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THESIS BOOKLET

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Essays on Waste Generation

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1. Background and justification of the topic

Achieving sustainability is one of the most important global challenges that will shape the future of social, economic, and environmental development. Limited natural resources, a growing population, and consumption driven by economic growth present complex problems that require comprehensive strategies to address. Waste generation and management is a key element of sustainability, as it involves reducing waste, recycling effectively, and handling materials in an environmentally sound way.

The scientific study of this issue has received considerable attention in recent decades, particularly from the perspective of the circular economy and sustainable consumption. Several studies have addressed the issue of increasing the efficiency of waste management, the functioning of selective waste collection systems, and the technological potential of recycling. However, the literature still pays little attention to the mechanisms and behavioral factors that influence the evolution of waste generation and the efficiency of sustainable waste management systems.

The existing literature on waste management focuses mainly on the principles of the circular economy, the promotion of sustainable consumption, and the efficiency of waste management systems. Much of this research examines how socio-demographic factors influence littering patterns or how different policies contribute to sustainability goals. Various theoretical models – such as the Theory of

Planned Behavior or the Attitude Model – are used to explain and predict people’s environmental behavior, and the study of sustainability attitudes and political preferences is becoming increasingly popular.

However, despite the diversity and breadth of the literature, there are still significant gaps in many areas. Research often assumes that selective waste collection reduces waste generation, but there is little empirical evidence to support this, especially with regard to the circular economy rebound effect, which is a very under-researched area. The environmental impact of the COVID-19 pandemic has also received little attention from researchers, while the pandemic may have had not only short-term but also long-term negative effects on consumption and waste generation patterns. Research on the efficiency of waste management systems tends to treat changes in the social and economic environment in isolation, without considering their combined effects. The literature on the relationship between political preferences and environmental behavior is mainly based on self-report questionnaires, meaning that empirical evidence on the impact of ideological attitudes on actual waste management behavior remains limited.

The aim of the dissertation is to fill these gaps in the literature and provide new perspectives on the interrelationships between waste management systems, social attitudes, and sustainability processes. Although the individual chapters may appear to deal with separate issues, the research as a whole forms a coherent framework. All four studies explore the complex relationship between waste management and sustainability, focusing on different aspects but with a common goal: to better understand the mechanisms that shape sustainability processes.

The first study examines the impact of the introduction of selective waste collection on total waste generation and provides empir-

ical evidence for the existence of the circular economy rebound effect. The second study investigates the pandemic's broader impact on consumption and municipal waste generation, while the third combines this perspective with changes in selective waste collection infrastructure, providing a unique natural experiment framework. The final study analyzes the relationship between political preferences and environmental behavior, challenging the often-voiced assumption that left-wing orientation automatically implies greater environmental awareness.

Even though these topics focus on different areas, the research as a whole provides a coherent picture of the complex relationship between waste management systems and sustainability. The chapters build on and complement each other, and together they highlight the fact that the study of waste management efficiency is not simply a technological or regulatory issue, but a set of social, economic, and behavioral factors that can only be properly understood through an integrated approach.

2. Applied methods

The dissertation employs a variety of empirical methods to examine different dimensions of waste generation and sustainability. These techniques include quasi-experimental designs, time-series analysis, panel regressions, and observational inference – each tailored to the specific question and data availability of the respective study.

The first part of the research applies a quasi-experimental framework using a difference-in-differences (DiD) approach to assess the causal impact of door-to-door selective waste collection systems. Administrative data from a Hungarian non-profit waste management company, covering the period 2009–2018 across one city and ten municipalities, served as the basis for the analysis. This method exploits variation over time and between treated and control units, allowing for robust identification of treatment effects while controlling for unobserved heterogeneity and common trends. As a robustness check, two-way fixed effects (TWFE) models were also estimated, confirming the stability of the results. Moreover, to complement the administrative data, a household survey was conducted to capture self-reported behavioral changes following the introduction of curbside collection infrastructure. The questionnaire focused on recycling habits, perceptions of convenience, and changes in waste-related practices. The combination of objective administrative records and subjective survey data provides a comprehensive

framework for assessing both systemic and behavioral dimensions of selective waste collection.

The second analysis applies two-way fixed effects panel regression models to examine changes in municipal waste generation over time, with particular attention to the COVID-19 period. The models control for both municipality-specific and time-specific effects, mitigating bias from unobserved heterogeneity and national-level shocks. The COVID-19 Stringency Index is introduced to capture the intensity of governmental restrictions over time. To isolate the pandemic’s effect, an “excess-over-expected” framework is used, estimating counterfactual waste values from pre-pandemic trends. Model estimation is performed using high-dimensional fixed effects techniques, ensuring computational efficiency and precise estimation. Also several robustness checks are conducted to validate the results and assess the sensitivity of the findings. These include the use of alternative model specifications, such as including quadratic time trends, interacting key variables with income and settlement type, and re-estimating models on pre-pandemic subsamples. Additionally, standard errors are clustered at the municipality level to correct for serial correlation, and placebo tests are run on pre-COVID periods to confirm that the estimated pandemic effects are not driven by spurious trends. These robustness strategies ensure the reliability and consistency of the analytical framework.

A third methodological approach applies a structured econometric framework to assess the causal impact of selective waste collection infrastructure under exogenous pressure. A key methodological innovation is the application of a natural experimental design that uses the COVID-19 pandemic as an exogenous shock to identify the behavioral and rebound effects of curbside double-bin systems. This setting allows for quasi-experimental inference by exploiting the plausibly exogenous timing and uniform implemen-

tation of pandemic-related restrictions across municipalities. The analysis introduces and empirically tests a novel theoretical construct termed the Perceived Disposal Ease Bias, which posits that the convenience of disposal infrastructure can inadvertently lead to increased total waste output. This concept provides new insights into how infrastructure, while improving recycling rates, may also reinforce unsustainable consumption patterns. The analysis employs a DiD framework within a two-way fixed effects (TWFE) regression model to isolate causal effects. This specification controls for time-invariant municipal characteristics and period-specific shocks that could confound the observed relationship between infrastructure and waste generation. The treatment is defined as the presence of curbside double-bin selective collection systems during the pandemic period. The interaction between treatment status and the COVID-19 period captures the average treatment effect of the infrastructure under pressure. The validity of this identification strategy lays on the parallel trends assumption, eave-one-out sensitivity analysis and placebo tests.

Lastly, the dissertation explores the relationship between political orientation and sustainability-related behavior at the district level in Budapest. Instead of relying on self-reported attitudes – which are often distorted by social desirability and nonresponse bias – administrative data are used to ensure greater validity. Political preferences are operationalized through the vote shares of parties and candidates in the 2014 and 2019 European Parliament and municipal elections, offering a quasi-continuous measure of ideological alignment across time and space. Environmental behavior is proxied by the per capita volume of waste collected selectively (paper and plastic/metal), based on the assumption that engagement in waste separation reflects underlying pro-environmental attitudes. These data are drawn from the capital’s municipal waste company and

are aggregated over two-year intervals to reduce noise from short-term variation. To control for confounding factors, the empirical strategy includes a rich set of district-level socioeconomic indicators such as real average taxable income, long-term unemployment, age composition, public healthcare eligibility, and population density. The estimation is based on a linear panel model with either fixed or random effects, depending on the outcome of a Hausman test. The dependent variable is the vote share of left-wing political actors, while the key independent variable is selective waste collection per capita. Standard errors are clustered at the district level to address within-unit correlation.

3. Scientific contributions of the dissertation

- The bag-based curbside collection system had no statistically significant effect on total, mixed, or source-separated waste, nor on the recycling rate.
- The amount of source-separated waste rose by nearly 60%, from 0.85 to 1.35 kg per capita per month after the switch to the double-bin system, while the amount of non-separated (mixed) waste did not decrease following the introduction of the double-bin system.
- The introduction of the double-bin system in Székesfehérvár resulted in a 4% increase in total household waste.
- The recycling rate increased by 1.7 percentage points, from 4.6% to 6.3%, following the implementation of the double-bin system.
- 59% of survey respondents agreed that they would produce less waste if selective collection were not available, indicating that curbside convenience contributes to increased consumption.
- 31–33% of respondents admitted to feeling less responsible for their waste or being less annoyed by using disposable plastic bags due to the availability of selective collection, highlighting a perceived mitigation of environmental harm.

- The results support the existence of a circular economy rebound effect, where perceived environmental benefits of recycling lead to increased consumption and waste.
- The COVID-19 pandemic led to a statistically significant increase in both selective and non-selective municipal waste generation. Based on the estimated panel models, a one-point rise in the Stringency Index corresponded to an annual per capita increase of 0.098–0.106 kg in mixed waste and 0.016–0.017 kg in selective waste.
- In total, the average Stringency Index value of 56.01 recorded in Hungary in 2020 is associated with an increase of approximately 5.5–5.94 kg of mixed waste and 0.9–0.95 kg of selectively collected waste per capita annually, adding up to 6.4–6.89 kg of additional municipal waste.
- Excess-over-expected analysis confirmed these findings. The average stringency level in 2020 corresponds to 3.81 kg of excess selective waste and 19.82 kg of excess mixed waste, resulting in 23.63 kg of additional municipal solid waste per capita.
- Municipal-level heterogeneity analysis shows that urban areas, especially major cities, experienced the largest increases.
- Despite rising selective waste volumes, the total amount of waste did not decrease, suggesting that infrastructure expansion and improved participation did not translate into more effective recycling outcomes.
- Municipalities equipped with door-to-door selective bin systems generated, on average, 11.76 kg more selectively collected waste per capita annually during the COVID-19 period, compared to municipalities lacking such infrastructure.

- No statistically significant reduction was observed in the quantity of mixed waste, suggesting that the increase in selective waste reflects additional total waste generation rather than substitution across waste streams.
- Placebo tests and leave-one-out robustness check reinforcing the methodology, and the findings support my own Perceived Disposal Ease Bias hypothesis: the convenience of infrastructure during the pandemic triggered a behavioral response that increased overall waste generation.
- Despite higher volumes of selectively collected waste, again there is no improvement in mixed waste reduction or recycling efficiency.
- These results suggest that the implementation of selective waste collection infrastructure, if not complemented by awareness campaigns or regulatory interventions, may inadvertently lead to greater material consumption under external stress conditions.
- Regression results show a negative and statistically significant relationship between changes in waste separation and the vote share of left-wing parties, suggesting that environmental behavior was more pronounced in right-leaning districts.
- The magnitude of the negative relationship between selective waste collection and left-wing vote share was larger in municipal elections than in EP elections, indicating possible differences in local versus national-level political behavior.

- Districts with more people per dwelling – where social monitoring is likely weaker – showed weaker associations between waste separation and political support for right-wing parties, especially in EP elections, supporting a peer pressure mechanism.
- The findings suggest that environmental attitudes are not clearly aligned with left-wing ideology in Budapest, contrasting with patterns observed in Western Europe and supporting earlier survey-based results from post-communist contexts.
- Social norms and historical legacies, such as the environmental record of socialist regimes and post-communist political alignments, may explain why right-wing voters in Hungary exhibit stronger pro-environmental behaviors.
- The use of revealed preferences – district-level selective waste collection – rather than survey responses adds empirical robustness, and supports the view that left-wing voters in Hungary are not more engaged in pro-environmental practices than their right-leaning counterparts.

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5. List of publications related to the dissertation

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