach would be far beyond the scope of what is possible in this study as it would require extensive collection of data from each household. The large number of variables involved in this process has already been discussed in the review of previous studies, and while spatial variables are fairly unproblematic, measurement of the associated obstacles which so far have been undefined remains an issue as there is no useful model of how these variables interact. For this reason, when it comes to providing a context for the spatial variables, the development of any model will be driven by qualitative data that is expressed in feelings and attitudes. This approach to understanding householder behaviour is a data-driven approach to research where a specific model is not defined, rather the goal of finding what can be done to facilitate householder recycling behaviour is accomplished through a data-driven model where issues, and opportunities are presented by the data (Simchi-Levi, 2014).

> *"In problem-driven research, an academic or industry professional identifies a problem and uses models and data to develop insights and possibly make improvements in practice. In data-driven research, data are gathered from an organization before any specific model is developed; it is the academic's careful analysis of the data that sheds light on possible opportunities to make improvements." (Simchi-Levi, 2014, p. 8)*

The above distinction comes from industrial research with a procedural focus rather than the type of data, and the divide between quantitative and qualitative research methods less polarised than it seems to be in social research where there is a clear divide (Bryman, 2012, p. 614). This distinction is also

important, as this research will be survey-based and use quantitative and *"quasi-quantitative"* methods in a way that makes it more of a "*exploratory*" study, rather than one where a model/hypothesis is tested as is often assumed is the case for quantitative research (Bryman, 2012, p. 621). Although the specifics of these quantitative methods will be saved for the next section, the way that the qualitative data will be organised and put in relation to the quantitative data needs to be discussed, as it will take a queue from *grounded theory* which in qualitative research is synonymous with a data-driven approach. Specific for this study will be the use of *open* and *selective coding,* whereby text provided by the respondents will be categorised and linked, to allow for the data to be defined through *inductive* means as is part of the process in grounded theory (Bryman, 2012, pp. 568–569). This *mixed methods* approach is useful in that it allows for the different types of data to complement each other in a variety of different interrelated ways, these ways were identified in the methodology literature used here and show that combining quantitative and qualitative data has a broad range of benefits (Bryman, 2012, pp. 633–634):

> **Triangulation or greater validity**: Where the qualitative and quantitative data will potentially corroborate each other.
>
> **Offset**: The quantitative data will be able to compensate for the biases from the qualitative data, whilst the qualitative data reduces potential problems that can be associated with long surveys (more in next section).
>
> **Completeness**: Combining both types of research will allow for a more complete account of what goes on in the households.
>
> **Process**: While quantitative data will suffice to provide static metrics that relate to the dwelling, qualitative data is procedural and well suited to providing a description of the process of recycling where gathering measurements is impractical.
>
> **Different research questions**: The first research question (RQ1) could be reasonably answered with a purely quantitative approach, but the second (RQ2) deals with a far greater number of variables of which many were covered in the review of previous research.
>
> **Explanation:** The different types of data will help explain each other and answer the research questions.
>
> **Unexpected results**: As a lot of this research is inductive there is the possibility for some unexpected results.

Instrument development: The results of the open coding could be used to assist in future studies by providing new items that are relevant for household recycling behaviours.

Sampling: Depending on the response rate, data can be used to create specific cases in the analysis that represent a large enough group of respondents to be representative.

Credibility: Not letting just one type of data speak for itself increases the credibility of the findings.

Context: The qualitative answers can provide a lot of context to how the spatial metrics of the dwelling relate to the recycling behaviour in households.

Illustration: Answers to open-ended questions can help illustrate the '*dry'* quantitative data.

Utility or improving the usefulness of findings: The combination of research methods improves the usefulness of the findings by allowing referencing to both the qualitative and quantitative data.

Confirm and discover: Hypotheses could potentially be generated from the qualitative data and tested with the quantitative data given a large enough sample size.

Diversity of views: Whilst a researcher may have an opinion about a relationship that can be represented in quantitative data, the qualitative data allows for a diversity of views that could present an alternative theory.

Enhancement: Findings from one part of the research can be used to enhance the other, by giving the findings a higher resolution.

Other/unclear: Will have to wait and see in the results, apart from unexpected results there may be other unspecified benefits that are unknown at this time.

Taking a note of the versatility that is provided by a mixed methods approach through all these different ways that were identified by Bryman (2012), the methodology chosen for this study aims at utilising these strengths in the combination of qualitative and quantitative data to provide a more comprehensive analysis of household waste segregation.

3 Methodology

This chapter will present the methods and procedures used. Specifically, how and why specific data will be collected, how it will be interpreted, and what methods of analysis will be used to compare the data. By providing a detailed account of how this research is conducted, not only will the results be easier to contextualize, the framework of this study will also be easier to replicate and extend in future research (Bryman, 2012, p. 177).

3.1 Data Collection

The research will follow a cross-sectional design. As is typical for this type of research, data will be collected from multiple cases (households) through an online survey that will ask a series of questions in a systematic and standardised way, so that patterns of association may be identified in-between variables through the subsequent analysis (Bryman, 2012, p. 59). To collect relevant and accurate data, special considerations need to be taken in the way that the survey is created and deployed. In the case of this study these considerations also need to be balanced with resource and ethical constraints (more on this below, see: 3.1.3), and therefore Facebook will be used for collecting the data since recent research has shown it to be an efficient platform for reaching target demographics (Kalimeri et al., 2020).

3.1.1 Sources and potential biases

Potential biases need to be accounted for in advance with the data-driven approach that is being taken, as data collection through social media may have biases which could be transferred to the results. One key issue is that where the data comes from and which householders answer the survey has a direct impact on the results, therefore there needs to be some control over who the respondents are. To achieve this the survey will through its disposition control for the location of the respondents, in part by being posted to Polish Facebook groups, but also by using the local language and asking respondents to provide a Polish postal code. There are potential sampling issues to take into consideration where there may be a bias in some variables based on the background of the respondents. With one source of bias being that internet-users have a tendency to be a better educated, wealthier, and younger part of the population (Bryman, 2012, p. 673), while another is that Facebook respondents tend to exhibit additional behavioural biases when self-reporting behaviour (Kalimeri et al., 2020). Some of this bias will however be controlled for by the study due to its focus on whole households rather than individuals, with the respondent being instrumental in measuring the household rather than being the subject of the study. This does limit the study in generalisability, as households that do not contain an internet user lack the ability to participate. The nature of this study seeks to address this bias by focusing on practical household matters, such as spatial factors and obstacles faced, rather than

the more complex matter of the ethno-socio-economic composition of the household which would require a far more extensive study. And though this study may yield some generalisable results within the contemporary Polish context, these results will not necessarily be applicable to the same extent in other localities where socio-economic conditions and recycling standards differ (Bryman, 2012, p. 176).

3.1.2 Survey and data processing

The survey will use Google Forms to ask respondents to answer during a period of one week a selection of quantitative and qualitative questions. The survey will have four parts which include an introduction followed by distinct parts with questions about recycling, the household, and personal information. The answers will then be exported into Microsoft Excel and coded for a quantitative analysis in IBM SPSS Statistics (more on this in 3.2). While the survey and how it is coded can be found in Appendix A, the structure and coding of each part, and how it relates to the study in general will be as follows:

> **Introduction:** Participants are informed that the survey is on the topic of waste segregation in various households, that the estimated completion time is about 5 minutes, and that all answers are anonymous. This is so that they understand why the survey is being conducted and what is being asked of them before they proceed to answer the questions. One downside here is that householders who are not interested in the topic or consider themselves too busy may be underrepresented, because they can readily exit the survey as it is voluntary with no incentive provided for participation.
>
> **Recycling**: This part consists of two pages that collect quasi-quantitative and qualitative data where respondents provide estimates or express opinions. On the first page respondents will be asked to rate the level to which they segregate their waste in the four categories that are standardised Paper and cardboard, Product (plastic/metal), Glass packaging, and Biological waste (Ministerstwo Klimatu i Środowiska, 2020). The rating will be done on a five-point Likert scale[3] (Scale: Not segregated, Rarely, Sometimes, Often, Always), and the result will be transformed into a composite variable that represents a percentage of the respondents' overall segregation rate, this will be the main dependant variable for the analysis of the survey results. This format was chosen as it is not likely that householders will be able to provide an exact quantitative measurement that represents how much they segregate, such as a weight, volume, or percentage of either.

[3] A multiple-item measure named after Rensis Likert. It is a common technique used to let respondents answer/rate a given question/statement by indicating on a scale their level of agreement, frequency, or evaluation. (Bryman, 2012, p. 166).

The second page of this part will ask respondents to rate their willingness to put effort into waste segregation on a ten-point scale, this question provides some Socio-Psychological insight into the respondents that is equivalent of the *personal effort* variable in previous studies. While this is by no means an objective measure and closer represents the attitude of the respondent, it will serve an important role by acting as a control for the respondents' subjectivity and allow other metrics to be more objective. This question will be followed by two open questions about what they experience as the biggest obstacle and motivator with regard to household waste segregation. The answers to the open questions will be coded into groups, these groups are not predetermined and will be created in accordance with the answers the respondents provide. The exact disposition of this coding will be apparent in the results. To allow for the discussion of each respondents' specific answer to these questions, the respondents each will be provided with a unique random five-digit ID number that can be used to refer to their specific response.

Household: This part will consist of three pages, with one of these being skipped based on what response is provided. The first page has some contextual questions that provide some insight into the circumstances in which the householders and the dwelling are located. Here respondents provide their postal code, along with information regarding whether they live in a single-family or multi-family building, if their dwelling is shared in the case of a room being rented out, and what recycling options are available in their area.

On the next page the respondents get relevant questions about their dwelling, with the page/questions being based on the answer they provided to the question about the type of building the dwelling is located in. These ask the respondents to specify the size of their dwelling, the number of rooms, how many people live in the dwelling, if there are any children, and if there are any convenience factors that might influence the effort required for waste disposal (garage or garden if single-family was selected, and elevator/ground-floor if multi-family was selected).

The answers provided in this part provide the spatial data about the dwelling and its occupancy. These metrics can then be combined in the analysis to provide composite variables for each household including: rooms per person, area per person, area per room. Composites that will allow a more detailed discussion about what spatial factors influence the segregation rate the most. When it comes to the postal code, that is to verify that the respondents are in Poland and also to provide a geographic reference with population data. Population data and name of the location will be entered manually based on Google for the postal code, this as available data

online has been incomplete for referencing all the postal codes and the original use case for this data has changed since the planning phase of this study (see next section: 3.1.3).

Personal: Last section is thanks for participation, and asking respondents to provide age and sex so as to give an idea of who answered the survey. This allows the data to be framed demographically, and to see where it is lacking with regard to the representation of the various household demographics discussed in the introduction (see: 1.1.3, figure 1). While spatial techno-organisational factors in a dwelling may in many ways depend on outside factors, for example how many categories waste needs to be sorted into. How the interactions between these factors are experienced is based on socio-psychological factors which are more subjective and could vary between demographics (see: 2.1).

Overall, the mix of questions in this survey seeks to quantify the household engagement in waste segregation, and the specified spatial circumstances of the dwelling. And the data from the open questions is then used to provide qualitative context to the interactions that the households have when it comes to waste segregation through the respondents own eyes (Bryman, 2012, p. 408). Whilst this context could potentially be provided through a purely quantitative survey, the amount of options necessary to capture all the possible answers would likely substantially increase the length of the survey and increase the risk of not gathering enough responses due to respondent fatigue (Bryman, 2012, p. 235).

To further engage the respondents and give them a clear indication that the questions being asked are relevant to the topic, the order of the questions was also taken into consideration by placing the ones relating to waste segregation first so as to keep the respondents on track (Bryman, 2012, p. 221). Whilst also following the general guideline of placing questions that deal with opinions and attitudes before those that deal with behaviours and knowledge, as this order reduces the risk of one answer affecting the other (Bryman, 2012, p. 222).

3.1.3 Ethical Considerations

With this research being conducted during the third quarter of 2020, a primary concern was how to avoid contributing to the harm being caused by the ongoing coronavirus pandemic (Holder et al., 2020). Part of addressing this concern was conducting this research online through social media, instead of as initially intended through in-person surveys and focusing on the Wrocław metropolitan area, an approach that would have allowed this study to collect data from a broader demographic and avoid any of the mentioned biases associated with online social media surveys (see: 3.1.1).

When it comes to other ethical concerns that may arise in social research, these are also addressed by using data provided voluntarily for the explicit purpose of studying household waste segregation. Participants will be informed about their anonymity and the topic being researched at the start of the survey. Personal socio-demographic information is limited to the basics, as previous research has shown it to be rather ambiguous with regard to household recycling behaviour (see: 2.1). This targeted and transparent nature of the study also protects the anonymity and integrity of participants, thereby covering the main areas where ethical concerns may arise by avoiding harm to participants, lack of informed consent, invasion of privacy, or deception (Bryman, 2012, p. 135).

3.2 Data Analysis

After providing a summary of the responses and a review of the coding, the data will be analysed in three steps. The first part will attempt to answer: *RQ1: How strong, if any, is the relationship between a households' rate of waste segregation and various spatial factors that relate to the dwelling?* This will be done with an initial bivariate analysis that compares variables in pairs. The relationships between scale (interval/ratio) variables will be measured with the Pearson correlation coefficient, and for the relationships between the scale variables and the dichotomous variables Spearman's correlation coefficient will be used as that is the correct method for these combinations of variables (Bryman, 2012, p. 340). In both cases the result is between 0 which indicates no correlation, and 1 which indicates perfect correlation (Bryman, 2012, pp. 341–344). In both cases bootstrapping will be used to resample the data and produce confidence intervals for a given value which gives a possible range for the correlation coefficient (Diciccio & Efron, 1996), and in both cases the analysis will look at correlations that are at least 95% certain or in other words are significant at the 0.05 level (Bryman, 2012, p. 348). This combination of analyses will indicate any significant bivariate correlation between the measured spatial factors of the dwelling and the households' rate of waste segregation,

The second part will attempt to answer *RQ2: What obstacles in sorting waste do households face in relation to their dwelling, and how can they be mitigated?* The preliminary analysis to answer this question will take an approach often used in addressing the most important issues, namely the Pareto principle which estimates "*that 80% of the impact comes from only 20% of the potential causes"* (Harvey & Sotardi, 2018). This will be done by putting the coded obstacles for household segregation into a Pareto chart (bar chart in descending order for values of the y-axis, and a line showing the cumulative percentage of the bars), then interpreting the results by putting the motivational factors in relation to the obstacles. Further analysis will be performed with the help of box diagrams which will illustrate the distribution of the obstacles in relation to various scales, including the participants

willingness to put effort into segregation and various household special variables for which some kind of correlation is established in the first part of the analysis.

Finally, in the last part of the analysis all the collected variables that are relevant to this study will be put in relation to one another. This way it will be possible to measure the importance of each variable in predicting recycling behaviour and thereby try to provide some basis to a more comprehensive answer for the second part of RQ2, that is *how the various obstacles to household recycling can be mitigated*. For this part of the study an artificial neural network will be used instead of linear regression, as neural networks are better at accounting for nonlinear data (IBM, 2019). Specifically the procedure that will be used is the multilayer perceptron (MLP), which is one of the modules in the *IBM SPSS Statistics Version 26* software being used for this study (IBM, 2019). These neural networks have been proven in multiple studies to be more effective at predicting behaviours than traditional statistical models (Akın, 2011; Assi et al., 2018; Noori et al., 2009). The downside here is that the underlying processes are not very interpretable (IBM, 2019), with some authors going as far as describing them as a *'black box'* (Leppink, 2020, p. 45). However, understanding the underlying processes is not a priority here given that the data will already have been interpreted in earlier parts of the analysis and that nonlinear qualitative data will be included in the analysis, the resulting model will need to speak for itself based on its ability to predict the segregation rate of households that answered the survey. What is important to mention is that repeatability is largely dependent on the sample size, with neural networks generating much more consistent results when the number of respondents is in the thousands and varying results with smaller populations (Leppink, 2020, pp. 45–47).

4 Results

4.1 Responses

This section will start by briefly presenting the response rate to the survey, including how the demographic and geographic properties of the respondents relate to this study. This will be followed by a summary of the responses to the open questions about what householders consider to be the greatest obstacle and motivator when it comes to the segregation of waste, and a review of how these responses are categorised and coded.

After having the survey run for a period of seven days the yield was 50 responses, while lower than expected, this ought to provide a representative sample of the households which fit into the demographic that was reached. The respondents were predominantly female with an average age of 24 years, the age and gender distribution can be seen in the figure 5 below.

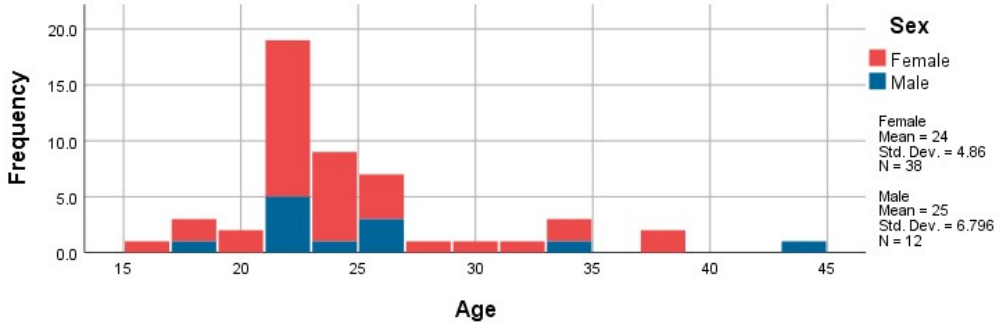

Figure 5 Distribution of age and gender among the survey respondents.

Taking this into consideration it becomes quite clear that the data will be demographically biased towards representing households that contain someone in this demographic, and this data is insufficient to provide an accurate representation of the single households by age and gender that were mentioned in the introduction (see: 1.1.3). On the bright side of things, previous research has shown socio-demographic variables to be largely ambiguous when it comes to household recycling behaviour (see: 2.1), and therefore any study where these factors could be studied in a relevant manner would need a far greater number of responses. The overall household composition among respondents can be seen in figure 6 to the right, 10% were single households and the average number of people per household is 3.2 which given the age distribution indicates that many of the respondents either live with family or friends. A more representative average for Poland would be around 2.6, with single households representing around 25% of the total (EC, 2020).

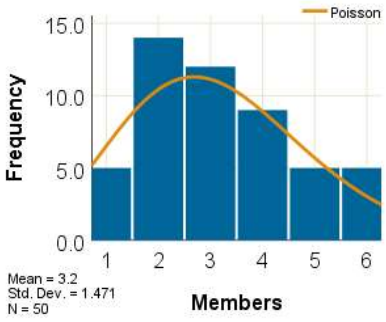

Figure 6 Distribution of household sizes among respondents

When it comes to the dwellings, 33 of the respondents lived in multi-family buildings, with smaller localities having a higher share of single-family buildings, although the younger demographic seems to be reflected in the considerable amount of multi-family buildings for the less populated areas.

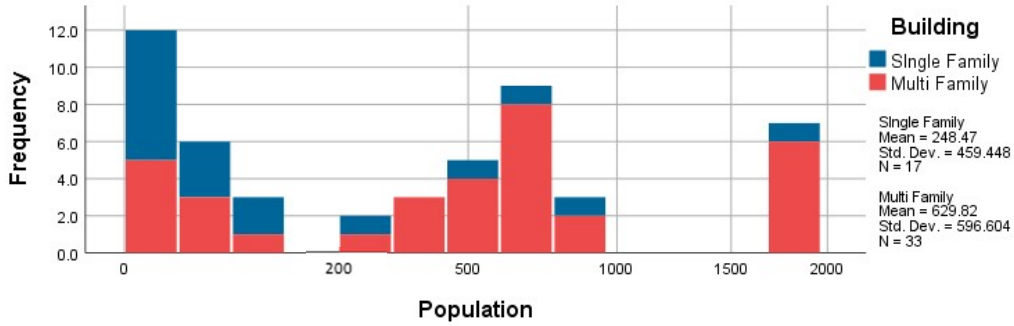

Figure 7 Building type by municipal population.

Thanks to the post codes being used in the survey, more precise geographic distribution can also be explored among the respondents. Here we can see that almost a third of the respondents came from Warsaw and Wroclaw, the remainder was considerably more spread out. The disproportionally large response rate from Wroclaw can be attributed one of the Facebook groups that the survey was posted to being a more local one. However, this ought not affect any results as this study has a rather small number of respondents and geographic factors will therefore not be analysed.

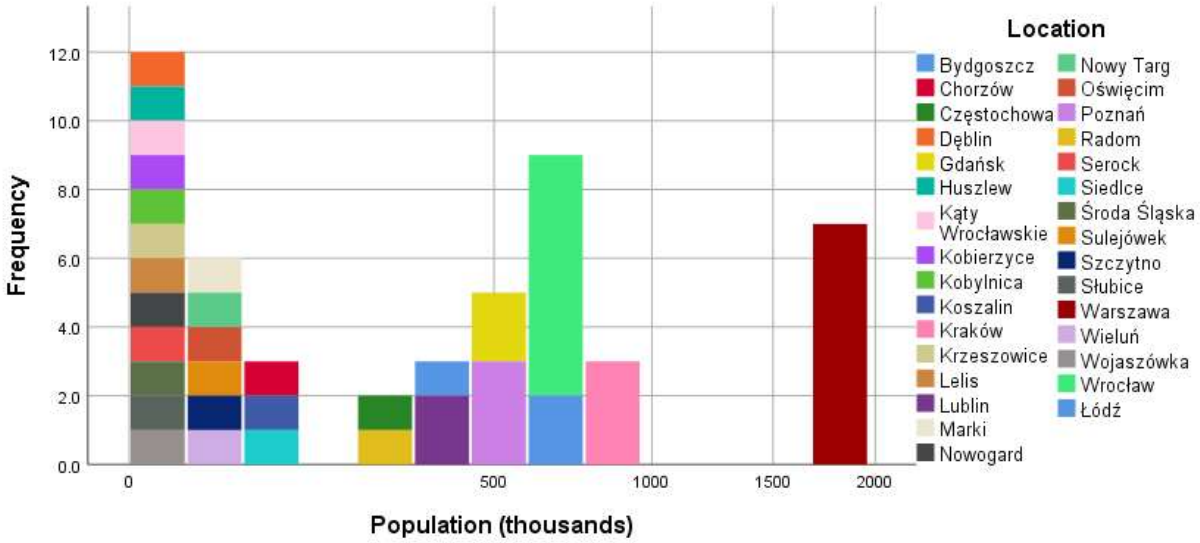

Figure 8 The geographic distribution of respondents by municipality

When it comes to the main variable for this study, the segregation rate of the householders, it is a composite (% of max total) based on the first four questions in the survey where respondents were asked to rate their rate of segregation across categories. The average value here was 70% which would indicate a relatively high level for Poland where the average recycling rate is 34% (Smol et al., 2020), the only issue being that these values cannot be compared as one is a frequency while the other refers to weight. The subjective frequency provided by the respondents doesn't require a volume/weight measure, and functions as a point of reference to measure against the other variables. It may however be worth noting that a weight statistic is biased towards organic kitchen waste, as that weighs more than inorganic recyclables like plastic packaging (Palanivel & Sulaiman, 2014). In that way a frequency measure is more accurate in describing the effort put into waste segregation.

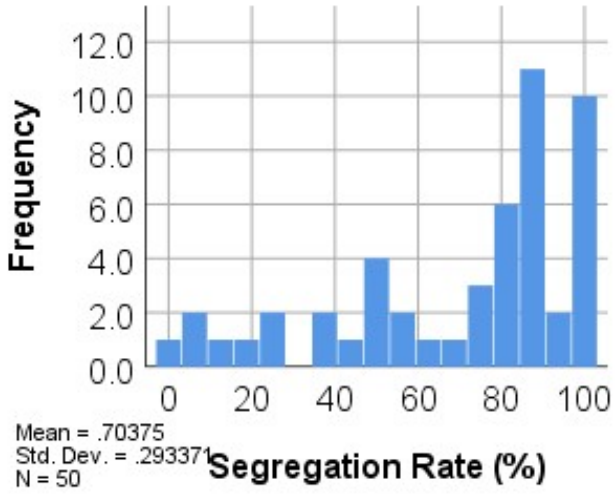

Figure 9 Histogram illustrating the segregation rate of the respondents

4.1.1 Coding

As results of this survey are transformed into an appropriate format for SPSS that is seen in Appendix B, one of the more crucial steps is the qualitative coding where the responses that were provided to the open questions are organised for analysis. In this study a simple table will be used to tally the obstacles/motivators experienced by householders as they can be most reasonably interpreted, and these will be grouped/labelled in categories that also have a numeric code for use in SPSS. The first of these tables can be seen below and it shows how the obstacles were coded.

Obstacle	n	tot	Label	Code
Space under sink	2	23	Space [in dwelling]	4
Space in kitchen	3			
Space in dwelling	12			
Space for bins	3			
Too many bins	3			
Have to wash packaging	3	9	Recyclability [of packaging]	5
Mixed materials	2			
Recycling info on products/packing	4			
Personal laziness	3	6	[personal] Effort	1
Laborious/Complicated	3			
Lack of time	4	4	Time	2
Collection dates not specified	1	4	[municipal] Containers	3
Lack of clearly labelled containers	1			
No bio-container in neighbourhood	1			
Smelly bio-waste container	1			
Too expensive	1	1	Costs	6
No Obstacle	3	3	No Obstacle	0

Figure 10 Coding of the obstacles. n = number of respondents.

The table shows how the responses were coded/standardised into **obstacles**. With repeat cases being tallied (**n**) and then totalled (**tot**). They were then linked with a **label** into groups based on what the underlying reason is, with a number **code** being provided for use in the dataset (see: Appendix B). Overall, this procedure provided a clear standardised way for the data to be categorised for analysis.

The coding of the obstacles revealed that the responses could be grouped into seven categories that could be expanded in a larger study, but given the small number of respondents these groupings give an adequate resolution for the study. While the categories can be debated, the overall current structure is the most intuitive for the purpose of the study. Some groupings of obstacles that were considered but not used for this study included:

> **Information:** This one could contain obstacles such as *recycling info on products/packaging* and *lack of clearly labelled containers,* and would be in line with the socio-psychological categories used in previous research. However, it was deemed more appropriate to see this from a techno-organisational perspective and group these with the place/object that is at fault, in this case the lack of information affects the recyclability of the packaging, and the lack of clear labelling on the municipal containers makes waste segregation harder.
>
> **Complicated recycling:** Another possible category that was considered to house the *too many bins* and *laborious/complicated* responses. But the number of bins at home was mostly

associated with space, and the responses where the obstacle was a laborious or complicated segregation process all provided an incentive as their motivator, therefore their placement in the current categories is the most reasonable interpretation of these less than crystal clear responses.

A similar analysis can be made with regard to the motivational factors provided by the respondents, these were grouped into six categories and in many ways, they can be paired with the obstacles. The table of how these motivators were coded can be seen below.

Motivator	**n**	**tot**	**Label**	**Code**
Nature or doing the right thing	24	24	Environment	1
Financial compensation	3	10	Incentive	2
Discount on waste collection	4			
Penalties/fines	1			
e.g., plant saplings [eco incentive]	1			
Why me, not the landfill worker?	1			
Less complicated rules	1	4	Simplification [of the recycling process]	3
Fewer categories	1			
Less things in foil packaging	1			
Clear info on product/packaging	1			
More space at home	2	4	Space [in dwelling]	4
Designated space at home	2			
More frequent waste collection	2	4	[municipal] Containers	5
Clearly marked containers	1			
Availability of containers	1			
Don't know	4	4	Don't know	0

Figure 11 Coding of the motivators. n = number of respondents.

By far the largest category is that respondents were in one way or another motivated by the *environment.* This category could easily be split into *general environmental concern* and *personal satisfaction* from doing the right thing for the environment, one is more altruistic and the other more egoistic. However, as this study is not focused on the socio-psychological factors, all the responses that fit this general template were grouped together into one for the purpose of this study.

The remainder of the categories was quite intuitive to code and a relationship can be seen between motivators and obstacles. Providing an *incentive* would for example in some form reasonably motivate people to put more *effort* into waste segregation, although considering that previous research has shown that people do not always act in accordance with this kind of motivation would make it crucial to consider how such an incentive programme ought to work (see: 2.1). The *simplification* category deals with most obstacles in one way or another, a property that will be explored in the analysis. And the *containers* motivator group clearly correlates with its obstacle sibling in that it represents the main

interaction and all the associated grievances respondents had with the municipal recycling system. In all container related replies, it was either the container quantity, labelling quality, or the associated service of emptying that was at fault.

4.2 Analysis

Having coded and discussed the coding of the qualitative data, this section will proceed with a three-part analysis in accordance with what was specified in the methodology chapter.

4.2.1 Bivariate Correlations

The bivariate correlation of variables did find a statistically significant correlation between householder rate of recycling and the number of rooms in a dwelling, with the relationship between these two variables having a Pearson's correlation coefficient of .319. To put this into perspective with the other interval variables analysed with the Pearson's method, respondents self-reported willingness to put effort into waste segregation had the strongest correlation at .589, and the population data derived from the respondents postal codes was not found to be statistically significant with a coefficient of .040 despite urban areas having fewer single-family buildings in the which in previous studies been a significant variable and town centres having been described as problematic (one would expect a slight negative coefficient here).

The number of rooms correlated in turn strongly with several spatial factors, including dwelling space (.771), number of household members (.599), space per person (.559), and rooms per person (.396). These strong secondary relationships warrant further analysis with regard to the obstacles faced by householders in the next section.

When it comes to householder segregation rate and the dichotomous variables, there was a statistically significant correlation (.407) with householders reporting that biological waste containers are available in the neighbourhood, which also indicates that the householders are informed as the opposite relationship can be observed in the data (Appendix B) with the householders that had the poorest segregation rates also being the most frequently uninformed about the availability of designated containers for recycling. This relationship is in line with what previous studies have found about information and knowledge playing an important role, what can be asked though is if the householders recycle because they are informed or whether they are informed because they recycle, .

The other two dichotomous variables that were found to correlate with household segregation were gender (-.321 indicating that males segregated less among respondents), and the presence of children (.354) which correlated with several of the earlier mentioned spatial factors.

With the exception of householder willingness to put effort into waste segregation, these correlation coefficients need to be taken with a large grain of salt as due to the low sample size they are by no means certain to be statistically significant. This can be seen in the 95% confidence intervals that can be seen in the correlation tables Appendix C and D. In the case of the relationship between householder segregation rate and the number of rooms in a dwelling, the upper end of the confidence interval suggests a statistically very significant correlation of .547, whilst the lower end places it at a rather insignificant .107 which is equivalent to a coin flip.

Overall, what can be said to answer RQ1 at this point in the analysis? At most that based on the sample size, there is a likely statistically significant correlation between the number of rooms in a dwelling and the households segregation rate that is enough to warrant further exploration when put into perspective with other variables.

4.2.2 Review of Householder Obstacles

When it comes to the obstacles that households face, it was apparent already in the coding phase which factors were most prevalent. Taking into consideration that special care was taken in the order of the questions so that those about the spatial factors of the dwelling would not influence the responses provided with regard to the obstacles, a particularly surprising result was that almost half of the respondents found a special factor in the dwelling to be their greatest obstacle. This can be seen in the chart below which shows that 46% of the respondents had an obstacle relating to the amount of space in the dwelling, which also provides an answer to the first part of RQ2.

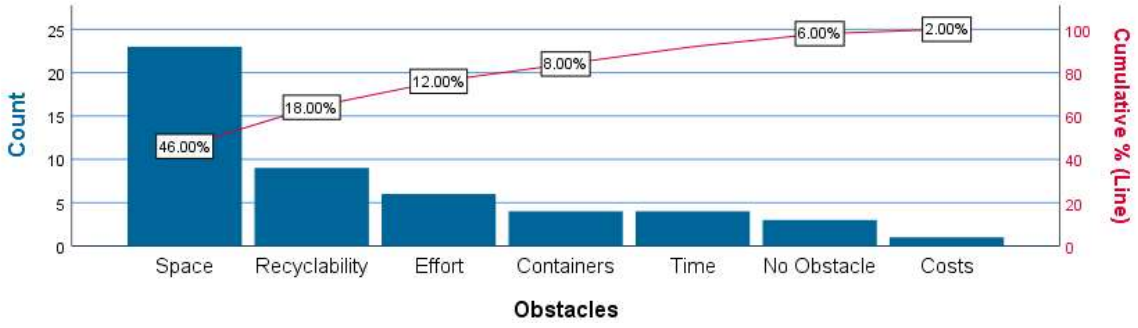

Figure 12 Pareto chart of the obstacles reported

Here it is also clear that most of these obstacles are connected to the process of segregation as it is experienced at home, with space and recyclability accounting for 64% of the responses. Even time and effort may be seen as being connected to these factors, which based on this data would mean that up to 84% of the obstacles householders face in the segregation of waste could be mitigated by focusing on the dwelling. The next step would be to take a look at what would motivate householders to

segregate more and by putting the self-reported motivational factors in relation to the obstacles, this provides us with the following chart.

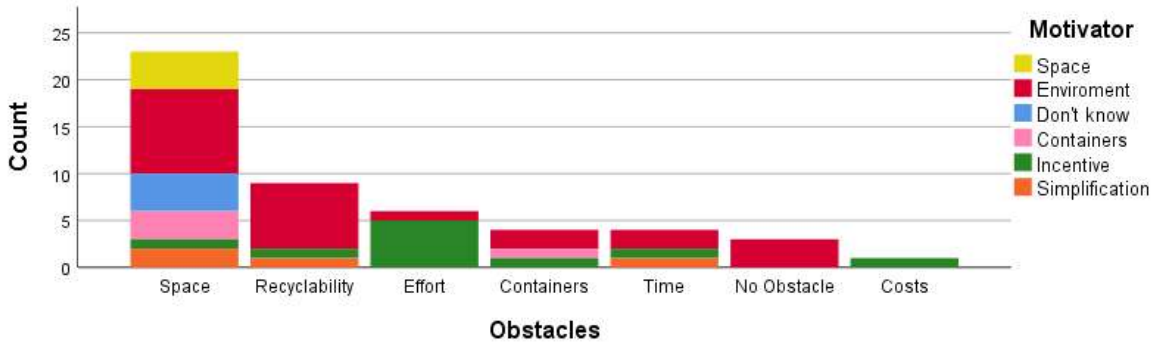

Figure 13 Chart showing the associated motivational factors for each obstacle.

By seeing which motivators were provided with each obstacle, it becomes apparent that motivational factors varied among respondents with regard to the obstacle they specified. Although even if the sample size is too low to draw any statistical conclusions for the pairings, there are some observations to be made with regard to the connection between obstacles and motivators.

Firstly, those who would be motivated to segregate more by having more space, and those who did not know what could motivate them all had specified space as an obstacle. This could be indicitative of these respondents experiencing space as an absolute obstacle with regard to their level of engagement in the segregation of waste. Secondly a majority/all of those for whom effort or cost was the greatest obstacle, specified that an incentive would motivate them (although the costs relationship is a single respondent). Here, as has already been mentioned in the coding of these results, the way in which people would be incentivised would need special consideration as previous research has shown that behaviour is not always consistent with this motivator (See: 2.1 & 4.1.1). Similarly a majority of those for whom recyclability was an obstacle, and all of those who did not see any obstacle, were motivated by the environment. This can be interpereded as people who have overcome most of their own obstacles when it comes to segregation, with the recyclability obstacle indicating an issue seen by a thusly enlightened group of individuals.

These observations while plausible have little relevance without being put into context of what impact they could have, for this the various factors can be put in relation to the householders rate of segregation.

Looking at the relationship between stated obstacles and the segregation rate of householders we see that those with the lowest rate often felt like time, space, or the necessary effort were the greatest obstacles. While the respondents with a less than 50% rate of recycling only make up about 28% of the respondents, it is these respondents that are the most crucial to understand in the pursuit of a circular economy as the rest are already relatively active participants in the segregation of waste. Addressing the remaining minority requires a good understanding of the dynamics involved, as they will require the most resources and effort due to the problem of diminishing returns in the outcomes of management efforts (Hone et al., 2017). For those with a high rate of segregation we can see a confirmation of the previously mentioned observation, in that those who had recyclability as an obstacle, or did not experience any obstacles, are indeed active participants with a mean segregation rate of ~87% and ~98% (see: Figure 14). For a further inquiry a similar comparison of the motivating factors can be seen in the figure below, here we see that those who would be motivated by incentive or did not know what would motivate them were overrepresented among those with a low rate of segregation.

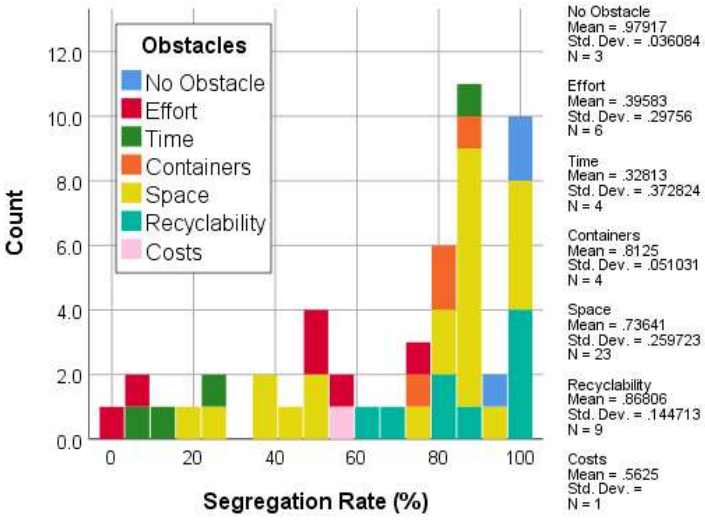

Figure 14 Distribution of obstacles by segregation rate

Given the higher diversity of obstacles and motivators among those with a higher rate of participation in waste segregation, it would seem that those who actively participate in waste segregation have a greater knowledge with regard to what the actual challenges are. While the available data makes any statistically reliable test of these relationships impossible due to the low sample size

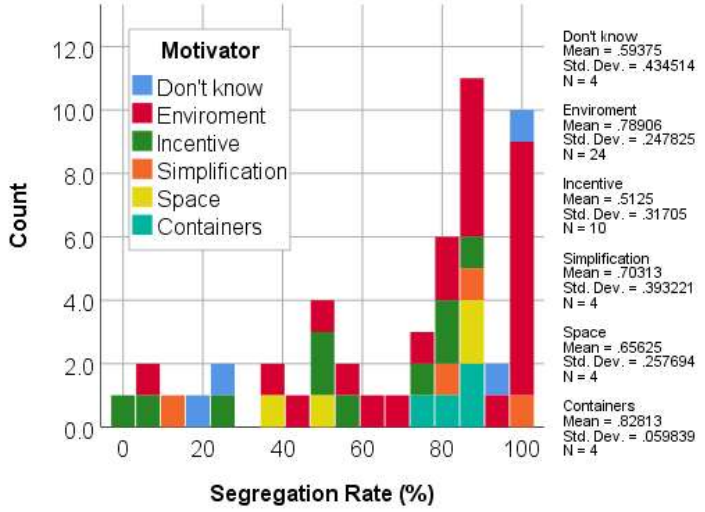

Figure 15 Distribution of motivators by segregation rate

of any given pairing of factors, some additional observations can be made of how the obstacles relate to the spatial factors of the dwellings to see if any of the factors overrepresented by the householders with a low segregation rate are limited to certain metrics. Seeing this overrepresentation of relatively infrequent factors among this part of the population at the same time as they occur among respondents with a higher rate of segregation, it would not be too surprising if the qualitative factors would exhibit that kind of grouping around some of the variables to which the segregation rate correlated. This can be explored by illustrating the obstacles in relation to those variables.

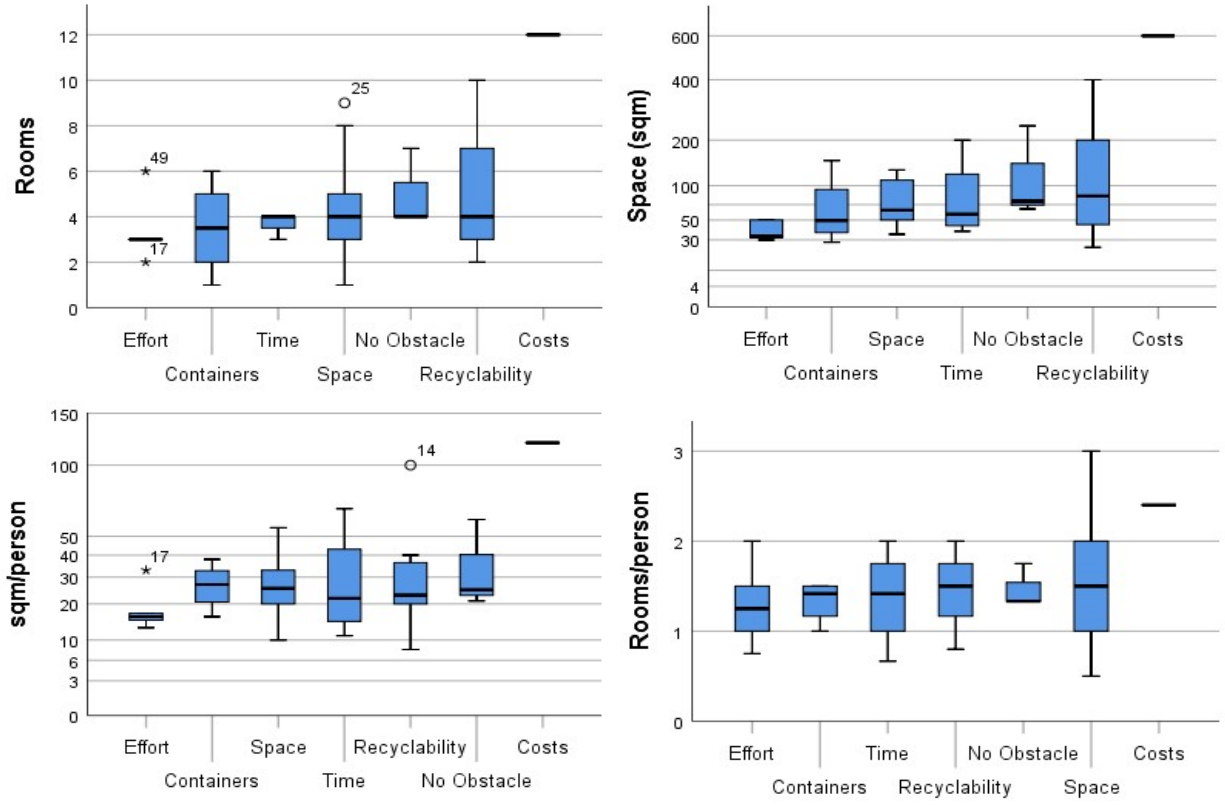

Figure 16 Charts showing the distribution of obstacles by various spatial factors

The charts above show that there seems to be a stronger relationship between obstacles and spatial factors than was the case directly with the segregation rate, with effort followed by containers being concentrated to the smallest metrics, followed by either time or space. The importance of the containers obstacle when it comes to the amount of available space in the dwelling could depend on those respondents having less space to store a surplus of recyclables for when the containers are full due to delayed service. The clearest illustration to this can be seen in the top right chart showing that a significant portion of those that experienced the effort required or container related issues are located in dwellings of less than 50 metres squared. As has already been mentioned by previous studies there is an abundance of relationships and explaining them is not a trivial matter (see: 2.1), in this case the

differences between the distribution of obstacles with regard to the segregation rate and the spatial factors could in part be attributed to certain householders being more willing to exert effort than others. This can be seen in figure 17, with those who stated that effort was an obstacle being the least willing, while those with no obstacles were the most willing to put effort into waste segregation. The same could be said of the possibility of larger groups of people dealing with problems differently as the order among the obstacles changes again as seen in figure 18 below.

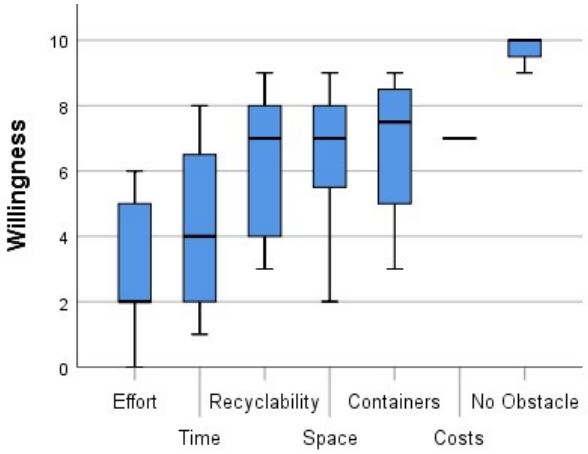

Figure 17 Distribution of obstacles according to willingness

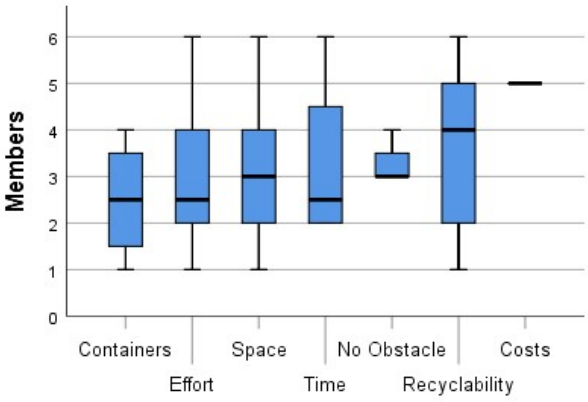

Figure 18 Distribution of obstacles by the number of household members

Therefore, before moving onto a more advanced multivariate analysis to try and put everything into perspective, a practical preliminary answer to the second part of RQ2 would have to be based on the three most common things that respondents said would motivate them for which anything could be done. It is also the only three groups that are practical in nature, and directly affected by how the recycling system is built up, namely incentive, simplification, and containers. The most prominent of these would be a simplification of the segregation process, as that could reduce the need for incentives and simplify the logistical challenges associated with having to manage the collection of a multitude of waste categories. A simpler segregation scheme also addresses the issue of space that was the most prevalent obstacle, and reduces the third-place obstacle which is the effort required in sorting waste. Simplification is also the solution to recyclability, although this would have to be a regulatory process whereby the packaging design is regulated so that it becomes easier to recycle. Regulation with regard to packaging even has the potential to make it easier for more detailed waste segregation to happen through an automated process, instead of having to be the burden of the householders. The cause of the vast majority of the obstacles experienced by the householders seems therefor like it could be remedied by simplification of the recycling process, even though only the parts associated with the municipal recycling scheme can be addressed locally. This is because the two parts of the

simplification with regard to recycling belong to different jurisdictions that need to cooperate. One is the European Union working through its Circular Economy Action Plan to regulate the single market including what packaging design is permissible. The other is the combination of national and municipal governments which need to work in tandem to create a working recycling scheme that meets the needs of their citizens and utilises the regulatory efforts of the EU. The next section will look at what could be prioritised in this improvement process based on the data provided by the respondents.

4.2.3 Nonlinear Multivariate Analysis with Multilayer Perceptron (MLP)

This analysis takes the segregation, dwelling, and recycling related answers, then puts them through an automated analysis that will assign a certain level of importance to each of these based on how well they can be used to predict the level of household segregation. Age and gender variables were left out as the respondents belonged to a very limited and narrow range, whilst various circumstantial data was left out either because of missing data (like the availability of various recycling options), or because the sample size for each distinct variable was deemed too low (for example postal codes which in most cases consisted of single cases). What will be presented here is just these results and a discussion of how these results can be used. The complete information regarding the specific model is for the initiated available in Appendix E. The one important thing to reiterate with regard to this model is that it is based on a very small sample size, and results can in cases such as these have an order of magnitude more variance between trials than in cases based on a few hundred samples (Leppink, 2020, pp. 45–47).

Model Summary

Training	Sum of Squares Error	3.753
	Relative Error	.208
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.02
Testing	Sum of Squares Error	1.466
	Relative Error	.335

Dependent Variable: Segregation Rate

a. Error computations are based on the testing sample.

Figure 19 MLP model summary

As seen in figure 19, the model resulting from the trial presented in this study managed to predict the segregation rate of householders with a relative error of .335 in testing (scale between 0 and 1: lower is better). These predictions are based on the interrelations between the numerous variables that went into the model, the scatter plot below shows that the predicted values correlated quite well with the data.

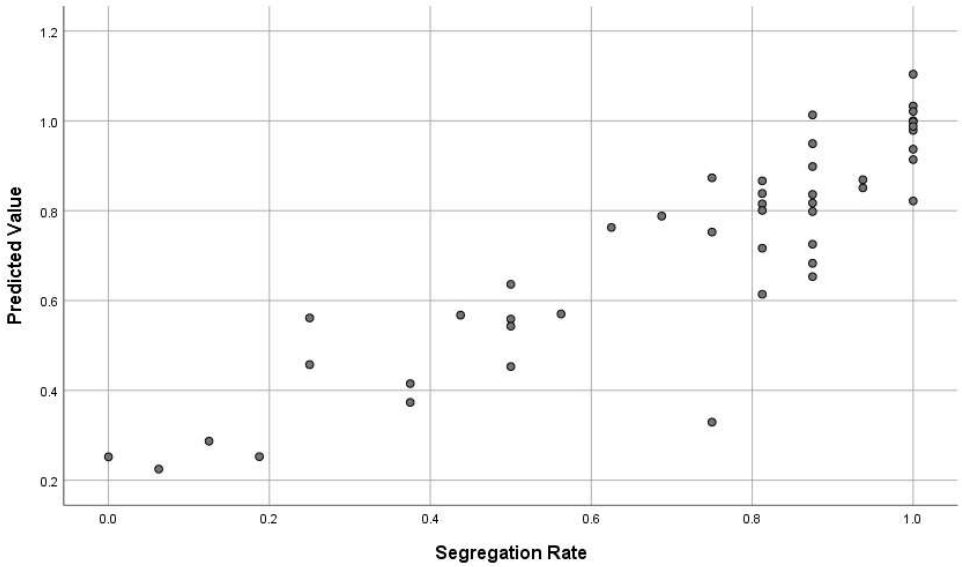

Figure 20 Scatter plot of MLP model predicted values vs. actual values

Looking at the residual scatter plot pictured below, we see that most predictions were within 0.2 of the data. And even though the model was predicting higher than possible segregation rates in some cases (over 1.0), the deviation from actual values was smaller in the prediction of high levels of segregation than for the lower segregation values. The higher deviation in the prediction of lower segregation rates can be explained by the fact that there were only ten respondents with a rate under 0.5.

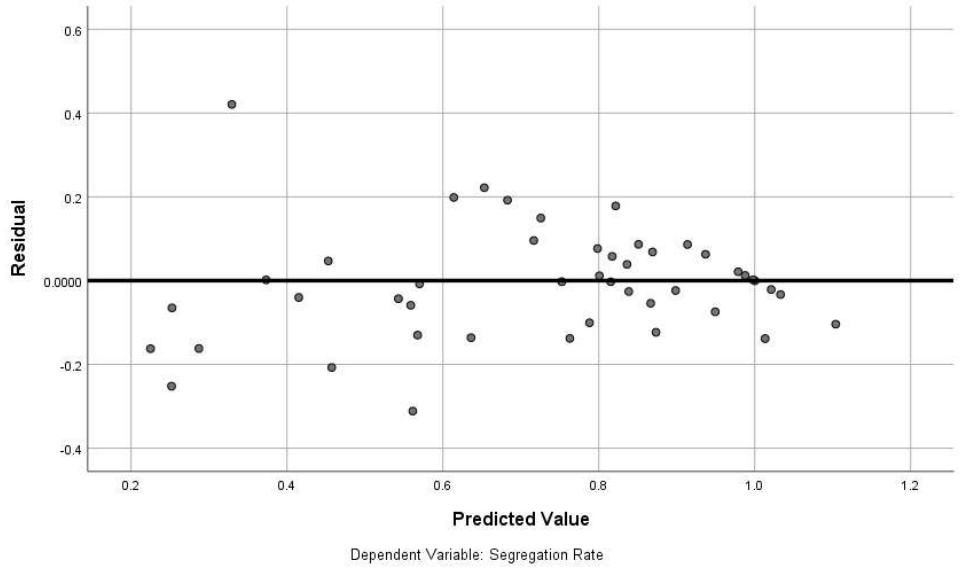

Figure 21 Residual scatter plot showing the difference between predicted values and actual values.

The predictive ability of this model rests on assigning a certain importance to variables based on how much they contribute to the ability to predict the segregation rate of the respondents in the context of all the other variables. Taking a look at these values can help focus the answer to RQ2 by showing which variables are the most important based on the data as it is seen by the model. In the present case we see these values in the table below which shows the ranking provided by the model. This allows us to go through a selection of the more relevant variables.

One of the first variables which the model assigned a high level of importance, just like in the bivariate correlation, is the socio-psychological factor of the respondent's willingness to exert effort. Here it can be said that based on this model's interpretation of the data, that either motivating householders through some type of incentive, or minimising the amount of effort necessary in the recycling process would, have the greatest impact on the rate of household waste segregation. This incentive could be through the raising of environmental awareness as that was the most common motivator or some kind of serious penalties which make not segregating waste considerably more expensive. Direct monetary rewards do not seem like an efficient use of resources, as earlier research shows that people are not as motivates as they claim to be.

Independent Variable Importance

	Importance	Normalized Importance
Willingness	.196	100.0%
Rooms/person	.137	69.9%
sqm/person	.111	56.7%
Space (sqm)	.104	53.2%
Motivator	.084	42.7%
Obstacles	.078	39.8%
Children	.071	36.4%
Rooms	.054	27.4%
Members	.047	24.1%
sqm/room	.039	20.0%
Shared Dwelling	.039	19.9%
Building Type	.028	14.5%
Conveinience	.012	6.1%

Figure 22 MLP model ranking of the variables according to their importance in predicting the rate of household segregation

In next place comes a group of three spatial factors with rooms per person ranking the highest among them by a fair margin, whilst the number of rooms which had a direct bivariate correlation was ranked considerably lower in this analysis. This shows that based on the interactions between factors the model placed a higher importance on the density of householders in a dwelling than the more basic analysis of bivariate correlation would indicate. It also shows that the definition for overcrowded dwellings used by the European Union is, based on this sample of respondents, more relevant to the rate of household segregation than the other spatial metrics. This could, based on further research, give the possibility for existing European data to be used in the creation of policy that addresses dwelling related challenges of householders on a targeted local basis, through either allocation of special

resources that help alleviate these challenges in areas with high rates of overcrowding or through making the overall recycling system cater to smaller dwellings.

The third set of variables found to be important are the reported motivators and obstacles, with the model ranking them higher than the presence of children in the household which the bivariate analysis found to have statistical significance or the type of building which was a relevant factor in previous research. Based on the previous section, simplification of the waste segregation process would have a considerable impact here as it can address many of the issues faced by the householders

4.3 Conclusions

This paper has introduced the relevant background with regard to household segregation, looked at the previous research, and documented a study designed to fill a gap in said research. While the number of respondents was low, this study has managed to achieve its overall objective of answering the research questions, with the answers that sum up the research in relation to each question being:

RQ1: How strong, if any, is the relationship between a households' rate of waste segregation and various spatial factors that relate to the dwelling?

Answer: While a bivariate analysis did find a statistically significant correlation between the number of rooms and the rate of household segregation, the sample size was too low to provide a significant level of confidence to that correlation. This can be seen in the 95% confidence interval of .107 to .547, which places the range of the correlation coefficient between a statistically insignificant value which has little predictive value and a strong moderate correlation. Based on a further multivariate MLP analysis that took nonlinear relationships into account, the number of rooms per person was found to be the strongest spatial factor in relation to the dwelling when it comes to predicting the segregation rate of households. The MLP analysis also ranked space, and space per person highly. While these variables did allow for household segregation rates to be predicted with a relative error of .335, given the low sample size it is hard to provide a definitive ranking of these variables other than that they do seem statistically significant based on the predictive capability of the model.

RQ2: What obstacles in sorting waste do households face in relation to their dwelling, and how can they be mitigated?

Answer: Based on an analysis of responses provided to the open questions, the main obstacles with regard to the dwelling are based on the number of respondents: the availability of space (46%), the recyclability of waste (18%), and the effort necessary to segregate waste (12%). These factors could, as has been discussed in the analysis, be addressed through the simplification of the recycling system

from the perspective of householders with fewer waste categories and improvements in the recyclability of packaging.

During the latter part of this research, at the end of December 2020, there has been an interesting development in Poland, with reports of the national standard for waste segregation being reformed through a significant reduction of the number of waste categories, individual billing with bar-codes, and the introduction of much higher fines (Tomaszkiewicz, 2020). Part of this reform, the reduction in the number of waste categories from five to three, is in line with the results of this study and likely to have a positive effect on the segregation rate. Although the environmental impact depends on how the municipalities handle these waste streams. The more controversial part of this reform is the plan to have people place bar-code stickers on their garbage bags so that they may be billed individually, a scheme that has already received ridicule for underestimating the creativity people have when it comes to avoiding costs (Lewandowski, 2021). These developments bring an opportunity for further research to study the effects of the reform if it gets implemented, the individual billing is especially interesting, as applying stickers identifying the household not only complicates the waste management process but also raises a range of potential privacy issues. Further far more extensive research would also be necessary on the broader European scale, as household compositions and living conditions vary (EC, 2020; Eurostat, 2018). The results of this study indicate that effective policy would at least to some extent have to take the regional differences into consideration.

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6 Table of Appendices

Appendix A – Survey Questions

Translated from Polish. Coding guide in [square brackets]. Answers were compulsory.

Section 1:
Survey on waste segregation

This survey is part of a study on recycling in different households and what can be done to improve municipal waste management.

The survey consists of five sections of questions that should take approximately five minutes to complete.

Responses will be anonymous and only the data necessary for the purposes of the study will be collected.

Thank you for your interest and please continue to go to the questions.

Section 2:
Waste segregation level.

Instructions:
"Not segregated" means that this category of waste is always disposed of as mixed waste. Please select this category if you never separate a specific waste category, otherwise please select the appropriate option.

How often do you separate the following categories of waste?
Categories/Rows: Paper and cardboard, Product (plastic/metal), Glass packaging, Biological waste.
Scale/Columns: Not segregated, Rarely, Sometimes, Often, Always.
[A1-4: 0, 1, 2, 3, 4]

Section 3:
Effort to segregate waste.

How much effort are you willing to put into waste segregation?
Minimum effort 0 – 10 Unlimited effort
[A5: Scale]

Instructions:
Please answer each of the next two questions with a single sentence.

What is the biggest obstacle for you when it comes to segregating waste?
…….
[A6: Qualitative data coded into categories, see *3.1.2 Survey and data processing* and *4.1 Data* for details]

What motivates or would motivate you to separate waste?
…….
[A7: Qualitative data coded into categories, see *3.1.2 Survey and data processing* and *4.1 Data* for details]

Section 4:
Circumstantial information

Please enter your postal code.
…….
[A8: Nominal]

What type of building do you live in?
Multi-family (apartment)
>>>>>>>>>>>>>>>*this selection skips over section 5*
Single-family (e.g. a detached house or a whole vertical section in a row house)
>>>>>>>>>>>>>>>*this selection skips over section 6*
[A9: 0 = Single, 1 = Multi]
[Note: See methodology for how A15-A19 are coded]

Is the household shared with other tenants? For example, a student renting a room?
Yes, # No
[A10: 1, 0]

What recycling options are available in your area?
Categories/Rows: Paper and cardboard, Product (plastic/metal), Glass packaging, Biological waste.
Scale/Columns: Available, Not Available, Don't Know
[A11-14: 1, 0, 99]

Section 5:
Single-family building
Please provide the following information on living conditions

Living area (in square meters):
…….
[A15: Scale, 9999 = missing]

Number of rooms, including the living room and kitchen, if they are separate:
…….
[A16: Scale]

How many people live in your household?
…….
[A17: Scale]

Are there any children?
Yes, # No
[A18: 1, 0]

Does the house have a garden or garage?
Yes, # No
[A19: 1, 0]

Section 6:
Apartment
Please provide the following information on living conditions

Living area (in square meters):
…….
[A15: Scale, 9999 = missing]

Number of rooms, including the living room and kitchen, if they are separate:
…….
[A16: Scale]

How many people live in the apartment?

…….
[A17: Scale]

Are there any children?
Yes, # No
[A18: 1, 0]

Is the apartment upstairs?
Yes, # No. The apartment is on the ground floor.
[A19: 0, 1]

Is there an elevator in the building?
Yes, # No
[A19: 1, 0]

Section 7:
Final questions

Sex:
Female
Male
[A20: 0, 1]

How old are you?
…….
[A21: Scale]

Thank you for participating. Click "Submit" to complete the survey.

Appendix B – Survey Quantitative Data

*[see Appendix A for coding information. 99/9999 are missing values. The ID of those with a segregation rate under 50% is **coloured** for easy reference.]*

ID	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21
97358	3	3	4	0	3	5	1	54220	1	0	1	1	1	1	24	2	1	0	0	1	33
51230	4	4	4	4	10	0	1	54060	1	0	1	1	1	1	64	4	3	0	1	0	18
16767	0	4	4	0	5	1	2	08530	0	0	0	1	1	0	30	3	2	0	1	1	22
69895	3	4	4	3	9	4	1	01471	1	0	1	1	1	1	9999	3	3	1	1	0	16
88436	4	4	4	0	2	1	2	42200	1	0	99	99	99	99	50	3	3	0	1	1	25
54530	4	4	4	1	8	3	1	12100	1	0	1	1	1	1	47	4	3	0	0	1	17
77760	4	4	4	2	9	3	1	54212	1	0	1	1	1	0	28	1	1	0	1	0	24
53671	3	3	2	1	7	6	2	08110	0	0	1	1	1	0	600	12	5	1	1	1	25
92665	4	4	4	4	7	5	1	80226	1	0	1	1	1	1	40	3	2	0	0	0	22
51471	4	4	4	4	10	0	1	30224	0	0	1	1	1	1	240	7	4	0	1	1	25
85817	4	4	4	4	7	5	1	55040	0	0	1	1	1	1	200	10	5	0	1	1	23
62736	4	4	2	2	7	4	1	93322	1	0	1	1	1	1	60	4	2	0	0	0	25
59941	4	4	4	2	3	4	4	61643	1	0	1	1	1	1	50	3	1	0	1	0	28
51776	2	4	4	3	8	5	1	05070	0	0	1	1	1	1	400	7	4	0	1	0	23
46862	4	4	4	1	3	4	5	53405	0	0	1	1	1	1	50	3	2	0	0	0	33
89711	0	0	2	0	1	2	3	04398	1	0	99	99	99	99	50	3	2	0	0	0	29
19253	2	2	2	2	0	1	2	03775	1	0	1	1	99	1	33	2	1	0	1	1	43
65761	3	3	4	4	6	4	5	91350	1	0	1	1	1	1	65	5	2	0	1	0	23
76591	0	1	1	2	5	2	2	32067	1	0	1	0	99	0	200	4	3	0	1	1	22
13215	4	4	4	1	3	3	2	05140	0	0	1	1	1	1	150	6	4	0	1	0	26
23377	1	0	0	0	3	2	1	50028	1	1	99	99	99	99	38	4	2	0	1	0	22
30367	4	4	4	4	4	5	1	98300	0	0	1	1	1	1	200	7	6	1	1	0	21
82227	2	4	2	0	6	4	4	50418	1	0	1	1	1	0	40	1	2	0	1	0	25
53154	1	2	3	2	6	4	1	34400	1	0	1	0	0	99	120	6	3	0	0	1	22
22059	4	4	4	4	8	4	1	76251	0	0	1	1	1	1	130	9	4	1	1	0	18
63494	4	4	4	4	9	5	1	26600	0	0	1	1	1	1	100	4	5	1	0	0	22
46443	0	0	3	4	7	4	1	20814	1	0	1	0	1	1	55	2	1	0	1	0	34
78022	4	4	4	2	5	4	5	55300	0	0	1	1	1	1	130	5	5	0	1	0	23
93478	3	3	3	0	6	1	1	75320	1	0	1	1	1	99	32	3	2	0	0	0	21
97898	2	2	2	0	4	4	4	55080	1	0	1	1	1	99	35	2	2	0	1	0	25
66332	3	3	4	4	7	5	3	60769	1	1	1	1	1	1	9999	3	2	0	0	1	22
80338	3	4	4	3	7	4	1	50305	1	0	1	1	1	1	80	5	4	1	1	0	37
64625	3	4	4	4	7	4	0	01793	1	0	1	1	1	1	110	4	4	1	1	0	37
84332	3	4	4	1	7	3	5	02703	1	0	1	1	1	1	52	3	2	0	1	0	31
25487	4	1	4	4	9	4	3	00735	1	1	1	1	1	1	50	4	2	0	0	0	22
80825	0	2	1	0	2	4	0	61634	0	1	99	99	1	99	52	4	3	0	0	0	22
55423	4	4	4	1	3	5	2	30091	1	0	1	1	1	99	50	6	6	1	1	0	22
31795	0	2	3	1	4	4	1	69100	1	0	1	1	1	1	45	3	2	0	1	0	23
19693	4	4	4	4	8	4	1	38471	1	1	1	1	1	1	120	8	3	0	1	0	22
36417	3	3	4	4	8	4	4	80416	1	1	1	1	1	1	54	3	3	0	0	0	24
33697	1	1	1	1	7	4	0	07402	0	0	1	1	1	1	60	4	6	0	1	0	23
80600	4	4	4	2	7	4	1	72200	0	0	1	1	1	1	90	5	5	1	1	0	19
67489	0	0	0	0	2	1	2	32600	1	0	1	1	1	0	50	3	4	0	0	1	21
47132	4	4	4	4	8	4	0	30605	1	0	1	1	1	1	100	3	4	1	1	0	20
87753	4	3	4	0	8	5	1	20059	1	1	1	1	1	1	67	4	3	0	1	0	22
20608	4	4	4	3	9	0	1	05270	0	0	1	1	1	1	75	4	3	0	1	0	22
37269	4	4	4	2	7	4	2	41500	0	0	1	1	1	0	120	6	4	1	1	0	24
94717	4	4	4	4	8	4	3	03589	0	0	1	1	1	1	86	5	3	0	1	0	21
82886	0	0	1	0	2	1	2	08206	1	0	99	1	1	99	9999	6	6	1	1	0	22
49729	3	4	4	3	8	2	1	85047	1	1	1	1	1	1	65	4	6	0	0	0	21

Appendix C - Correlations: Scales vs Scales[d]

				Willingness	Rooms	Members	Space (sqm)	Age	Rooms/ person	sqm/ pers...	sqm/ room	Population
Segregation Rate	Pearson Correlation			**.589****	**.319***	.260	.140	-.11	.086	.050	.042	.040
	Sig. (2-tailed)			.000	.029	.078	.348	.457	.566	.740	.781	.788
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		-.003	.011	.006	.037	.001	-.004	.018	.014	.010
		Std. Error		.096	.111	.136	.139	.122	.143	.137	.150	.155
		95% Confidence Interval	Lower	.378	.107	-.006	-.059	-.35	-.199	-.19	-.233	-.268
			Upper	.764	.547	.512	.473	.123	.350	.354	.337	.360
Space (sqm)	Pearson Correlation			.221	**.771****	.442**	1	-.09	.250	.88**	.75**	-.254
	Sig. (2-tailed)			.135	.000	.002		.535	.090	.000	.000	.085
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		.011	-.003	.026	0	.00	-.020	-.03	-.008	-.006
		Std. Error		.093	.075	.096	0	.084	.131	.110	.108	.077
		95% Confidence Interval	Lower	.042	.601	.298	1	-.29	-.060	.529	.454	-.408
			Upper	.421	.892	.666	1	.068	.480	.955	.896	-.089
Members	Pearson Correlation			.215	**.599****	1	.442**	-.36*	-.402**	.044	.213	-.339*
	Sig. (2-tailed)			.147	.000		.002	.014	.005	.767	.151	.020
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		-.001	.005	0	.026	.007	.004	-.01	.010	.001
		Std. Error		.139	.075	0	.096	.123	.134	.164	.135	.112
		95% Confidence Interval	Lower	-.072	.453	1	.298	-.56	-.640	-.33	-.039	-.546
			Upper	.480	.748	1	.666	-.08	-.124	.327	.469	-.094
sqm/person	Pearson Correlation			.153	**.559****	.044	.882**	.108	.504**	1	.77**	-.129
	Sig. (2-tailed)			.306	.000	.767	.000	.470	.000		.000	.388
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		-.003	-.029	-.014	-.034	.017	.009	0	-.024	.015
		Std. Error		.105	.162	.164	.110	.091	.078	0	.116	.093
		95% Confidence Interval	Lower	-.063	.169	-.332	.529	-.03	.357	1	.456	-.261
			Upper	.342	.767	.327	.955	.343	.666	1	.896	.098
Age	Pearson Correlation			**-.370***	-.271	-.357*	-.093	1	.156	.108	.032	.499**
	Sig. (2-tailed)			.010	.066	.014	.535		.294	.470	.833	.000
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		.010	.002	.007	-.005	0	.000	.017	.013	-.007
		Std. Error		.152	.102	.123	.084	0	.117	.091	.101	.144
		95% Confidence Interval	Lower	-.630	-.458	-.565	-.286	1	-.076	-.03	-.134	.187
			Upper	-.038	-.058	-.083	.068	1	.376	.343	.274	.739
Rooms/person	Pearson Correlation			-.048	**.396****	-.402**	.250	.156	1	.50**	-.081	.080
	Sig. (2-tailed)			.749	.006	.005	.090	.294		.000	.590	.593
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		.003	-.006	.004	-.020	.000	0	.009	-.018	.007
		Std. Error		.140	.137	.134	.131	.117	0	.078	.152	.118
		95% Confidence Interval	Lower	-.310	.087	-.640	-.060	-.08	1	.357	-.402	-.142
			Upper	.240	.632	-.124	.480	.376	1	.666	.211	.315
Population	Pearson Correlation			-.077	**-.300***	-.339*	-.254	.50**	.080	-.13	-.150	1
	Sig. (2-tailed)			.609	.040	.020	.085	.000	.593	.388	.313	
	N			47	47	47	47	47	47	47	47	47
	Bootstrap[c]	Bias		.018	.004	.001	-.006	-.01	.007	.015	.010	0
		Std. Error		.176	.090	.112	.077	.144	.118	.093	.106	0
		95% Confidence Interval	Lower	-.387	-.460	-.546	-.408	.187	-.142	-.26	-.321	1
			Upper	.298	-.104	-.094	-.089	.739	.315	.098	.102	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

c. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

d. Excess rows removed, all significant correlations remain

Appendix D - Correlations: Scales vs Dichotomous variable.[e]

					Bio Avail.	Children	Sex	Building Type	Shared Dwelling	Conveinience
Spearman's rho	Segregation Rate	Correlation Coefficient			**.407***	**.354***	**-.321***	-.240	.052	.072
		Sig. (2-tailed)			.010	.027	.046	.141	.754	.665
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		-.006	-.009	-.004	-.003	.000[d]	.001
			Std. Error		.135	.133	.175	.155	.129[d]	.154
			95% Confidence Interval	Lower	.105	.078	-.622	-.554	-.207[d]	-.226
				Upper	.636	.586	.048	.071	.303[d]	.365
	Willingness	Correlation Coefficient			.194	.088	-.259	-.038	**.358***	-.037
		Sig. (2-tailed)			.238	.594	.111	.819	.025	.822
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		.000	-.002	-.011	-.001	-.004[d]	.005
			Std. Error		.154	.131	.170	.163	.099[d]	.185
			95% Confidence Interval	Lower	-.123	-.162	-.569	-.340	.166[d]	-.403
				Upper	.471	.330	.092	.297	.548[d]	.334
	Space (sqm)	Correlation Coefficient			.092	**.455****	-.041	**-.542****	-.038	**.405***
		Sig. (2-tailed)			.577	.004	.806	.000	.821	.011
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		.000	-.008	-.005	.008	.006[d]	-.005
			Std. Error		.214	.110	.225	.135	.116[d]	.124
			95% Confidence Interval	Lower	-.334	.223	-.481	-.765	-.270[d]	.127
				Upper	.502	.649	.401	-.242	.189[d]	.616
	Rooms	Correlation Coefficient			.160	**.372***	-.006	**-.581****	.042	.298
		Sig. (2-tailed)			.329	.020	.973	.000	.801	.066
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		-.001	-.003	-.011	.004	.004[d]	-.001
			Std. Error		.199	.134	.190	.117	.133[d]	.125
			95% Confidence Interval	Lower	-.272	.095	-.377	-.778	-.203[d]	.045
				Upper	.528	.603	.353	-.312	.305[d]	.527
	Members	Correlation Coefficient			.064	**.524****	-.028	**-.557****	.024	.112
		Sig. (2-tailed)			.701	.001	.868	.000	.883	.499
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		-.003	-.008	-.003	.005	-.001[d]	-.003
			Std. Error		.158	.103	.167	.120	.148[d]	.167
			95% Confidence Interval	Lower	-.256	.307	-.355	-.771	-.248[d]	-.229
				Upper	.350	.711	.287	-.309	.326[d]	.412
	sqm/person	Correlation Coefficient			-.003	.038	.108	-.183	-.195	**.465****
		Sig. (2-tailed)			.986	.819	.511	.264	.235	.003
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		.004	-.001	-.003	.003	.007[d]	-.004
			Std. Error		.199	.159	.205	.163	.160[d]	.120
			95% Confidence Interval	Lower	-.370	-.278	-.302	-.484	-.471[d]	.204
				Upper	.395	.337	.483	.138	.159[d]	.683
	sqm/room	Correlation Coefficient			-.276	.271	-.035	-.281	-.211	**.405***
		Sig. (2-tailed)			.089	.096	.832	.084	.196	.011
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		.005	-.006	.000	.007	.002[d]	-.006
			Std. Error		.184	.150	.204	.161	.118[d]	.129
			95% Confidence Interval	Lower	-.590	-.034	-.437	-.579	-.438[d]	.116
				Upper	.131	.544	.379	.057	.024[d]	.635
	Population	Correlation Coefficient			.125	-.035	-.100	**.448****	.010	-.186
		Sig. (2-tailed)			.448	.831	.543	.004	.951	.257
		N			39	39	39	39	39	39
		Bootstrap[c]	Bias		.003	-.002	.001	-.006	-.005[d]	.007
			Std. Error		.128	.158	.164	.149	.167[d]	.134
			95% Confidence Interval	Lower	-.119	-.360	-.414	.145	-.332[d]	-.439
				Upper	.377	.270	.226	.726	.322[d]	.084

**. Correlation is significant at the 0.01 level (2-tailed).

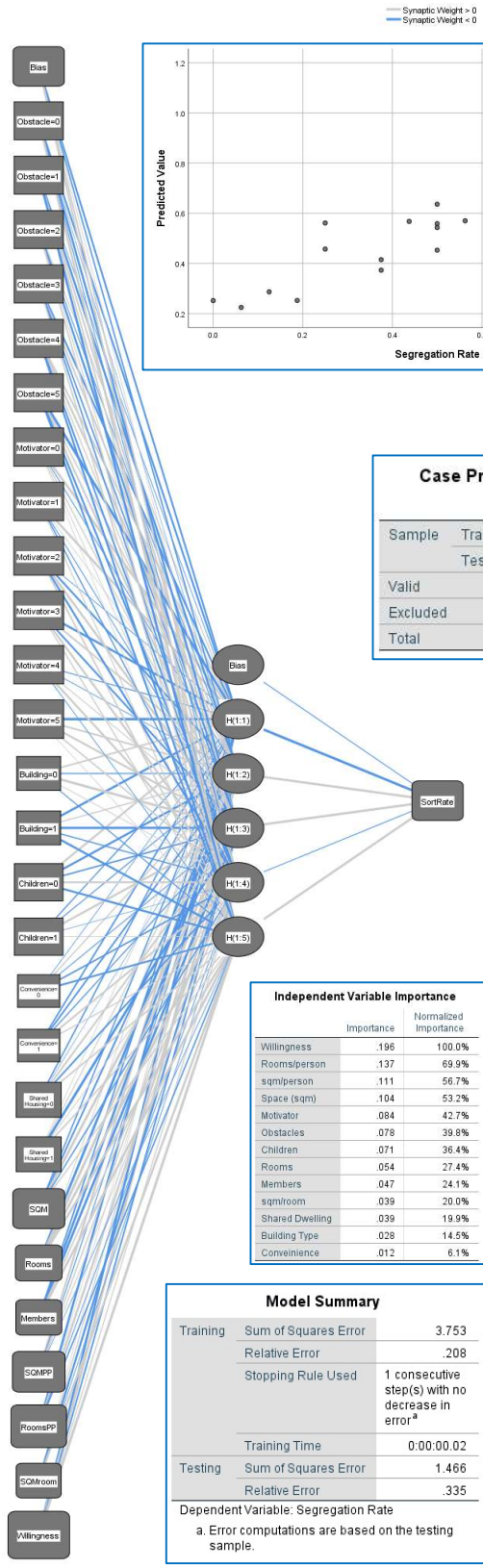
*. Correlation is significant at the 0.05 level (2-tailed).

c. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

d. Based on 998 samples

e. Rows = Scales. Columns = Dichotomous vars. Several of the dichotomous values missing, see data in Appendix B.

Appendix E – MLP Output



Network Information

Input Layer	Factors	1	Obstacles
		2	Motivator
		3	Building Type
		4	Children
		5	Conveinience
		6	Shared Dwelling
	Covariates	1	Space (sqm)
		2	Rooms
		3	Members
		4	sqm/person
		5	Rooms/person
		6	sqm/room
		7	Willingness
	Number of Units[a]		27
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		1
	Number of Units in Hidden Layer 1[a]		5
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	Segregation Rate
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

a. Excluding the bias unit

Case Processing Summary

		N	Percent
Sample	Training	37	80.4%
	Testing	9	19.6%
Valid		46	100.0%
Excluded		4	
Total		50	

Independent Variable Importance

	Importance	Normalized Importance
Willingness	.196	100.0%
Rooms/person	.137	69.9%
sqm/person	.111	56.7%
Space (sqm)	.104	53.2%
Motivator	.084	42.7%
Obstacles	.078	39.8%
Children	.071	36.4%
Rooms	.054	27.4%
Members	.047	24.1%
sqm/room	.039	20.0%
Shared Dwelling	.039	19.9%
Building Type	.028	14.5%
Conveinience	.012	6.1%

Model Summary

Training	Sum of Squares Error	3.753
	Relative Error	.208
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.02
Testing	Sum of Squares Error	1.466
	Relative Error	.335

Dependent Variable: Segregation Rate

a. Error computations are based on the testing sample.

Hidden layer activation function: Hyperbolic tangent

Output layer activation function: Identity

Parameter Estimates

		Predicted					
		Hidden Layer 1					Output Layer
Predictor		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	SortRate
Input Layer	(Bias)	-.314	-.225	.034	.278	.292	
	[Obstacle=0]	-.359	-.011	-.422	-.096	.448	
	[Obstacle=1]	-.046	-.425	.294	.239	-.485	
	[Obstacle=2]	.121	-.108	-.399	.086	.226	
	[Obstacle=3]	-.351	.273	-.227	-.231	.220	
	[Obstacle=4]	.287	.386	.142	-.295	-.373	
	[Obstacle=5]	-.749	.198	.371	-.367	-.342	
	[Motivator=0]	.541	-.100	.153	.049	.025	
	[Motivator=1]	.512	.023	-.098	-.176	.119	
	[Motivator=2]	-.052	-.379	.427	-.392	.244	
	[Motivator=3]	-.443	.327	-.346	.413	.167	
	[Motivator=4]	-.131	-.068	.118	.413	-.082	
	[Motivator=5]	-.884	.307	.399	.239	.035	
	[Building=0]	.305	-.165	.627	.075	-.145	
	[Building=1]	-.478	.198	-.624	-.187	-.429	
	[Children=0]	.406	-.427	-.243	.385	-.423	
	[Children=1]	-.174	-.131	.429	-.015	.026	
	[Convenience=0]	-.045	.180	-.102	-.248	-.362	
	[Convenience=1]	-.264	-.288	-.163	.367	.153	
	[SharedHousing=0]	-.222	-.010	.336	-.300	.271	
	[SharedHousing=1]	.041	.129	-.622	.076	.241	
	SQM	-.199	-.302	.548	-.206	.184	
	Rooms	.048	-.558	.632	.612	.519	
	Members	-.241	-.497	-.519	.212	.519	
	SQMPP	.412	-.112	.192	.100	-.042	
	RoomsPP	-.466	.016	.465	-.096	-.220	
	SQMroom	.017	.146	-.401	-.046	.441	
	Willingness	-.479	.748	-.254	.126	.798	
Hidden Layer 1	(Bias)						-.119
	H(1:1)						-.861
	H(1:2)						.541
	H(1:3)						.571
	H(1:4)						-.110
	H(1:5)						.549