CHARLES UNIVERSITY
FACULTY OF SOCIAL SCIENCES
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Municipal Waste Management and Analysis of Influencing Factors with respect to Municipal Solid Waste Generation

Bachelor thesis

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Declaration of Authorship

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Prague, May 7, 2019

Diana Kmetkova

Abstract

This thesis presents the topic of municipal waste management in the Czech Republic and describes the current trends within this area. We analyse the data on the generation and treatment of municipal solid waste in the Czech Republic and then we compare several waste indicators in the EU countries. The main goal of the thesis is to describe the relationship between municipal solid waste generation (MSW) and socio-economic factors. In order to identify the variables that might have a significant impact on the generation of MSW, we carry out a panel data regression using data from 28 EU countries over a time period from 1995 to 2017. We present four model specifications that were created based on the studied research articles. Our findings suggest that GDP and income have a significant positive impact on MSW generation, which is in accordance with the majority of research works. On the other hand, two other significant variables, population and density, are estimated to be negatively related to MSW production. Moreover, urbanization and unemployment rate result to be insignificant.

JEL Classification	C33, Q53, Q56, R11, H76
Keywords	municipal waste management, circular economy, sustainable targets, recycling, panel data analysis

Title	Municipal Waste Management and Analysis of Influencing Factors with respect to Municipal Solid Waste Generation

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Abstrakt

Táto bakalárska práca sa zaoberá témou komunálneho odpadového hospodárstva v Českej republike a opisuje súčasné trendy v tejto oblasti. Analyzovali sme dáta na produkciu komunálnych odpadov v Českej republike a zaobchádzanie s nimi a potom sme porovnali niektoré odpadové indikátory s ďalšími krajinami EU. Hlavným cieľom bakalárskej práce bolo opísať vzťah medzi tvorbou komunálneho odpadu a socioekonomickými faktormi. Na identifikovanie premenných, ktoré by mohli mať výrazný vplyv na produkciu komunálneho odpadu, sme použili regresiu panelových dát, kde sme pracovali s dátami z 28 krajín EU za časové obdobie 1995-2017. Prezentovali sme štyri špecifikácie modelu, ktoré sme vytvorili na základe preštudovanej literatúry. Naše výslekdy ukazujú, že HDP a príjem majú signifikantný pozitívny efekt na tvorbu komunálneho odpadu, čo je v súlade s väčšinou výskumných prác. Na druhú stranu, dve ďalšie významné premenné, populácia a hustota zaľudnenia, boli odhadnuté, že negatívne ovplyvňujú tvorbu komunálneho odpadu. Ďalej sme zistili, že miera urbanizácie a nezamestnanosť pre náš model signifikantné nie sú.

Klasifikace JEL	C33, Q53, Q56, R11, H76
Klíčová slova	management komunálního odpadu, cirkulární ekonomika, udržitelné cíle, recyklace, analýza panelových dat
Název práce	Municipal Waste Management and Analysis of Influencing Factors with respect to Municipal Solid Waste Generation

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Acronyms

CSU Czech Statistical Office

CENIA Czech Environmental Informational Agency

EU European Union

EC European Commission

Eurostat European Statistical Office

FD First Difference estimation

FE Fixed Effects estimation

GDP Gross domestic product

MSW Municipal solid waste

OECD Organisation for Economic Co-operation and Development

OLS Ordinary Least Squares

RE Random Effects estimation

UN United Nations

Bachelor's Thesis Proposal

Author	Bc. Diana Kmeťková
Supervisor	doc. Ing. Tomáš Cahlík, CSc.
Proposed topic	Municipal Waste Management and Analysis of Influencing Factors with respect to Municipal Solid Waste Generation

Motivation Which socioeconomic factors influence the generation of municipal solid waste? Nearly every human activity is associated with the production of waste. However, a lot of the waste we throw away can be recycled. Recycling is beneficial for the environment; it can encourage innovation and create job opportunities. According to EUROSTAT, total recycling of municipal waste increased significantly in the Czech Republic, however, data from the Ministry of Environment has shown other results. In this thesis, we will have a better look at whether the Czech Republic is performing well regarding the waste production and its subsequent treatment. Taking into consideration all the possible data sources, I will also try to evaluate the fulfilment of European objectives and targets related to municipal solid waste generation and its treatment.

Hypotheses

Hypothesis #1: Municipal solid waste generation is positively influenced by GDP/income.

Hypothesis #2: Municipal solid waste generation is positively influenced by population.

Hypothesis #3: Municipal solid waste generation is positively influenced by population density.

Hypothesis #4: Municipal solid waste generation is positively influenced by urbanization.

Hypothesis #5: Municipal solid waste is negatively influenced by unemployment rate.

Methodology The bachelor thesis will include econometric analysis and panel data methods. For the comprehensive analysis and evaluation of the state of waste management and recycling, data from various sources will be used, specifically, EUROSTAT, which offers a great range of waste data of all EU member countries, CENIA, which provides a database for the Ministry of the Environment and EKO-KOM, the authorized packaging management company.

The main indicator will be the overall municipal waste by waste operations. In order to compare waste generation among various countries, I will use data of municipal waste generated per person. Another indicator will be municipal waste treatment with the focus on recycling.

I will be working in the R environment.

Expected Contribution The thesis will consist of presenting the current situation of waste management and Waste Management Plan of the Czech Republic for the period 2015-2024 and the most relevant targets for the municipal waste set by EU. In addition, I will analyze the acquired data, making a summary of trends and evaluation of waste management in the past as well as comparing waste generation in the EU countries. Moreover, I will estimate an econometric model with the aim to find explanatory variables for municipal solid waste generated based on available data. The purpose of this thesis is to show the potential deficiencies we have regarding this topic and to highlight the importance of waste recycling.

Outline

1. Introduction
2. Brief history overview
3. Waste Management Plan of the Czech Republic
4. Comparison of waste generation and treatment with other EU countries
5. Theoretical background, methodology
6. Empirical model
7. Results and discussion
8. Conclusion

Core bibliography

Waste Management Plan of the Czech Republic for the period 2015 â€“ 2024, Ministry of the Environment, Prague, November 2014.

Municipal Waste Management, Czech Republic, European Environmental Agency, European Topic Centre on Waste and Materials in a Green Economy, October 2016.

Zpráva o plnění cílu Plánu odpadového hospodářství České republiky za období 2015-2016 (1. Hodnotící zpráva), Ministerstvo životního prostředí, Praha, prosinec 2017.

Mazzanti, M. and Zoboli, R., Waste Generation, Incineration and Landfill Diversion: De-Coupling Trends, Socio-Economic Drivers and Policy Effectiveness in the EU, December 10, 2008.

Author Supervisor

Chapter 1

Introduction

Nearly every human activity is associated with the production of waste. There are tremendous amounts of waste generated from activities such as construction, manufacturing, water supply and energy production. In addition to that, each person living in the EU throws away, on average, approximately half a tonne of household rubbish every year (EC 2010). Due to the increased urbanization and industrialization, growth of population, change in lifestyle, consumption patterns and food habits, waste has become one of the major concerns for our society. Excessive waste production has a massive impact on the environment and consequently affects each one of us one way or another. Inappropriate waste management could increase greenhouse gas emissions, either directly from landfills or indirectly by extracting and processing materials that could be recycled otherwise. Moreover, it might cause landscape deterioration due to landfilling, water and air pollution or health problems, therefore, improving waste management is an essential component for countries to enhance the standard of living and to become more resource efficient. The amount and composition of waste generated offer primary information that is needed for planning, operation and optimization of waste management systems.

In this thesis, we present the current strategy of the Czech Republic in the field of waste management called 'Waste management plan of the Czech Republic for the period 2015 – 2024'. In particular, we focus on municipal waste, its generation and treatment. Even though municipal waste consists of only around 10% of the total waste generated (OECD 2015), its heterogeneous composition makes environmentally friendly waste management quite challenging. The way this problem is handled might give us a good indication of the quality of the overall waste management system in the country.

The thesis aims to answer the question: 'Which socio-economic factors influence the generation of municipal solid waste?'. We are interested in testing several hypotheses about selected explanatory variables, namely GDP, income, population, density, urbanization and unemployment, and we would like to estimate their effect on the production of municipal solid waste (MSW). To be specific, the first hypothesis put to test is whether GDP or income, have a positive effect on the amount of MSW. Also, we will test if population, density or urbanization rate are positively related to MSW generation. In contrast, we want to determine whether unemployment rate negatively affects the production of MSW. In order to do that, we will carry out an econometric analysis for panel data using four estimation methods on four different models that are chosen based on the studied articles and other relevant literature on municipal solid waste.

The thesis is structured as follows: Chapter 2 provides a review of recent literature about waste management and models used to evaluate waste generation. In Chapter 3, the overview of waste management in Europe and particularly in the Czech Republic is presented. Chapter 4 describes and analyses the current situation in the Czech Republic, comparing it with the past one as well as comparisons with other EU countries are made. Chapter 5 explains the econometric theory behind the models that are used. Chapter 6 starts with data specification, elaborates on several issues that might occur and presents the empirical model. Afterwards, the results are shown and discussed. Lastly, Chapter 7 summarizes our findings.

Chapter 2

Literature review

Municipal solid waste is one of the by-products of our lifestyles and as it was suggested by Liu (2010), its generation is influenced by socio-economic conditions, living standards, urbanization and population. Hence, the identification of these influencing factors plays a crucial role in evaluating an effective waste management plan. In the recent literature on waste management, there is present a certain degree of integration of the above-mentioned factors that pay considerable attention to environmental, economic and social aspects.

The majority of studies uses per capita municipal solid waste generation indicator as a key measure for evaluating the intensity of waste generation over time because it enables data on MSW generation to be normalized and as a result, it eliminates the effects of changes in population (EEA 2013). Several European studies tried to identify possible significant factors that could have an effect on MSW generation. One of them was conducted by Beigl *et al.* (2004), who described the development of a prognosis model for MSW generation using the extensive dataset from 55 European cities and 32 European countries with annual time series up to 32 years. As a result, they identified a significant relationship between the status of regional development and MSW generation. Among the factors that were found to have a large impact on the amount of MSW, they include GDP, social indicators, age structure and household size.

As a continuation to Beigl *et al.* (2004), Kolekar *et al.* (2016) reviews more recent MSW generation methods and prediction models. In the article, it was shown that the most common attributes that affect the generation of waste are the overall size of household, the income level of the household, and the level of education. On the other hand, Wang & Nie (2001) concluded that rapid growth of urban population and GDP were one of the major drivers of MSW increase. Urbanization appears to have a positive effect on increasing MSW generation per capita, particularly in developing countries, where there are great discrepancies in economic activities and living standards between urban and rural areas. Grossman *et al.* (1974) included in the linear regression model also factors such as the increase of population, income level and housing type. Three dimensions to consider, identified by Liu (2010), who made a multiple statistical analysis focused on municipal solid waste production in China, are economy and urban development, energy consumption and urban scale. Other factors that might have an effect on the generation and composition of waste are the average income of people, level of education, living habits, climate, religious and cultural beliefs or social and public attitudes as it was presented by Bandara *et al.* (2007) and Ysabel Marquez *et al.* (2008).

Chapter 3

Overview of waste management

3.1 Definition

Even though the legal definition of waste varies among countries, according to Article 4 in 2008 Directive (EC 2008), waste is defined as ’any substance or object which the holder discards or intends or is required to discard’. Waste management then means ’the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker.’

Firstly, it is essential to understand that also the term ’municipal waste’ might vary depending on the country, reflecting different waste management operations and practices. Because of the existence of various definitions of MSW, the interpretation and comparison of MSW generation are quite challenging.

This thesis focuses mainly on municipal solid waste, which is defined by OECD (2015) as follows:

> ’Municipal waste is waste collected by or on behalf of municipalities. It includes household waste originating from households and similar waste from small commercial activities, office buildings, institutions such as schools and government buildings, and small businesses that treat or dispose of waste at the same facilities used for municipally collected waste.’

In order to collect and compare data from the EU countries, municipal waste was defined as ’waste from households, as well as other waste which, because of its nature or composition, is similar to waste from households’ (EC 2008). Municipal waste as an indicator is measured yearly in thousand tonnes and in kilograms per capita. To compare the intensity of MSW production among different places and times, we use per capita data because it enables data on MSW generation to be normalized, hence eliminating the effects of changes in population (EEA 2013).

According to European legislation, waste management distinguishes two groups of waste management operations: recovery and disposal. Municipal waste treatment data can be categorized into the following four categories:

- landfilling,
- recycling (excluding composting or fermentation),
- composting and digestion,
- incineration (separately for with and without energy recovery).

3.2 Waste management in the EU

One of the reasons for the increase in waste generation is that our consumption has changed dramatically. Nowadays, consumers face a grand selection of products, often of low quality or specifically designed to have shorter lifespans. On top of that, the surge of disposable and single-use products did not help the situation. This vicious cycle of consumption and disposal means that we are producing more waste than ever before, hence there is an urgent need for effective policies and adequate waste treatment.

EU waste policy has evolved over the last decades through a series of environmental action plans and a framework of legislation with the objective to reduce negative environmental and health impacts as well as to create an energy and resource-efficient economy. This led to the introduction of the Waste Framework Directive, the base of EU waste policy. The updated version focuses on seeing waste as a valued resource rather than an unwanted burden, which is also one of the main goals of a circular economy. Targets set by EU aim to improve waste management, stimulate innovation in recycling, limit the use of landfilling, create incentives to change consumer behaviour, and the major attention is by all means on waste prevention.

Many waste management approaches are therefore based on the waste-generation hierarchy, which was introduced in 2008 Waste Framework Directive. It is a tool that emphasizes the importance of waste minimization together with putting the protection of the environment and human health as a priority (EC 2008). As it is demonstrated in Figure 3.1, it consists of 5 steps indicating the order of preference for actions to reduce and manage waste. The emphasis is put on prevention, in other words, reducing waste generation. The second step would be preparation for reuse, then recycling, other forms of recovery and finally, the least preferred option is disposal, which includes landfilling and incineration without energy recovery.

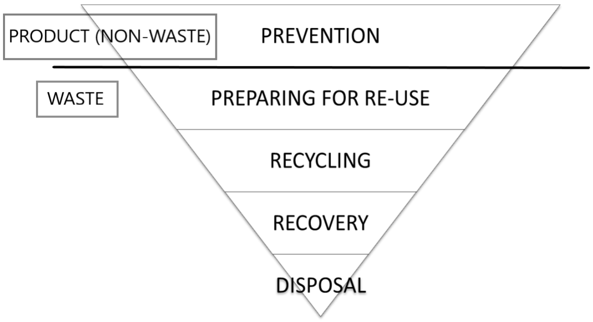

Figure 3.1: Waste hierarchy, source: EC (2008)

According to the newest reports (EP 2018), updated waste management rules include new targets, such as:

- municipal waste recycling targets: 50% by 2020, 55% by 2025, 60% by 2030 and 65% by 2035,
- separate targets for packaging materials,
- 10% maximum for landfilling by 2035.

Member states are required to report on waste management activities under various EU Directives and Regulations. Also, since the European Commission continues to support member states in their implementation efforts, helping them with technical assistance or through EU funds, over the last decades there has been a notable shift in the EU countries from waste disposal methods to prevention and recycling. Nevertheless, almost a third of municipal waste is still landfilled and less than half is recycled or composted, with wide variations between member states. Furthermore, 14 member states have been identified in 2018 as at risk of missing the 2020 target of 50% recycling (EC 2018b), (EC 2018a).

3.3 Waste management in the Czech Republic

The Czech Republic, also known as Czechia, is a landlocked country located in central Europe, which borders by Germany to the north, Austria to the south, Slovakia to the east and Poland to the northeast. The total area of the country is almost 79 thousand km^2 with a population of approximately 10.6 million inhabitants (UN 2018). In 2018, the population density was around 137.6 inhabitants per km^2. The capital, Prague, is the biggest city with a population of almost 1.3 million. The country consists of thirteen districts and a capital city with regional status.

The situation in the Czech Republic before the year 1989 was characterized by the expansion of black dump sites, barely any legislative concern with regards to waste management and the lack of information about waste and its treatment. Nevertheless, in the following years, there was a significant advancement in this area - waste controls at borders became stricter, dangerous landfills were closed down, new landfills that satisfied European directives and safe environmental parameters were built (CENIA 2005).

Thus, a new sector of the national economy called waste management began to play an important role. It all started in 1991 with the first Waste Act. Since that time, waste has become an essential part of the discussion and more and more policies are being implemented as a result of ever-increasing generation of waste. Furthermore, the nature of waste has been changing, too. This means that waste contains a complex mix of materials, including plastics, precious metals and hazardous materials, which makes it more difficult to deal with safely. All this waste and its improper treatment have a huge impact on the environment, causing pollution and greenhouse gas emissions that contribute to climate change. Moreover, the loss of materials is crucial in Europe as we are dependent on imported raw materials. To successfully solve all the problems associated with waste, such as resource inefficiency, negative environmental and health impacts; proper waste management is the key (EC 2010).

3.3.1 Waste management plan of the Czech Republic

According to EC (2008), each EU member state is obliged to create waste a management plan in their territory, which in the case of the Czech Republic was handled by the Ministry of the Environment in cooperation with relevant public authorities and public. The waste management plan of the Czech Republic is a key instrument for managing the waste situation in Czechia as well as for the implementation of long term strategies with regards to waste management. Waste prevention together with recycling and material recovery are the main objectives presented in the Waste Management Plan.

In general, we distinguish four strategic targets of the Czech Republic for the period 2015-2024 (Ministersrvo životního prostředí 2014):

- prevention and reduction of specific waste production,
- minimization of adverse effects of waste generation and waste management on human health and the environment,
- sustainable development of the society and moving closer towards the European 'recycling society',
- maximum utilization of waste as a substitute for primary sources; and the transition towards the circular economy.

With respect to municipal waste, there were introduced also additional targets based on EC (2008).

1. By the year 2015, introduce separate collection at least for waste consisting of paper, plastics, glass and metal.
2. By the year 2020, the preparing for re-use and recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50% by weight.
3. Use mixed municipal waste (in other words remaining waste after the sorting out of materially recoverable components, hazardous substances and biodegradable waste) principally for energy recovery in facilities designed for this purpose in accordance with effective legislation.

Table 3.1: Intermediate values for MSW target 2

Year	Target
2016	46%
2018	48%
2020	50%

Source: Waste Management Plan of the Czech Republic 2015-2024.

Chapter 4

Analysis

4.1 The Czech Republic now and then

Current trends in waste management aim to move towards a circular economy, where instead of extraction of raw materials and the increasing number of landfills, waste prevention, reuse of products, recycling and energy recovery play a crucial role.

4.1.1 Scope and composition of MSW

According to the Eurostat[1], the total amount of waste generated in the Czech Republic in 2017 reached 24.9 million tonnes, which implies 3.2% decrease compared to 2016 when the total amount of waste was 25.8 million tonnes. The municipal waste generation in 2017 reached 3.6 million tonnes, which translates to 344 kg per capita.

At the same time, since 2009, the Ministry of Environment in the Czech Republic together with CENIA have been publishing their own data on waste. In their reports it was suggested that in 2017, as opposed to Eurostat data, the total waste generation rose up to 34.5 million tonnes, causing 0.8% increase from 2016. Czech citizens also produced more municipal waste than in previous years, to be specific, the figure rose to 5.7 million tonnes of MSW, which represents around 16.5.% of the whole waste production. It corresponds to 1.4% growth from 2016 and 6.9% growth from 2009, which is the year when the data from the Ministry of Environment became available. Thus, one inhabitant generated 537 kg of municipal waste in 2017 compared to 531 kg in 2016 and 507 kg in 2009. The figures on total waste generation and MSW

[1] The data are extracted from Czech Statistical Office (CSU).

generation that are reported by CSU (Eurostat) and the ones reported by the Ministry of Environment (CENIA) are shown in the Figure 4.1. We can note the obvious discrepancies in the amount reported between the organisations, with CSU exhibiting lower values, whereas the figures CENIA works with are higher in all years and both the total and MSW generation.

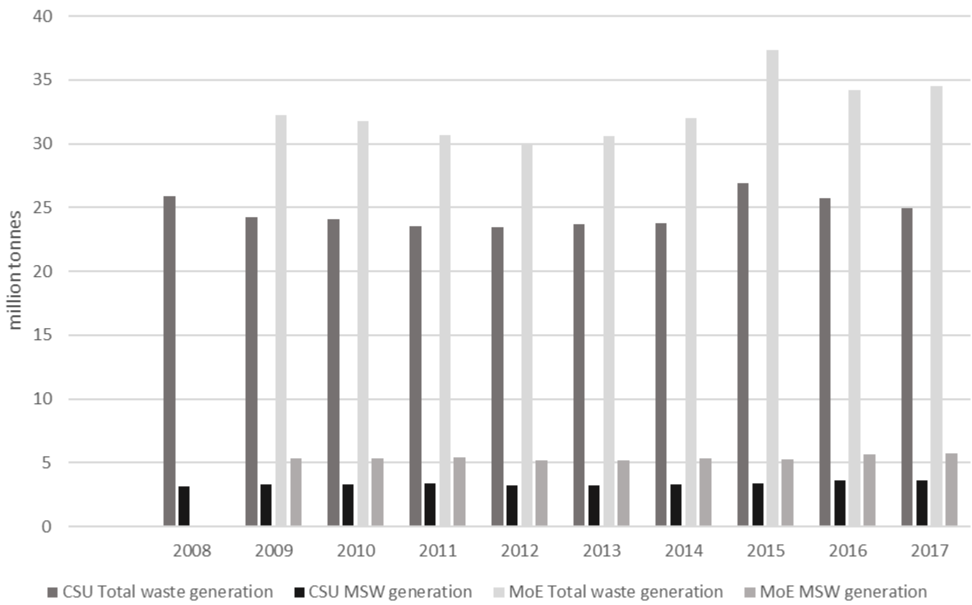

Figure 4.1: Waste generation in the Czech Republic, source: CSU and CENIA

The Ministry of Environment also publishes the figures of MSW generation and treatment in regions of the Czech Republic. Figure 4.2 shows municipal solid waste production in kg per capita in Czech regions for the year 2017. As it is indicated, only 2 of them generated less than 500 kg per capita, in particular, Zlinsky region with 484 kg and Jihomoravsky with 491 kg. On the contrary, Stredocesky, Vysocina, Olomoucky and the capital city, Prague reached the highest numbers on per capita MSW generation.

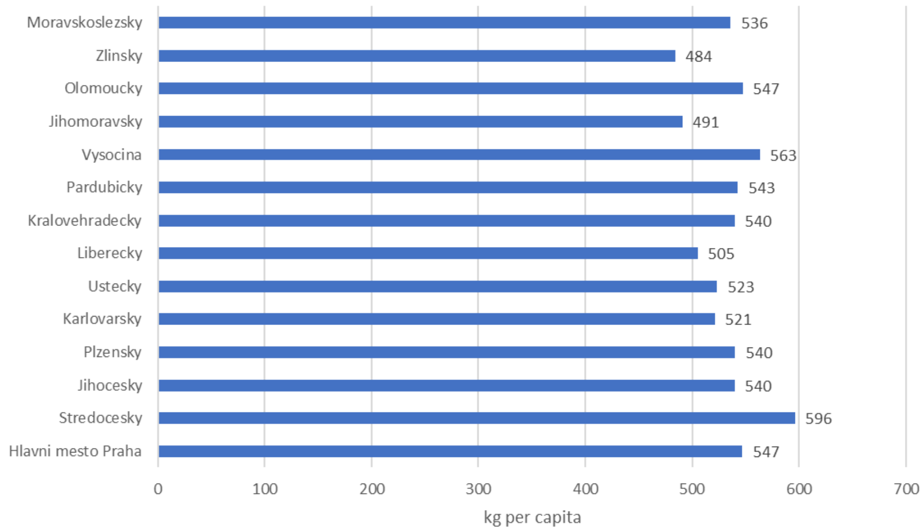

Figure 4.2: MSW generation in kg per capita in Czech regions, source: CENIA

If we want to have a look at the regional share of municipal waste generation, Figure 4.3 depicts the proportion of the total municipal waste for each region. It is ordered from the highest share, which belongs to Stredocesky region, down to the lowest proportion generated in Karlovarsky region. We can also notice that only 4 regions contribute to almost half of the total MSW production, specifically, Stredocesky, Praha, Moravskoslezsky and Jihomoravsky region.

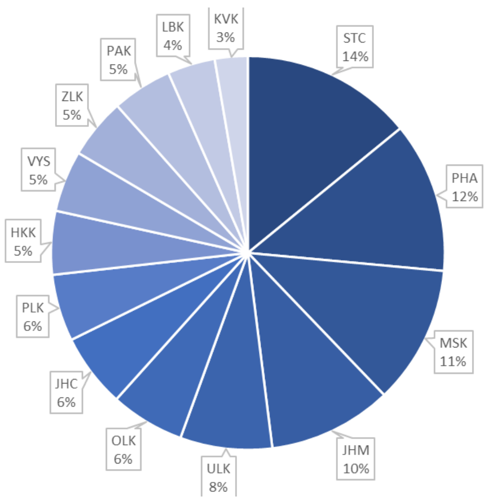

Figure 4.3: Regional share of MSW generation in the Czech Republic, source: CENIA

4.1.2 Treatment of MSW

The municipal waste treatment in the Czech Republic has gone through various stages throughout the years. Historically, the oldest way is landfill, however, nowadays, the emphasis is put on material and energy recovery, such as incineration, composting and recycling, with the aim to 'close the loop'. In other words, we want the material flow to be closed in long time cycles.

Generally speaking, the Czech Republic knows how to deal with waste since 84% of the total waste generation was recovered, out of which 80.5% materially and 3.6% energetically. Only 9.8% of all waste ended in landfills (Ministersrvo životního prostředí 2017).

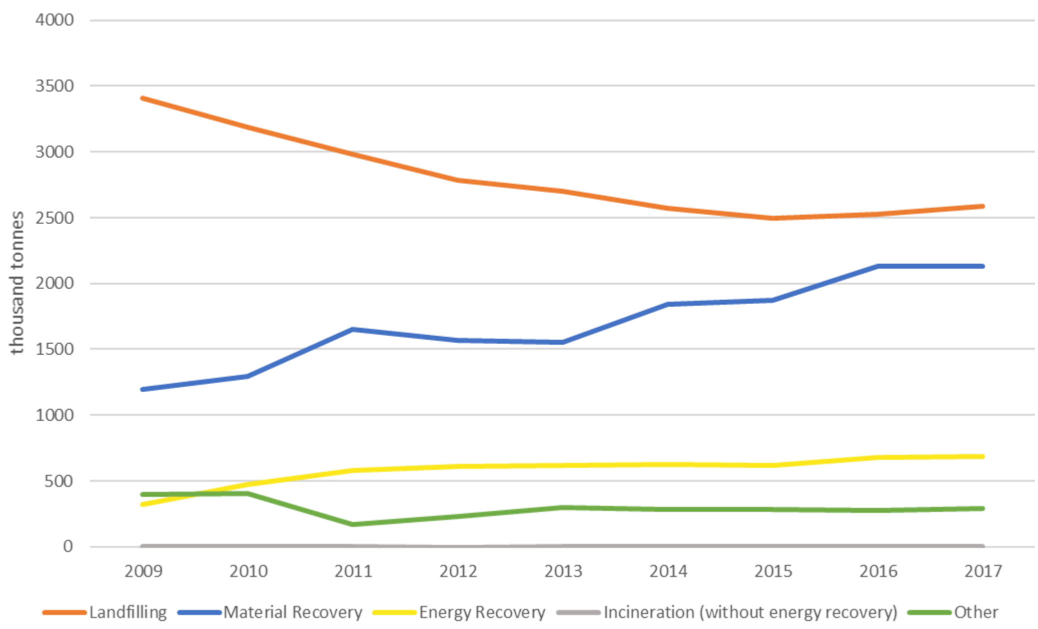

Figure 4.4: Treatment of MSW in the Czech Republic for the period 2009-2017, source: CENIA

Notwithstanding, landfilling still dominates when it comes to municipal waste treatment. That being said, the amount of MSW treated this way is gradually decreasing. Because of this trend, the proportion of municipal waste used for material recovery and energy recovery is on the other side growing. Figure 4.4 depicts the amount of MSW in thousand tonnes based on the treatment method in the Czech Republic from 2009 to 2017. In 2017, the share of landfilling was 45.4%, the share of materially recovered municipal waste was 37.5% and the share of municipal waste used for energy recovery rose to 12%. These figures indicate that the current situation in MSW treatment is not satisfying because landfilling is above EU-28 average and recycling is below average.

To meet the targets presented in Waste Management Plan of the Czech Republic as well as European targets of a circular economy, the Czech Republic needs to focus more on moving away and reducing the proportion of landfilling and at the same time increasing material and energy recovery of MSW.

To evaluate the fulfilment of the goals presented in Subsection 3.3.1, we will refer to Ministry of the Environment (2014). With respect to municipal solid waste, there were presented three key targets as described in the previous chapter. Now, we outline what managed to be achieved.

1. In 2015, the municipalities introduced an obligatory collection for paper, plastics, glass and metal. This target was therefore fulfilled.

2. In 2016, the Czech Republic accomplished to fulfil in advance the partial steps towards the 2020 target for increasing the preparing for re-use and recycling of waste materials such as at least paper, metal, plastic and glass. The recycling rate of paper, glass, plastics and metal waste from households and similar waste for the year 2016 reached 51.2%, surpassing the goal of 46%.

3. The significant part of municipal solid waste is still treated by landfilling, which has increased from 2015 to 2017. The energy recovery has increased but only slightly. The target is partially being fulfilled, however, according to the newest information, the Ministry of Environment is thinking about postponing the end of landfilling, which was planned for 2024, to 2030.

4.2 The Czech Republic within the EU

4.2.1 Analysis of MSW

The amount and composition of municipal waste vary greatly among EU countries since it is influenced by national waste management practices, level of consumption, rate of urbanisation and our lifestyle. Regardless of these differences, significant efforts have been put into limiting MSW generation. The intention is to redirect waste from landfills and incinerators to recycling as the main treatment since it can be fed back into the economy this way. Although landfilling of MSW has been banned in some countries, it still remains the main disposal method.

Now, we will compare several waste indicators and their trends for EU-28 countries. Figure 4.5 shows municipal waste generation by country expressed in kilograms per capita, covering the years 2008 and 2017. As we can see, in 2017 the amount of MSW differed considerably, ranging from 272 kg per capita in Romania up to 781 kg per capita in Denmark. In the Czech Republic, the amount of MSW reached 344 kg per capita, which leaves the country in the third place if we rank the countries in increasing order. Compared to the EU-28 average, it seems that the Czech Republic is performing well with regards to per capita waste generation. Furthermore, we will have a look also on the percentage change. Based on 2008 and 2017 figures, the highest average annual growth rates of MSW generation were recorded in Latvia (27%), Slovakia (21%) and Czechia (12%). On the other hand, Romania (−34%), Bulgaria (−27%), Spain (−16%) and Hungary (−15%) were the leading countries in decreasing their MSW generation during the above-mentioned period. The EU-28 average was −7% so even though the Czech Republic generated one of the least amounts of MSW per capita, positive growth rate indicates we ought to think more about how much we dispose of.

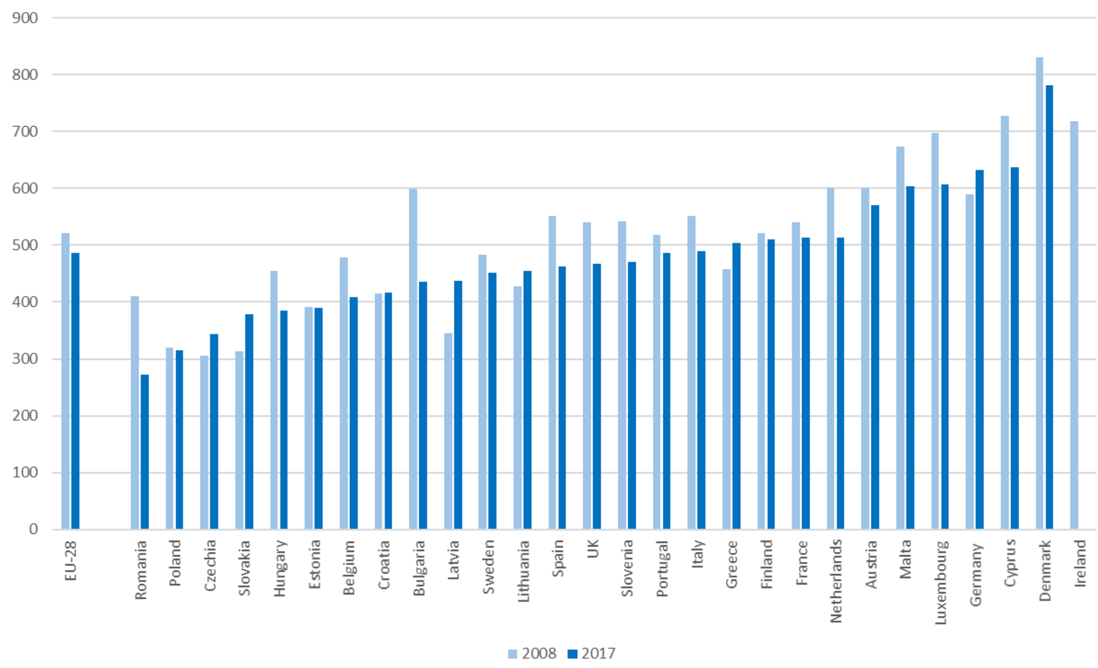

Figure 4.5: Municipal waste generated in 2008 and 2017 sorted by 2017 level, kg per capita, source: Eurostat

4.2.2 Treatment of MSW

In this section, we show the differences in the management of MSW that are present in Europe. We distinguish the following methods in the treatment of waste: landfill, incineration (with or without energy recovery), material recycling and composting and digestion.

Table 4.1: MSW treatment in EU-28

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Land	101	98	93	86	79	73	68	64	60	58
Inc	55	54	57	60	59	62	64	65	68	68
Rec	60	61	63	64	66	65	68	71	73	74
Comp	34	35	35	34	35	36	38	38	41	43
Other	11	9	6	5	6	6	5	7	6	6

Source: Eurostat

Overall figures on the amount of municipal waste expressed in million tonnes based on the treatment method in the European Union (EU-28) for the period from 2008 to 2017 are indicated in the Table 4.1. Although more and more waste is being generated in the EU, the total amount of MSW landfilled has diminished from 101 million tonnes in 2008 to 58 million tonnes in 2017, which corresponds to 43% decrease. This declining trend can be associated with the implementation of European legislation and new targets that all member states are obliged to meet. Table 4.2 summarizes the percentage change from 2008 to 2017 for the respective treatment methods. The data suggest that the amount of waste recycled has been growing steadily, in particular, it rose from 60 million tonnes in 2008 to 74 million tonnes in 2017, resulting in 23% growth. Composting follows a similar trend of growth with 26% increase as well as incineration with 24% rise in the same period as above.

To compare the performance of each state individually, we work with data expressed in kg per capita. Figure 4.6 depicts different ways of treating MSW, where countries are ordered in descending order based on landfilling. Currently, Malta, Cyprus and Greece dispose of the majority of their MSW in landfills. On the contrary, Sweden, Belgium, Finland, Germany, Netherlands and Denmark leave close to nothing to disposal and they try to either use energy recovery, material recycling or composting. The graph also indicates that the Czech Republic is somewhere in the middle but still above the average when it comes to landfill disposal and we should put more focus on the material recycling,

Table 4.2: EU-28 percentage change from 2008 to 2017 for MSW based on treatment method

	2008	2017	% change
Landfill	101	58	-43
Incineration	55	68	24
Recycling	60	74	23
Composting	34	43	26
Other	11	6	-46

energy recovery and especially on composting, where we are greatly below the average.

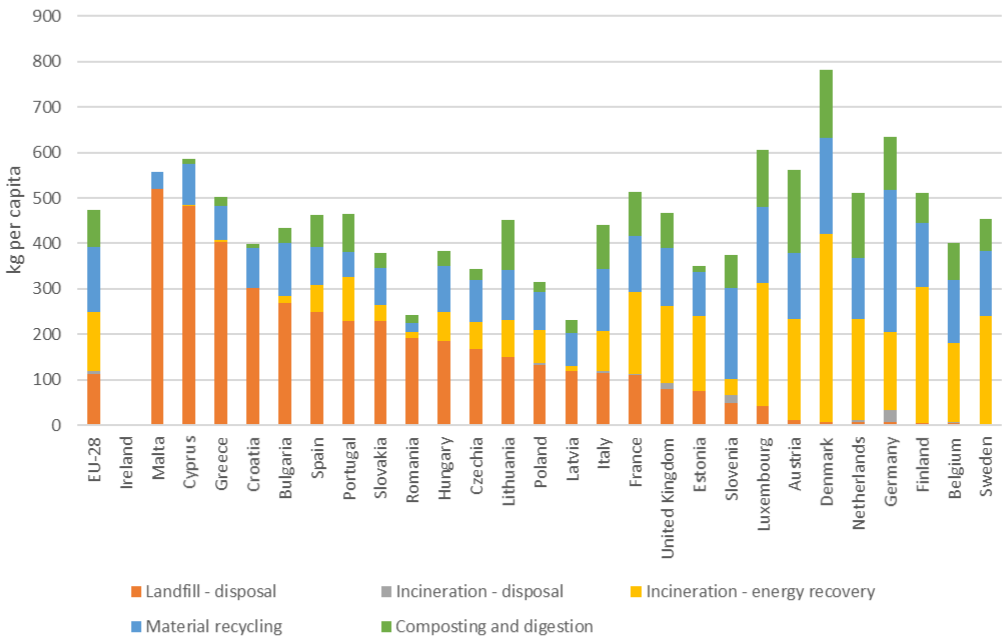

Figure 4.6: Treatment of MSW in EU countries in 2017, source: Eurostat

Chapter 5

Theoretical Background

5.1 Panel Data Analysis

Panel data, also called longitudinal data, are multidimensional data that take into consideration measurements over time. This type of data is being used to a great extent in applied work, in particular for policy analysis. It consists of a time series for each cross-sectional member in the data set. The basic idea is that we follow the same individuals across time, be it countries, cities, families, firms, etc. In consequence of following the same individuals, some time-constant, unobserved attributes of the units studied might be present, therefore, while conducting an econometric analysis of panel data, we cannot assume that the observations are independently distributed over time. For this reason, there are special models and methods that have been developed in order to analyse panel data properly, which we introduce in Section 5.2.

Let us consider the following general panel data model linear in parameters:

$$y_{it} = \beta_0 + \beta_1^T X_{it} + u_{it}, \quad \text{where } u_{it} \sim \mathcal{N}(0, \sigma^2), \tag{5.1}$$

where $i = 1, \dots, N$ denotes entities and $t = 1, \dots, T$ denotes time periods. In this equation, y_{it} represents the dependent variable and $X_{it} = (x_{it1}, x_{it2}, \dots, x_{itK})$ is a vector of independent, also called explanatory, variables. Random variable u_{it} is called idiosyncratic error because it changes across time t as well as across entities i, β_0 represents the intercept and β_1 is a $K \times 1$ vector of coefficients. Our goal is to estimate the parameters β_0, β_1, specifically the vector β_1.

One of the principal motivations for using panel data is to solve the omitted variables problem. In some applications, the assumption that the error term in each time period is uncorrelated with the independent variables in the same time periods is too strong. In our case, we deal with a model that contains a time-constant, unobserved effect. As it is explained in Wooldridge (2010), the unobserved effects are treated as random variables and are drawn from the population along with the dependent and independent variables. In this framework, we want to find out whether the unobserved effect is uncorrelated with the independent variables. In the case of correlation, putting the unobserved effect into the error term might indeed cause some serious problems. The basic unobserved effects model or fixed effects model can be written as:

$$y_{it} = \beta_0 + \beta_1^T X_{it} + c_i + u_{it}, \quad \text{where } u_{it} \sim \mathcal{N}(0, \sigma^2), \tag{5.2}$$

where i denotes the i^{th} cross-sectional unit and t is a time period. The variable c_i captures all unobserved, time-constant factors that affect y_{it}. It often encompasses features of a specific entity or individual that are given and do not change over time, hence, c_i only contains subscript i. The sum of the unobserved time-constant factor c_i and the idiosyncratic error u_{it} is often referred to as a composite error.

Based on the data available, we can come across two ways of having panel data sets.

- Assuming that we have the same time periods, denoted $t = 1, \ldots, T$, for each N cross-sectional units, we say that we have a balanced panel. In this case, the total number of observations is equal to $N \cdot T$.
- However, some panel data sets might have missing years for certain cross-sectional units in the sample, therefore, the total number of observations is less than $N \cdot T$ and the panel data set is unbalanced.

In our case, our dataset suffers from missing data, not containing all $N \cdot T$ observations, which means that we are working with unbalanced panel.

5.2 Models

There are several approaches on how to estimate the parameter of interest, β_1. We will present the most common and basic methods and their corresponding assumptions.

5.2.1 Pooled OLS regression

Under certain assumptions, we can use the pooled OLS to obtain a consistent estimator of β_1. The key assumption here is the strict exogeneity of explanatory variables. In other words, idiosyncratic errors are uncorrelated with explanatory variables, hence $\text{cov}(x_{itj}, u_{is}) = 0$ for all $t, s = 1, \ldots, T$ and for all $j = 1, \ldots, K$.

If c_i from the Equation 5.5 contains only a constant term, then the resulting OLS estimates are consistent and efficient.

In many cases, though, c_i does not contain only a constant term and is treated as a random variable. Usually, we also want to allow for the unobserved effect to be correlated with the independent variables. If there is a correlation between the unobserved effect c_i and any of the independent variables, then using pooled OLS will result in the estimates that are biased and inconsistent. Correlation between c_i and x_{itj} implies that x_{itj} will be correlated with the composite error $v_{it} = c_i + u_{it}$. This problem can be solved by a method called First Differences (FD), which consists of differencing adjacent periods and therefore eliminating the unobserved effect.

First difference estimation

First difference estimation eliminates the latent heterogeneity out of the model. By first differencing adjacent time periods in the Equation 5.5, we obtain the following equation:

$$\Delta y_{it} = y_{it} - y_{it-1} = \delta_0 + \beta_1^T \Delta X_{it} + \Delta u_{it}, \tag{5.3}$$

where Δ denotes the change from the period t to $t-1$. We have $T-1$ time periods for each entity i so now the total number of observation is $N(T-1)$. As we can see, the unobserved effect does not appear in the equation anymore as it was 'differenced away' and the intercept δ_0 is in fact the change in the intercept from t to $t-1$. The Equation 5.3 is called first-difference equation and it can be estimated by pooled OLS consistently under certain assumptions.

The assumptions for Pooled OLS using First Differences are as follows:

1. For each i, we have the model

$$y_{it} = \beta_1^T X_{it} + c_i + u_{it}, \qquad t = 1, \ldots, T,$$

where $X_{it} = (x_{it1}, \ldots, x_{itK})$, β_1 is a vector of parameters to be estimated and c_i is the unobserved effect.

2. We have a random sample from the cross section.

3. There is no perfect linear relationship among the independent variables. Moreover, each independent variable for at least some i changes over time.

4. For each t, $\mathbb{E}(u_{it}|\mathbf{X_i}, c_i) = 0$, where $\mathbf{X_i}$ denotes the independent variables for all time periods for the cross-sectional observation i, hence containing such x_{itj} for which $t = 1, \ldots, T$, $j = 1, \ldots, K$.

5. The variance of the differenced errors, conditional on all independent variables, is constant: $\mathrm{var}(\Delta u_{it}|\mathbf{X_i}) = \sigma^2$, $t = 2, \ldots, T$.

6. For all $t \neq s$, the differences in the errors, conditional on all independent variables, are uncorrelated: $\mathrm{cov}(\Delta u_{it}, \Delta u_{is}|\mathbf{X_i}) = 0$, $t \neq s$.

7. Conditional on $\mathbf{X_i}$, the Δu_{it} are independent and identically distributed normal random variables.

Under the assumptions 1-4, the first-difference estimators are unbiased and consistent with a fixed T and as $N \to \infty$. Assumption 5 secures that the differenced errors, Δu_{it}, do not suffer from heteroskedasticity and assumption 6 states that the differenced errors are serially uncorrelated. Hence, the assumptions item 5 and item 6 together ensure the (asymptotical) validity of standard errors and test statistics obtained from pooled OLS and first-differencing estimation, therefore, under the assumptions 1-6, the first-difference estimator is the best linear unbiased estimator, conditional on the independent variables. Including the assumption 7 will assure that FD estimator is normally distributed and that t and F statistics from the pooled OLS on the differenced data have the exact t and F distributions. If the assumption 7 does not hold, we can work with the asymptotic distribution.

5.2.2 Fixed Effects

In this section, we will introduce the Fixed Effects (FE) estimation, which uses a transformation to eliminate the latent effect c_i prior to estimation (as it was in the case of FD estimation). Hence, any time-constant independent variables are removed together with the c_i.

Let us consider the general unobserved effects model as in Equation 5.5. For each i, we average the unobserved effects model over time, obtaining:

$$\bar{y_i} = \beta_0 + \beta_1^T \bar{X}_i + c_i + \bar{u_i}, \tag{5.4}$$

where $\bar{X}_i = (\bar{X}_{i1}, \ldots, \bar{X}_{iK})$, $\bar{X}_{ik} = \frac{1}{T}\sum_{t=1}^{T} x_{itk}$, $k = 1, \ldots, K$, $\bar{y_i} = \frac{1}{T}\sum_{t=1}^{T} y_{it}$ and $\bar{u_i} = \frac{1}{T}\sum_{t=1}^{T} u_{it}$. Since c_i is fixed over time, we get $\bar{c_i} = \frac{1}{T}\sum_{t=1}^{T} c_i = c_i$. Then subtracting Equation 5.4 from Equation 5.5, we obtain so called time-demeaned model:

$$\ddot{y}_{it} = \beta_1^T \ddot{X}_{it} + \ddot{u}_{it}, \qquad t = 1, \ldots, T. \tag{5.5}$$

This model no longer includes the intercept, neither the unobserved effects term c_i so it can be estimated by pooled OLS. The corresponding estimator is called fixed effects estimator. The advantage is that the FE estimator allows for arbitrary correlation between c_i and the independent variables in any time period. On the other hand, thanks to the FE transformation, any independent variable that is constant over time for all i also disappears. This can be seen as one of the disadvantages as well as losing one degree of freedom in each cross-sectional observation i because of the time-demeaning, leaving us with the total of $N(T-1) - K$ degrees of freedom.

Let us discuss the necessary assumptions for fixed effects estimation. According to Wooldridge (2013), the first four assumptions for fixed effects, let us name them FE 1-FE 4, are identical to the first-difference assumptions 1-4. Under these four assumptions, the fixed effects estimator is unbiased and consistent with a fixed T as $N \to \infty$. Now, we will add assumptions specifically for fixed effects.

5. Conditional on $\mathbf{X_i}$ and c_i, the variance of idiosyncratic errors is constant: $\mathrm{var}(u_{it}|\mathbf{X_i}, c_i) = \mathrm{var}(u_{it}) = \sigma_u^2$, for all $t = 1, \ldots, T$.

6. For all $t \neq s$, the idiosyncratic errors, conditional on all independent variables and c_i, are uncorrelated: $\mathrm{cov}(u_{it}, u_{is}|\mathbf{X_i}, c_i) = 0$, $t \neq s$.

7. Conditional on $\mathbf{X_i}$ and c_i, the u_{it} are independent and identically distributed normal random variables: $u_{it} \sim \mathcal{N}(0, \sigma_u^2)$.

Under the assumptions FE 1-FE 6, the fixed effects estimator is the best linear unbiased estimator. Adding assumption FE 7, fixed effects estimator is normally distributed and t and F statistics have the exact t and F distributions. If the assumption FE 7 does not hold, we can work with the asymptotic approximations provided that we have enough observations.

5.2.3 Random Effects

Assuming that the unobserved effect c_i is uncorrelated with each independent variable, that is to say $\text{cov}(x_{itj}, c_i) = 0$, $t = 1, \ldots, T$; $j = 1, \ldots, K$, Equation 5.5 becomes a Random Effects model (RE). It can be also written as

$$y_{it} = \beta_0 + \beta_1^T X_{it} + v_{it}, \tag{5.6}$$

where $v_{it} = c_i + u_{it}$ is composite error term. Seeing that c_i is in the composite error in each time period, this model suffers from serial correlation: $\text{cov}(v_{it}, v_{is}) = \frac{\sigma_c^2}{\sigma_c^2+\sigma_u^2}$, $t \neq s$, where $\sigma_c^2 = \text{var}(c_i)$ and $\sigma_u^2 = \text{var}(u_{it})$.

Supposing that c_i is uncorrelated with each explanatory variable, FE and FD models do not result to be efficient because we eliminate the information contained in c_i. Thus, the solution is to use a random effects model. In contrast to FD or FE models, where the goal was to eliminate the unobserved effect since it was considered to be correlated with some x_{itj}, and then use pooled OLS, RE model employs general least squares (GLS) transformation in order to solve the serial correlation problem.

The assumptions RE 1, RE 2, RE 4, RE 5, RE 6 for random effects estimation are the same as for fixed effects. The assumption RE 3 is different because now we can allow for time-constant explanatory variables.

3. There are no perfect linear relationships among the explanatory variables.

By allowing time-constant independent variables, we must include additional assumptions about the relationship between the unobserved effect c_i and the explanatory variables.

RE 4b In addition to FE 4, the expected value of c_i, conditional on all explanatory variables, is constant: $\mathbb{E}(c_i|\mathbf{X_i}) = \beta_0$.

RE 5b In addition to FE 5, the variance of c_i given all explanatory variables is constant: $\text{var}(c_i|\mathbf{X_i}) = \sigma_c^2$.

The main distinction between FE and RE lies in the assumption RE 4b, which rules out the correlation between the unobserved effect and the independent variables. Under the assumptions RE 1-RE 4, RE estimator is consistent for fixed T as $N \to \infty$. Adding the assumptions RE 5 and RE 6, the estimator is asymptotically efficient and asymptotically normally distributed as $N \to \infty$. Moreover, standard errors, t and F statistics are valid.

Chapter 6

Empirical Model

6.1 Data Specification

To enable the analysis of national dynamics, the panel covers annual data for the period of 1995-2017. The population is therefore represented by 23 time periods on 28 units, specifically 28 EU countries[1]. The data we are working with were chosen based on the previous studies as it was explained in Chapter 2 and based on its accessibility. Data available for all EU-28 countries for certain variables were provided by Eurostat and World Bank, however, some data issues still arose that we could not avoid. They will be introduced in Subsection 6.1.3. In sum, according to data availability, the econometric analysis consists of an unbalanced panel made up of 28 countries that were observed over a period of 23 years.

Beigl *et al.* (2004) in his research for major European cities considers socio-economic indicators such as population, population age structure, infant mortality rate, life expectancy at birth, population density, GDP, sectoral employment, unemployment rate, overnight stay and average household size. Other factors that were repeatedly used in various studies are income levels (Kolekar *et al.* (2016), Grossman *et al.* (1974)), growth of urban population (Wang & Nie (2001), Liu (2010)) or energy consumption (Liu 2010). The following sections describe the variables that were introduced in our models.

[1]In this thesis, we are working with 28 countries, including the United Kingdom (EU-28 aggregate in Eurostat).

6.1.1 Dependent variable

The data for the dependent variable, municipal solid waste generation, were retrieved from the European Statistical Office, Eurostat. They cover the period 1995-2017 for the 28 EU member states. Table 6.1 offers a brief description of the dependent variable, including definition, unit and source. Yearly country-level data with regards to the municipal solid waste generation per capita are calculated as the total amount of MSW generated divided by the population of the country.

Table 6.1: Dependent variable of the model

Name	Definition	Unit	Source
MSW	Municipal solid waste generation consists of waste collected by or on behalf of municipal authorities and is disposed of through the waste management system.	kg per person	Eurostat

According to Eurostat, the data refer to the amount of municipal waste generated. For countries that have complete coverage of their MSW collection scheme, the total amount of MSW generated equals the total amount of MSW collected. However, not all countries cover all of their territory with MSW collection scheme. In this case, they have added an estimate of the waste produced in areas without coverage. Table 6.2 portrays the summary statistics for MSW generation from our panel data. As we can see, it seems to be rather heterogeneous, ranging from 224 kg per capita to 830 kg per capita with a mean of 483.97 kg per capita. Also, 11 out of 644 observations are missing since the MSW generation in those cases failed to be captured.

Table 6.2: Summary statistics for MSW

	min	max	mean	sd	na
MSW	224.00	830.00	483.97	124.10	11

6.1.2 Independent variables

Explanatory variables include mainly socio-economic indicators that we obtained from Eurostat. In fact, all variables except one were extracted from

Eurostat. The indicator for the degree of urbanization was not easily encountered there, hence we extracted this information from World Bank. After reviewing the literature on MSW management, we decided to include the following explanatory variables: gross domestic product (GDP) per capita, income per capita, total population, population density, unemployment rate and degree of urbanization. They are described in Table 6.3 and Table 6.4 shows summary statistics for every independent variable, concretely minimum value, maximum value, mean, standard deviation and the number of NA's (missing observations) are displayed. Firstly, GDP or income are one of the most used economic indicators which ought to explain well the amount of municipal waste that is generated. We are working with GDP in euros per capita and mean equivalised net income in euros. Secondly, it was suggested by Johnstone & Labonne (2004) that MSW production is approximately unit elastic with respect to population. Thirdly, it is assumed that higher population density leads to a positive effect on MSW generation, hence we include this variable into the model. The results by Mazzanti *et al.* (2007) and Johnstone & Labonne (2004) are consistent with previous studies, showing positive elasticities, but lower than one. On the other hand, Karousakis (2006) suggests that population density is not significant as the policy index, however, a strong relationship between urbanization and MSW was found. Lastly, employment status was used as a significant affluence-related proxy in a few studies (Beigl *et al.* 2008), though it is not that frequently used as the previous factors. We decided to include the unemployment rate as we believe it might as well affect the production of MSW.

Similar to the case of MSW values, the data for independent variables suffer from missing observations, which can cause problems later in the modelling process. Usually, the issue of the missing observations arises when dealing with historical data, which failed to be captured in some countries. For example, the dataset for income lacks 175 observation out of the total of 664 observations. The possible cause is that European Statistics on Income and Living Conditions, the primary source of our data on income, was launched in different EU countries at different times. On the other hand, in the case of population and urbanization, we are working with complete datasets. The whole overview of summary statistics for each explanatory variable is shown in Table 6.4. We can see that certain level of heterogeneity is present here, too, especially with regards to GDP, where the standard deviation is around 15400 euro per capita, and with regards to population with the standard deviation of 22.4 million.

Table 6.3: Explanatory variables of the model

Name	Definition	Unit	Source
GDP	Gross domestic product at market prices. It is calculated as the ratio of GDP to the average population of a specific year.	Euro per capita	Eurostat
income	The total disposable income of a household. It is calculated by adding together the personal income received by all of household members plus income received at household level.	Euro per capita	Eurostat
pop	Population refers to the total number of inhabitants in the country.	Integer	Eurostat
dens	Population density refers to the number of people living in an area per square kilometre.	inhabitants per km^2	Eurostat
un	Unemployment rate refers to the number of unemployed people as a percentage of the labour force.	%	Eurostat
urb	Urban population refers to people living in urban areas as defined by national statistical offices.	%	World bank

6.1.3 Issues

As Johnstone & Labonne (2004) noted, the differences in waste classifications used by different states might have an effect on OECD and EU datasets. Specifically, in the EU countries, the responsibility for the implementation of waste policies lies in the hands of the local authorities. Thus, the variations in the amount of MSW produced, as it was indicated in Figure 4.5, reflect not only differences in consumption patterns and economic wealth, but also depend on how the countries collect and manage the MSW.

Table 6.4: Summary statistics for explanatory variables

	GDP	pop	dens	un	urb	income
min	1200.00	376433.00	16.80	1.90	50.62	1582.00
max	92600.00	82536680.00	1495.20	27.50	97.96	41562.00
mean	21507.85	17728969.68	169.90	8.93	71.67	15136.30
sd	15399.34	22399884.70	241.17	4.26	12.30	8440.95
na	7	0	15	44	0	175

Elasticities obtained from international datasets are rather difficult to interpret because if we want to provide policy makers with informative results, elasticities should be calculated at the most decentralised level possible. Hence, policy implications from international cross-country studies are sometimes regarded as weak. Single country case studies using data at the regional, provincial or municipal level are still scarce in the literature. Moreover, Ercolano *et al.* (2018) claim that single country municipal level-data makes it possible to detect the consistent within-country heterogeneity in MSW production that is present among municipalities. They continue by stating that MSW management strategies are developed by local governments, hence, the examination of municipal-level determinants becomes more valuable. Unfortunately, we do not possess enough data regarding the MSW per capita generation on the regional level and neither the municipal or provincial data are available. For that reason, we cannot carry out a relevant econometric analysis specifically within the municipalities in the Czech Republic, though it would provide us with more valuable information. The analysis using EU data must suffice for now, notwithstanding, we must be cautious whilst interpreting the results.

Technical issues

One of the main indicators for testing some kind of relationship between random variables is the correlation coefficient. It is defined as follows:

Definition 6.1 (correlation coefficient). Let X, Y be random variables, for which it holds $0 < \text{var}(X) < \infty$, $0 < \text{var}(Y) < \infty$, then the correlation coefficient of X, Y, denoted $\text{corr}(X, Y)$, is

$$\rho_{X,Y} = \text{corr}(X,Y) = \frac{\text{cov}(X,Y)}{\sqrt{\text{var}(X)}\sqrt{\text{var}(Y)}},$$

where $\mathrm{cov}(X, Y) = \mathbb{E}(X - \mathbb{E}X)(Y - \mathbb{E}Y)$ is covariance between X, Y and $\mathrm{var}(X) = \mathbb{E}(X - \mathbb{E}X)^2$ is variance of X.

Its consistent estimate is the Pearson correlation coefficient, which is used in our case, as well. It was computed in R and Table 6.5 shows the respective correlations between variables that are used in the models. When looking at the lower triangular of the table[2], the first column indicates the correlation between the dependent variable MSW and each one of the independent variables, while the rest of the lower triangular of the table shows the correlation between the explanatory variables. Indeed, there is a high correlation between GDP and income and we will not include both of them in one specification at the same time. In any case, they are available, so we can choose one or the other for our model specifications. Some slightly higher values of correlation[3] might be encountered between GDP and urbanization (corr(GDP, urb)$= 0.51$), income and urbanization (corr(income, urb)$= 0.54$), density and urbanization (corr(dens, urb)$= 0.46$), GDP and unemployment (corr(GDP, un)$= -0.37$) and income and unemployment (corr(income, un)$= -0.36$). Multicollinearity between independent variables might cause some problems while executing the regression, particularly in the calculation of the estimators.

Table 6.5: Correlation between variables

	MSW	GDP	pop	dens	un	urb	income
MSW	1.00	0.62	0.09	0.24	-0.34	0.36	0.68
GDP	0.62	1.00	0.03	0.07	-0.37	0.51	0.95
pop	0.09	0.03	1.00	0.01	0.08	0.08	0.12
dens	0.24	0.07	0.01	1.00	-0.22	0.46	0.11
un	-0.34	-0.37	0.08	-0.22	1.00	-0.15	-0.36
urb	0.36	0.51	0.08	0.46	-0.15	1.00	0.54
income	0.68	0.95	0.12	0.11	-0.36	0.54	1.00

As a result of the detected correlation, we will carry out a simple linear regression for each one of the five cases in order to check once again if the problem of multicollinearity is present and should be properly treated. As shown in the Table 6.6, the resulting R^2 in all five regressions is below the benchmark of 0.3 so we will make use of the variables that were proposed in the previous section. Taking into consideration the possibility of multicollinearity in some scenarios, we will be wary during the interpretation process.

[2]We use the expression 'lower triangular of the table' inspired by the matrix nomenclature. Specifically, it is derived from 'lower triangular of the matrix', maintaining the same meaning.

[3]We consider slightly higher values of correlation when corr > 0.3.

Table 6.6: R^2 of the simple linear regression

Regression	R^2
GDP on urbanization	0.261
GDP on unemployment	0.150
density on urbanization	0.227
income on urbanization	0.285
income on unemployment	0.126

Another possible problem that we expect to arise is heteroskedasticity, in other words, the violation of the homoskedasticity assumption. It states that the variance of the unobserved error, u, conditional on the explanatory variables, is not constant but varies. Although it does not cause bias or inconsistency of the estimators, the usual standard errors are not valid, hence t and F statistics are not valid either. One of the solutions is to use heteroskedasticity-robust statistics (at least in the large samples), but their respective distribution will be asymptotic (in contrast to the exact distribution in case of no violation of the classical assumptions). In regression analysis, the presence of heteroskedasticity is a common problem, so in order to discover whether our model suffers from heteroskedasticity, we will use the Breusch-Pagan test.

The more pressing problem, though, might be a serial correlation in the error terms. It arises when the value of a variable affects its future value. Similarly to the case of heteroskedasticity, this problem might be detected in our analysis, therefore certain adjustments may be necessary. Still, we should bear in mind that heteroskedasticity or serial correlation adjusted robust standard errors are usually larger than OLS standard errors when there is no heteroskedasticity or serial correlation. Whether it is necessary to use this correction, we will run few tests.

6.2 Software approach

In this thesis, we are working in R environment. The plm package (Croissant & Millo 2008), which was designed to make the panel data estimation easier, is employed. The general plm function supports five estimation methods: pooled OLS, fixed effects, random effects, first differences and between estimation; out of which the first four of them are used in our models. For representation of results tables from R were extracted and using stargazer package (Hlavac 2018), LaTeX code was created.

To be able to detect a violation of some of the assumptions of the models, we perform various tests. R offers multiple functions for robust variance-covariance matrices. The robust inference might be required since we suspect heteroskedasticity or serial correlation in the error terms. Some additional packages shall be installed in order to carry out other specific tests.

6.3 Modelling for MSW

In order to analyse the dataset, in particular, the behaviour of countries over time, the panel data approach is used as it allows to account for individual heterogeneity. Ordinary least square method (OLS) is implemented to analyse the impact of the following explanatory variables: GDP or income, population, density of population, urbanization and unemployment rate. During the modelling process, four specifications were considered for this panel data. First, we present the hypotheses we are working with. After that, the specification of the models is introduced.

Hypotheses

After reviewing field-specific economic models and various research findings, we decided to form the following hypothesis:

- Hypothesis 1: Municipal solid waste generation is influenced by GDP or income in a positive way.

  It is believed by many that GDP or disposable income are very good determinants of MSW production. If GDP per capita is increased (or income), we expect a higher amount of MSW generated. GDP and income, as economic indicators for wealth, imply that generally, rich people can afford to purchase more products, hence leaving behind more waste.

- Hypothesis 2: Municipal solid waste generation is influenced by population in a positive way.

  Johnstone & Labonne (2004) argues that the population is unit elastic with respect to MSW generation. Once again, it seems natural to suspect that more people will produce more rubbish, hence we anticipate a positive relationship between these two variables.

- Hypothesis 3: Municipal solid waste generation is influenced by density of population in a positive way.

  Analogously to the population, we assume that an increase in density would result in an increase in MSW production. However, Karousakis (2006) claims that this factor is not very significant.

- Hypothesis 4: Municipal solid waste generation is influenced by urbanization in a positive way.

  Urbanization seems to be a factor of great significance, which was confirmed in the study by Karousakis (2006) We suspect that the higher the urbanization rate, the higher the amounts of MSW. This relationship might be perhaps explained by the way people live in the cities, their customs and the management practices of cities. Since we are dealing with mainly developed countries, where the waste management policies in cities should be on a good level (in contrast to developing countries), the problem might lie in different consumption habits compared to those living in the villages. On the one hand, urban people often go grocery shopping to supermarkets, ending up with many bags of packaged food. Moreover, they usually live in flats, which makes it harder to compost organic matters (if this option is not available to them by the municipality). On the other hand, people living in rural areas buy their produce from local markets or they grow their own plants, fruit and vegetables. The majority of them lives in houses, which makes it easier to compost.

- Hypothesis 5: Municipal solid waste generation is influenced by unemployment in a negative way.

  Although not so common to be included in the models, we decided to incorporate the unemployment rate as it might be seen as a significant affluence-related proxy. The lower the unemployment rate, more people will earn proper wages, hence more people can spend their money on purchasing goods. As a consequence, they will produce more waste.

Models

To verify the validity of the hypotheses, we will analyse four models. They were chosen based on the studied research articles and adjusted for our study, taking into consideration the availability of data. Still, we had to face the problem of missing observations, therefore we are working with unbalanced panel. In all of the presented specifications, MSW generation, expressed in kg per capita, appears as our variable of interest, the dependent variable. The explanatory variables, which are believed to have an impact on the dependent variable, were chosen after examining academic literature and other relevant publications in the field of waste management. Consequently, the explanatory variables selected for the specifications were adjusted to adequately represent and evaluate the situation in the Czech Republic.

The first model consists of the variables that are frequently used in the models, namely GDP and population. The correlation between the independent variables is very low, hence, no multicollinearity problems appear. In this case, level-level regression is employed. The hypothesis arising from this model is whether GDP and population, popular socio-economic indicators, influence the amount of municipal solid waste generated. If so, we want to evaluate the effect of each variable on MSW production, and whether this effect is positive, as it is often suggested by scholars and researchers.

Model 1:

$$MSW_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 pop_{it} + c_i + u_{it},$$

where $i = 1, \ldots, 28,\ t = 1, \ldots, 23,\ u_{it} \sim \mathcal{N}(0, \sigma^2),\ c_i$ is the unobserved country effect, GDP represents gross domestic product expressed in euros per capita and pop refers to population of the country.

In the second specification, we introduce income and population density as explanatory variables. Income is again a very good affluence-related determinant. The reason why this model contains population density indicator is that there are mixed findings on the effect of population density on MSW generation. Altogether, in this scenario, the aim is to scrutinize the effect of income and population density on the regressand and to make some contributions in clarifying the previous ambiguous results on population density.

Model 2:

$$MSW_{it} = \alpha + \beta_1 income_{it} + \beta_2 dens_{it} + c_i + u_{it},$$

where $i = 1, \ldots, 28,\ t = 1, \ldots, 23,\ u_{it} \sim \mathcal{N}(0, \sigma^2),\ c_i$ is the unobserved country effect, $dens$ stands for population density, which is expressed in number of inhabitants per kilometre square and $income$ is expressed in euros per capita.

The third specification proposed contains all of the independent variables that were presented in Subsection 6.1.2., while choosing income rather than GDP. We want to evaluate how well this model explains the changes in the amount of MSW generated. Besides that, we are interested in finding out which variables will result to be significant and how these explanatory variables affect the amount of MSW. In addition to the variables used in the first and the second model, we incorporate the variable for the urbanization rate called *urb*. Some studies suggest a strong relationship between urbanization rate and MSW production and this model will help us in determining if it is also significant when using data of EU countries. The model contains also data on the unemployment rate, seeing that we are very interested in how it performs with regards to MSW generation. This indicator is not as frequently used as the rest of the independent variables considered in this thesis, but we believe it might have a significant impact on the generation of the MSW.

Model 3:

$$MSW_{it} = \alpha + \beta_1 income_{it} + \beta_2 pop_{it} + \beta_3 dens_{it} + \beta_4 urb_{it} + \beta_5 un_{it} + c_i + u_{it},$$

where $i = 1, \ldots, 28$, $t = 1, \ldots, 23$, $u_{it} \sim \mathcal{N}(0, \sigma^2)$ and c_i is the unobserved country effect. The variables *income*, *pop*, *dens* are defined in the same way as in the previous specifications, *urb* stands for urbanization rate, which is expressed in %, and *un* stands for unemployment rate expressed in %.

Lastly, the fourth specification is composed of the variables as in the model 3, however, instead of conducting level-level regression, we use logarithmic transformation of some variables. We will be interested in determining the elasticities between MSW generation and income as well as MSW generation and population. These variables are often used in their logarithmic form for better interpretation.

Model 4:

$$\begin{aligned} \log(MSW)_{it} = \alpha + \beta_1 \log(income)_{it} + \beta_2 \log(pop)_{it} + \beta_3 dens_{it} \\ + \beta_4 urb_{it} + \beta_5 un_{it} + c_i + u_{it}, \end{aligned}$$

where $i = 1, \ldots, 28$, $t = 1, \ldots, 23$, $u_{it} \sim \mathcal{N}(0, \sigma^2)$ and c_i is the unobserved country effect.

6.4 Results

In this section, the results of our empirical work will be presented. The regression for each model was run on unbalanced data from 28 EU countries over a time period from 1995 to 2017. In each model, we run plmtest function with 'twoways' effect, which is testing for individual and time effects. The resulting p-value of plmtest test was considerably smaller than the benchmark of 0.05[4], which indicates that it makes sense to perform panel data analysis.

6.4.1 Model 1

The results of the regression using four estimation methods for panel data as presented in Section 5.2, namely Pooled OLS, FD, FE and RE, are included in the Table A.1 of Appendix A. After performing the Breusch-Pagan test against heteroskedasticity and Breusch-Godfrey test of serial correlation, the presence of both was detected. To solve this problem, we ran a regression with robust standard errors that correct for heteroskedasticity as well as for serial correlation. The respective results are summarized in Table 6.7. In the table, we can find the estimates for independent variables with respect to the estimation method used, which are denominated as follows: Pooled OLS, FD, FE and RE. The significance of the variables is marked by stars next to the corresponding estimates and serves as a graphical approximation for p-value of the estimate. The variable is considered to be significant when the p-value is smaller than $\alpha = 0.05$. Standard deviation can be found below the estimates in parentheses.

We executed three tests, specifically plmtest, pFtest and phtest, to help us determine which method for this specification should be used and interpreted. Both FE and RE estimations resulted to be better than pooled OLS, while FE was detected to be preferable to RE. Moreover, Wooldridge (2013) argues that FE is almost always more convincing than RE for policy analysis when using aggregated data.

As it was assumed in our hypothesis, GDP is positively related to MSW generation. In contrast, based on FE as well as RE or FD estimation, the population appears to be negatively related to our dependent variable. When comparing the results between non-robust and robust FE estimation (Table A.1 and Table 6.7), we can see how the significance of the explanatory variables

[4]The level of significance, α, is set to be 0.05. We reject the null hypothesis when p-value$< \alpha = 0.05$.

Table 6.7: Regression results for Model 1 (robust standard errors)

	Dependent variable: MSW			
	(Pooled OLS)	(FD)	(FE)	(RE)
GDP	0.005^{***}	0.005^{***}	0.002^{**}	0.002^{**}
	(0.001)	(0.001)	(0.001)	(0.001)
population	$2.7 \cdot 10^{-7}$	$-9.4 \cdot 10^{-6}$ **	$-9.2 \cdot 10^{-6}$ *	$-7.1 \cdot 10^{-7}$
	$(5.7 \cdot 10^{-7})$	$(4.1 \cdot 10^{-6})$	$(5.5 \cdot 10^{-6})$	$(1.1 \cdot 10^{-6})$
Constant	377.835^{***}	-1.077		449.759^{***}
	(32.046)	(1.305)		(31.241)
Observations	626	598	626	626
R^2	0.359	0.073	0.084	0.067
Adjusted R^2	0.357	0.070	0.039	0.064
Note:				*p<0.1; **p<0.05; ***p<0.01

using FE changed, to be precise, decreased. Therefore, it is crucial to be careful when dealing with issues such as serial correlation or heteroskedasticity in panel data.

FE estimation of GDP results to be significant. On the other hand, the population turns out to be insignificant[5]. The effect of GDP on MSW is positive and holding other variables fixed, if we increase GDP per capita by 1000 euro, the amount of yearly MSW generated by one inhabitant will increase by 2 kilograms. Surprisingly, if the population is increased by 1 million people, MSW per capita is estimated to decrease on average by 9.2 kilograms. It is not something that we would have expected but at the same time, as we set the significance level $\alpha = 0.05$, population turns out to be insignificant. The goodness of fit, also known as R^2, of this model is equal to 0.084. However, as we are dealing with multiple regression analysis, it is preferred to look at the value of adjusted R^2. Standard R^2 is increased every time we add more predictors to the model, hence the standard R^2 must be adjusted. The adjusted R^2 compensates for the addition of more variables in the model and it was

[5] Population is significant only when assuming the level of significance, α, to be equal to 0.1. If we assume that $\alpha = 0.05$ (as we do), then the population is not significant.

calculated to be 0.039, which means that almost 4% of the variation in MSW is explained by GDP and population.

6.4.2 Model 2

Similarly to the first model, Breusch-Pagan test and Breusch-Godfrey test revealed heteroskedasticity and serial correlation, hence we ran a regression with robust standard errors. The results are presented in Table 6.8., while the results of the regression without the correction for heteroskedasticity or autocorrelation can be found in Table A.2. Estimated coefficients are displayed for Pooled OLS, FD, FE and RE. Now, we have to decide which estimation method is appropriate and should be used to interpret the results. After performing the tests that compare Pooled OLS with FE and RE, FE and RE were found to be more suitable. Furthermore, the Hausman test confirmed (as we anticipated) that FE should be employed.

Table 6.8: Regression results for Model 2 (robust standard errors)

	Dependent variable: MSW			
	(Pooled OLS)	(FD)	(FE)	(RE)
income	0.009^{***}	0.006^{***}	0.004^{***}	0.003^{**}
	(0.002)	(0.002)	(0.001)	(0.001)
density	0.092^{***}	-0.380^{*}	-0.930^{**}	0.038
	(0.035)	(0.227)	(0.451)	(0.049)
Constant	341.994^{***}	-1.521		436.779^{***}
	(24.944)	(1.425)		(25.235)
Observations	461	433	461	461
R^2	0.494	0.056	0.079	0.051
Adjusted R^2	0.491	0.052	0.017	0.047
Note:				*p<0.1; **p<0.05; ***p<0.01

The hypothesis arising from this model is whether income and population density are significant and have a positive impact on the amount of MSW generated. The results indicate that income is indeed very significant. Holding density fixed, increasing income by 1000 euro is estimated to increase the

MSW on average by 4 kilograms. This supports the statement that income will positively impact the generation of MSW. Income acts as an affluence-related proxy and an increase in income implies that people can afford more. As a consequence, they will purchase more goods, which eventually results in the generation of waste, so our findings are in accordance with our hypothesis. Population density results to be significant, as well, however, the sign is estimated to be negative, as opposed to what we hypothesised. If population density is increased by 10, in other words, there are 10 more people per kilometre square, then MSW is supposed to decrease by more than 9 kilograms. One possible explanation supporting this result might be that higher population density implies scarce land resources, thus there is more pressure to protect land and preserve environmental quality.

R^2 of this regression is 0.079, however, adjusted R^2 was only 0.017, which implies that barely 2% of the variation in MSW generation is explained by income and population density. It might suggest that we include other relevant variables in the model, which we attempt to do in the following specifications.

6.4.3 Model 3

This model consists of 5 independent variables, namely income, population, population density, urbanization rate and unemployment rate. In this case, we must be cautious since the model includes some variables that are slightly correlated. The goal is to figure out what the effect of our explanatory variables on MSW generation is. In order to do that, first, we need to choose which evaluation method to use. We will proceed as in the previous models, using the corresponding tests. Similarly, as before, FE results to be the recommended model. The only exception is that RE estimation cannot be computed because 'system is computationally singular', which might be caused by highly correlated variables. Table 6.9 summarizes the results of the remaining estimation methods - Pooled OLS, FD and FE. Again, this table shows the robust estimation results because heteroskedasticity and serial correlation were identified[6].

Out of all explanatory variables used, only three of them were estimated to be significant. Income is shown to be very significant, which corresponds with the findings in Subsection 6.4.2. The model indicates that an increase in income by 1000 euros will cause a five-kilogram increase in MSW generated. Another significant variable, population, encompasses conflicting result. When

[6]The estimation without this correction is available in Appendix A, Table A.3

Table 6.9: Regression results for Model 3 (robust standard errors)

	Dependent variable: MSW		
	(Pooled OLS)	(FD)	(FE)
income		0.004^{***}	0.005^{***}
		(0.001)	(0.002)
population		$-7.8 \cdot 10^{-6}$ **	$-9.5 \cdot 10^{-6}$ **
		$(3.3 \cdot 10^{-6})$	$(4.2 \cdot 10^{-6})$
density	0.114^{***}	-0.232^{**}	-0.758^{**}
	(0.0001)	(0.108)	(0.298)
urbanization	-1.281^{***}	-1.603	-0.190
	(0.003)	(3.169)	(3.213)
unemployment	-1.554^{***}	-4.357^{***}	-3.872^{*}
	(0.005)	(0.666)	(2.008)
Constant	435.598^{***}	-0.119	
	(0.516)	(1.479)	
Observations	458	430	458
R^2	0.503	0.161	0.208
Adjusted R^2	0.498	0.152	0.148
Note:			*p<0.1; **p<0.05; ***p<0.01

increasing the population by 1 million, the amount of MSW is expected to decline by 9.5 kilograms. Furthermore, population density is likewise significant and negatively related to the dependent variable. Every increase in density by 10, in other words, if we increase the number of inhabitants per kilometre square by 10, then the expected amount of MSW should decrease by 7.6 kilograms. In this scenario, urbanization and unemployment rate were not found to be significant.[7] Adjusted R^2 is equal to 0.148, which implies that almost 15% of the variation in the regressand is explained by income, population, density, urbanization and unemployment.

6.4.4 Model 4

Lastly, we propose a model containing some variables in logarithmic forms. Based on the literature, several authors suggest that the relationship between income and MSW or population and MSW is better explained in terms of elasticities. The aim of this model is to assess whether it is true in our case, as well, when dealing with European countries. Essentially, we would like to compare the results between Model 3 and Model 4, and figure out which model performs better. The results using standard errors are included in Appendix A in Table A.4. Table 6.10 shows the robust estimation results, which already account for heteroskedasticity and autocorrelation that was detected using tests as mentioned in sections above.

FE estimation is the preferred method following the Hausman test, where p-value was computed to $3.4 \cdot 10^{-8}$. Income is once again positive in sign but not significant in all methods, particularly FE estimation. Neither population, urbanization or unemployment rate is significant using FE. The only variable that was evaluated as significant is population density. The estimate is negative and holding other variables fixed, if there is a 10-unit increase in population density, in other words, there are 10 more people per kilometre square, the MSW generation should fall by 1%. Perhaps, it is because highly dense areas in developing countries, as the majority of EU countries is, are often urban areas, which in the last years have been implementing better waste management practices. Interestingly, FD and RE method show that the unemployment rate would be significant with the estimate -0.009. It means that lowering the unemployment rate by 10 percentage points would cause, on average, a 9% grow in MSW generation.

[7] For $\alpha = 0.1$, unemployment would be identified as significant.

Table 6.10: Regression results for Model 4 (robust standard errors)

	Dependent variable: log(MSW)			
	(Pooled OLS)	(FD)	(FE)	(RE)
log(income)	0.249***	0.083**	0.040	0.053
	(0.064)	(0.037)	(0.068)	(0.055)
log(population)	−0.013	0.004	0.164	−0.023
	(0.014)	(0.285)	(0.319)	(0.029)
density	0.0001	−0.0003**	−0.001**	−0.00000
	(0.0001)	(0.0002)	(0.001)	(0.0001)
urbanization	−0.001	−0.003	0.002	0.003
	(0.003)	(0.007)	(0.007)	(0.005)
unemployment	−0.004	−0.009***	−0.009*	−0.009**
	(0.005)	(0.002)	(0.005)	(0.004)
Constant	4.127***	−0.001		5.896***
	(0.516)	(0.003)		(0.449)
Observations	458	430	458	458
R^2	0.506	0.145	0.120	0.502
Adjusted R^2	0.500	0.135	0.054	0.497

Note: *p<0.1; **p<0.05; ***p<0.01

When looking at the values of adjusted R^2 from FE estimation, we can say that around 5% of the variation in our dependent variable, in this case, $\log(MSW)$, is explained by our independent variables. The interpretation is more difficult to grasp when comparing to the basic linear models so it is not recommended to make comparisons between nonlinear models and multiple linear regressions.

Chapter 7

Conclusion

Nearly every human activity is associated with the production of waste, therefore, it is crucial to establish proper waste management practices. Current trends in waste management intend to move towards a circular economy, where the focus has shifted from disposal methods and now the emphasis is put on waste prevention, reuse of products, recycling and energy recovery. This change might encourage innovation and create job opportunities but more importantly, it can reduce the impact we have on the environment.

The goal of this thesis was to present the current situation in municipal waste management in the Czech Republic, in particular, Waste Management Plan of the Czech Republic for the period 2015-2024 and its targets with respect to municipal waste. In order to determine the performance of the Czech Republic, firstly, we analysed the acquired data, making comparisons with the past situation and evaluating recent trends in MSW generation and its treatment within the Czech Republic as well as the European Union. Furthermore, the thesis aims to describe the relationship between MSW production and socio-economic factors, such as GDP, income, population, population density, urbanization and unemployment rate. In other words, we carried out a panel data regression using data from EU countries over a period 1995-2017 to detect the influencing factors for per capita MSW generation.

The data we used for describing the changes in the scope and composition of MSW in the Czech Republic were extracted from the Ministry of Environment. One of the findings was that in 2017, there was an increase in the total waste generation as well as MSW generation compared to the year 2009. Having a closer look at the regional share of MSW generation in 2017, the number one contributor was Stredocesky region with 14% of the total share. This region also reached the highest value on per capita MSW production as opposed to Zlinsky region, where people produced the least amount of per capita MSW. We can also point out that only 4 regions contribute to almost half of the total MSW production in the Czech Republic, namely Stredocesky, Praha, Moravskoslezsky and Jihomoravsky.

Even though only 9.8% of the total waste production in the Czech Republic ended up in landfills, landfilling still dominates when it comes to MSW treatment. In 2017, it represented 45.4% of the total share, which was above the EU-28 average. It is gradually decreasing now, however, not as fast as it would be desired. Because of this trend, the proportion of MSW used for material and energy recovery is, on the other hand, growing. When evaluating the progress in the fulfilment of Waste Management Plan, two out of three targets on MSW were accomplished fully. However, as a significant part of MSW is still landfilled, this goal failed to be achieved. 'The end of the period of landfilling', as it is often called in the media, is now a widely discussed topic. Because of the pressure of certain entities, it may happen that the end of landfilling will be postponed from 2024 to 2030, when conversely, we should try our best to move away from landifilling altogether. We should put more attention to the material recycling, energy recovery and composting, where we are, in fact, greatly below the EU average.

It is interesting to compare the data on the European level. It was shown that a person in the Czech Republic generates around 344 kg of waste per year, the third smallest value among EU countries. It might seem that it is performing relatively well compared to other EU countries, where the EU average is almost 500 kg but based on 2008 and 2017 figures, one of the highest growth rates was actually detected in the Czech Republic, while the European average is -7%. This positive growth rate indicates we should think more about how much we dispose of. Also, as mentioned before, the Czech Republic is above the average when it comes to landfill disposal, which once again supports the idea we should aim to diminish the amount of waste treated this way and put more effort into material recycling, energy recovery and composting, which are areas that we lag behind.

Furthermore, the econometric analysis helped us answer the research question: 'Which socio-economic factors influence the generation of municipal solid waste?'. We worked with EU data over a 23-year period and we put several hypotheses to test. We evaluated four models, out of which the third one appears to be the best. The main findings suggest that GDP or income, and population density have a significant impact on the generation of MSW. It was expected since in academic literature those variables are often used to explain the variation in MSW generation as well as used in prediction models. The sign on income is positive as anticipated, while population and density were estimated to be negatively related to MSW generation. The results on the income are in accordance with the majority of research works and likewise, our hypothesis was not rejected. Nevertheless, the results on population are in contrast with Johnstone & Labonne (2004) findings and with what we initially thought, hence our hypothesis on the effect of the population with respect to MSW generation was rejected. Interestingly enough, although in the literature there are ambiguous results on population density, our models showed it is very significant on the European level. However, we did not expect to find a negative relationship between MSW production and density, therefore, the hypothesis about the effect of density on MSW was rejected, too. One possible explanation for the negative sign could be that highly dense areas imply scarce land resources so there is more pressure to protect land and preserve environmental quality. The remaining two explanatory variables, urbanization and unemployment rate, were identified as insignificant, which leads us to the rejection of our last two hypotheses. Even though the urbanization rate is often included in the models, in our context, when we are dealing with mostly developed countries, it does not result to influence the amount of municipal waste generated. Still, it can be useful when doing analysis in developing countries.

To sum up, there is no doubt that waste management plays a crucial role in the mitigation of our impact on the environment. This thesis describes the present state of municipal waste management in the Czech Republic and analyses trends within the country as well as current trends in the EU. The goal was to identify socio-economic factors that influence the generation of municipal solid waste. An analysis on the country level was made, revealing that income, density and population might, in fact, affect MSW generation. However, if we want to provide policy makers with informative results, which is necessary for effective waste management, it is suggested to use single country data on the provincial or municipal level. Since the MSW management strategies are developed by local governments, the examination of municipal-level determinants becomes more valuable. Because of the unavailability of data on this level, our results could be viewed as a first step in investigating the relationship between socio-econometric factors and MSW in the Czech Republic. If there is an improvement in the accessibility of data in the country, it is suggested to add missing variables that could be influencing the amount of waste generated. Further research in the field of municipal solid waste, or generally, waste management in the Czech Republic, is recommended in order to provide reliable information and results for policy makers so the most effective measures could be implemented.

Last but not least, we hope that this thesis would help the topic of waste management gain more attention of the public and that it makes some contributions to the field of municipal solid waste management. We also hope that more and more people will get educated in this area and will engage in the discussion because together we can not only lower the negative impacts we impose on the environment but make changes that would benefit the whole society.

Bibliography

Bandara, N., J. Hettiaratchi, S. Wirasinghe, & S. Pilapiiya (2007): "Relation of waste generation and composition to socio-economic factors: A case study." *Environmental monitoring and assessment* **135**: pp. 31–39.

Beigl, P., S. Lebersorger, & S. Salhofer (2008): "Modelling municipal solid waste generation: A review." *Waste Management* **28(1)**: pp. 200 – 214.

Beigl, P., G. Wassermann, F. Schneider, & S. Salhofer (2004): "Forecasting Municipal Solid Waste Generation in Major European Cities." .

CENIA (2005): "Životní prostředí v České republice." *Technical report*, CENIA.

Croissant, Y. & G. Millo (2008): "Panel data econometrics in R: The plm package." *Journal of Statistical Software* **27(2)**: pp. 1–43.

EC (2008): "Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives."

EC (2010): "Being wise with waste: the EU's approach to waste management." *Technical report*, European Commission.

EC (2018a): "Commission reviews implementation of EU waste rules, proposes actions to help 14 Member States meet recycling targets."

EC (2018b): "New waste rules will make EU global front-runner in waste management and recycling."

EEA (2013): "Managing municipal solid waste - a review of achievements in 32 European countries." *Technical report*, European Environment Agency.

EP (2018): "Circular economy: MEPs back plans to boost recycling and cut landfilling."

Ercolano, S., G. Gaeta, S. Ghinoi, & F. Silvestri (2018): "Kuznets curve in municipal solid waste production: An empirical analysis based on municipal-level panel data from the Lombardy region (Italy)." *Ecological Indicators* **93**: pp. 397–403.

Grossman, D., J. Hudson, & D. Mark (1974): "Waste generation methods for solid waste collection." *J. Environ. Eng. ASCE* **6**: pp. 1219–1230.

Hlavac, M. (2018): *stargazer: Well-Formatted Regression and Summary Statistics Tables*. Central European Labour Studies Institute (CELSI), Bratislava, Slovakia. R package version 5.2.2.

Johnstone, N. & J. Labonne (2004): "Generation of Household Solid Waste in OECD Countries: An Empirical Analysis Using Macroeconomic Data." *Land Economics* **80**.

Karousakis, K. (2006): "Municipal Solid Waste Generation, Disposal and Recycling: A Note on OECD Inter-Country Differences." *paper presented at envecon 2006: Applied Environmnetal Economics Conference, the Royal Society, London* .

Kolekar, K., T. Hazra, & S. Chakrabarty (2016): "A review on prediction of municipal solid waste generation models." *Procedia Environmental Sciences* **35**: pp. 238–244.

Liu, C. (2010): "Factors influencing municipal solid waste generation in China: A multiple statistical analysis study." *SAGE Journals* **29**: pp. 371–378.

Mazzanti, M., A. Montini, & R. Zoboli (2007): "Municipal Waste Production, Economic Drivers, and 'New' Waste Policies: EKC Evidence from Italian Regional and Provincial Panel Data." *SSRN Electronic Journal* **155**.

Ministersrvo životního prostředí (2014): "Zpráva o plnění cílu Plánu odpadového hospodářství České republiky za období 2015-2016." *Technical report*, Ministerstvo životního prostředí, CENIA.

Ministersrvo životního prostředí (2017): "Zpráva o životním prostředí České republiky." *Technical report*, Ministerstvo životního prostředí, CENIA.

Ministry of the Environment (2014): "Waste Management Plan of the Czech Republic for the period 2015-2024." *Technical report*, Ministry of the Environment.

OECD (2015): "Environment at a Glance 2015: OECD Indicators." *Technical report*, OECD.

UN (2018): "Czechia, General Information."

Wang, H. & Y. Nie (2001): "Municipal Solid Waste Characteristics and Management in China." *Journal of the Air and Waste Management Association (1995)* **51**: pp. 250–63.

Wooldridge, J. M. (2010): *Econometric Analysis of Cross Section and Panel Data*. The MIT Press.

Wooldridge, J. M. (2013): *Introductory Econometrics: A Modern Approach*, volume 5. Cengage Learning.

Ysabel Marquez, M., S. Ojeda, & H. Hidalgo-Silva (2008): "Identification of behavior patterns in household solid waste generation in Mexicali's city: Study case." *Resources Conservation and Recycling - RESOUR CONSERV RECYCL* **52**: pp. 1299–1306.

Appendix A

Regression results

Table A.1: Regresssion results for Model 1 (without robust standard errors)

	Dependent variable:			
	MSW			
	(Pooled OLS)	(FD)	(FE)	(RE)
GDP	0.005^{***}	0.005^{***}	0.002^{***}	0.002^{***}
	(0.0003)	(0.001)	(0.0003)	(0.0003)
population	$2.7 \cdot 10^{-7}$	$-9.4 \cdot 10^{-6}$ *	$-9.2 \cdot 10^{-6}$ ***	$-7.1 \cdot 10^{-7}$
	$(1.8 \cdot 10^{-7})$	$(5.3 \cdot 10^{-6})$	$(2.1 \cdot 10^{-6})$	$(7.3 \cdot 10^{-7})$
Constant	377.835^{***}	-1.077		449.759^{***}
	(7.298)	(1.067)		(22.177)
Observations	626	598	626	626
R^2	0.359	0.073	0.084	0.067
Adjusted R^2	0.357	0.070	0.039	0.064
F Statistic	174.605^{***} (df = 2; 623)	23.528^{***} (df = 2; 595)	27.229^{***} (df = 2; 596)	44.761^{***}

Note: *p<0.1; **p<0.05; ***p<0.01

Table A.2: Regresssion results for Model 2 (without robust standard errors)

	Dependent variable:			
	MSW			
	(Pooled OLS)	(FD)	(FE)	(RE)
income	0.009***	0.006***	0.004***	0.003***
	(0.0005)	(0.001)	(0.001)	(0.001)
density	0.092***	−0.380	−0.930***	0.038
	(0.018)	(0.304)	(0.205)	(0.058)
Constant	341.994***	−1.521		436.779***
	(8.447)	(1.212)		(18.657)
Observations	461	433	461	461
R^2	0.494	0.056	0.079	0.051
Adjusted R^2	0.491	0.052	0.017	0.047
F Statistic	223.206*** (df = 2; 458)	12.870*** (df = 2; 430)	18.489*** (df = 2; 431)	22.279***
Note:				*p<0.1; **p<0.05; ***p<0.01

Table A.3: Regresssion results for Model 3 (without robust standard errors)

	Dependent variable:		
	MSW		
	(Pooled OLS)	(FD)	(FE)
income	0.010^{***}	0.004^{***}	0.005^{***}
	(0.001)	(0.001)	(0.001)
population	$8.1 \cdot 10^{-8}$	$-7.8 \cdot 10^{-6}$	$-9.5 \cdot 10^{-6}$ ***
	$(1.7 \cdot 10^{-7})$	$(5 \cdot 10^{-6})$	$(2.1 \cdot 10^{-6})$
density	0.114^{***}	-0.232	-0.758^{***}
	(0.021)	(0.289)	(0.189)
urbanization	-1.281^{***}	-1.603	-0.190
	(0.450)	(3.237)	(1.240)
unemployment	-1.554	-4.357^{***}	-3.872^{***}
	(1.059)	(0.649)	(0.656)
Constant	435.598^{***}	-0.119	
	(28.307)	(1.286)	
Observations	458	430	458
R^2	0.503	0.161	0.208
Adjusted R^2	0.498	0.152	0.148
F Statistic	91.656^{***}	16.326^{***}	22.319^{***}
	(df = 5; 452)	(df = 5; 424)	(df = 5; 425)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table A.4: Regresssion results for Model 4 (without robust standard errors)

	Dependent variable:			
	log(MSW)			
	(Pooled OLS)	(FD)	(FE)	(RE)
log(income)	0.249***	0.083**	0.040*	0.053***
	(0.015)	(0.035)	(0.022)	(0.020)
log(population)	−0.013**	0.004	0.164	−0.023
	(0.006)	(0.287)	(0.127)	(0.023)
density	0.0001***	−0.0003	−0.001***	−0.00000
	(0.00004)	(0.001)	(0.0005)	(0.0001)
urbanization	−0.001	−0.003	0.002	0.003
	(0.001)	(0.007)	(0.003)	(0.002)
unemployment	−0.004*	−0.009***	−0.009***	−0.009***
	(0.002)	(0.002)	(0.001)	(0.001)
Constant	4.127***	−0.001		5.896***
	(0.153)	(0.003)		(0.378)
Observations	458	430	458	458
R^2	0.506	0.145	0.120	0.502
Adjusted R^2	0.500	0.135	0.054	0.497
F Statistic	92.524***	14.418***	11.568***	441.770***
	(df = 5; 452)	(df = 5; 424)	(df = 5; 425)	
Note:				*p<0.1; **p<0.05; ***p<0.01