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Inflationary Pressure and Municipal Waste Recycling Performance: Evidence from EU27 Recycling Systems (2010–2023)

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ABSTRACT

This thesis seeks to examine how macroeconomic instability is related to municipal waste recycling performance in the 27 member states of the European Union (EU27) from 2010 to 2023. The study uses a two-way fixed effects panel regression model with Driscoll–Kraay standard errors to analyse the relationship between inflation, selected socio-economic variables, and municipal waste recycling performance. The study adds to the environmental economics and circular economy literature by examining the role of macroeconomic instability in municipal waste recycling systems.

The empirical results indicate that inflation is not significantly associated with municipal waste recycling performance ($\beta = 0.0633$, $p = 0.522$). Structural socio-economic factors seem to have a stronger relation with recycling outcomes, though, in contrast. Both tertiary education attainment and unemployment are statistically significant predictors of recycling performance. Tertiary education exhibits a positive relationship with recycling performance ($\beta = 0.9514$, $p < 0.001$), whereas unemployment exhibits a negative relationship ($\beta = -0.8780$, $p < 0.001$). GDP per capita, renewable energy consumption, and circular material use rate do not show statistically significant effects in the final specification.

The results indicate that socio-economic factors might be more important in understanding inter-MS municipal waste recycling performance differences than short-term inflationary effects. The findings are relevant for circular economy policy and the European Green Deal, highlighting the importance of education, labour-market conditions, and resilient recycling infrastructure. Overall, the study highlights the importance of assessing the wider macroeconomic and socio-economic environment in policymaking for supporting sustainable transitions in economic uncertainty.

Keywords: Circular Economy; Inflation; Municipal Waste Recycling Performance; EU27; Panel Data Analysis; Macroeconomic Instability; Environmental Economics.

DEDICATION

To My Family & Friends

ACKNOWLEDGMENT

I would like to express my sincere gratitude to my supervisor, Professor Diana Barro, for her invaluable guidance, constructive feedback, and continuous support throughout the development of this thesis. Her expertise and dedication have been instrumental in shaping both the direction and quality of this research.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 CHAPTER 1: INTRODUCTION

1.1 Background of the Study

The world has been confronted with various challenges in recent years such as surging inflation rates in both developed and developing nations (European Central Bank, 2023). These inflationary pressures, together with global economic uncertainty, supply-chain disruptions, and the post-COVID-19 economic recovery, have placed significant pressure on consumer budgets and business investment. (International Monetary Fund, 2023).

This increase in inflation was particularly pronounced and enduring from the end of 2021 to the end of 2023, driven partly by the energy crisis following the Russia–Ukraine conflict, and by constraints in supply chains, as well as by the robust demand resulting from the post-COVID-19 recovery (European Central Bank, 2023; International Monetary Fund, 2023). This macroeconomic turbulence has not only made it more difficult for consumers but for businesses as well, resulting in some tough choices and re-thinking of priorities. The recent inflationary shock has also affected long-term investments in environmental sustainability and the green transition.

At the same time, the European Union (EU) has set itself a bold environmental target, with the European Green Deal to become a climate neutral continent by 2050 (European Commission, 2019). One of the key pillars of this agenda is the shift towards a circular economy, which aims to minimise waste, use resources efficiently and maximise the value of the materials by recycling or reusing them (Ellen MacArthur Foundation, 2021).

The Circular Economy Action Plan (CEAP) and the adoption of ambitious recycling targets for 2030 represent a major paradigm shift in the European industrial policy. In fact, these are elements that are being examined in regard to strategic resource resilience, especially in the wake of the current energy crisis that highlighted the fragility of linear resource supply chains. Circular economy policies seek to achieve climate neutrality, and increase resource efficiency, without economic growth being dependent on the use of resources. A circular economy is not only a matter of environmental goals but also of strategic autonomy and industrial competitiveness in the context of the evolution of the global markets.

The concept of circular economy is not only an environmental one but also an economic opportunity, as it offers the possibility of decreasing the use of virgin materials, improving the competitiveness of the industry and job creation (European Environment Agency, 2023). There is a high policy interest in this transition as the EU has established targets for municipal waste recycling and for circular material use (Eurostat, 2023). The transition from a linear "take–make–dispose" economy to a circular economy will require a systems change across the economy, significant investment in new technologies, infrastructure and consumer education.

The relationship between inflation and environmental sustainability creates a complex set of challenges for this transition. If inflation is ongoing, it could diminish consumers' purchasing power and drive up financing costs, which could have an impact on demand for sustainable products and investments. The high inflation rates can reduce the economic advantages of recycling if the costs of collecting and processing recycled materials increase more rapidly than the value of the recycled materials. This macroeconomic instability could pose challenges for

long-term environmental investments and may influence municipal waste recycling performance through economic and institutional channels.

However, such lofty environmental goals, overlaid by a challenging macroeconomic backdrop – particularly high inflation – create important policy challenges. Cost and budget pressures during inflation can impact consumer spending, business decisions and government policies, which can create a conflict between sustainability goals and increasing economic costs (Jeworrek & Tonzer, 2024). Rising energy costs, particularly during the recent inflationary period, have a direct impact on the operating costs of recycling plants, on logistics for waste collection and on the energy-intensive process of material reprocessing. This can increase the cost of recycled materials, potentially reducing their competitiveness relative to virgin materials.

In addition, as budgets tighten, consumers may be more hesitant to pay a ‘green premium' for sustainable products, or opt for lower cost products (PWC, 2024). This is one of the typical trade-offs between economic constraints and environmental objectives.

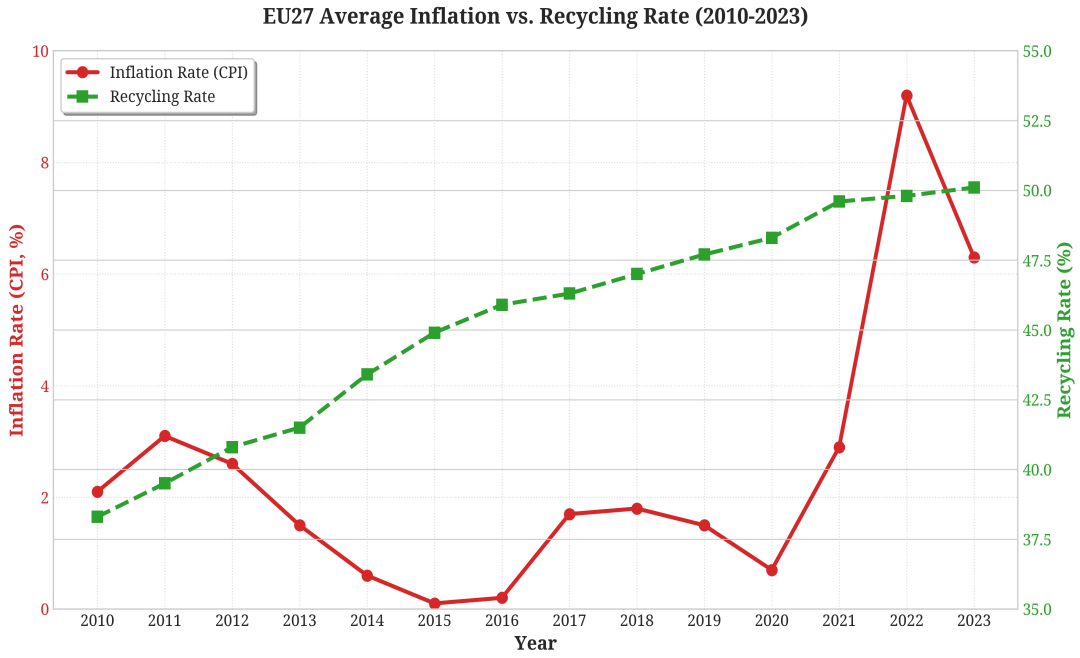

Figure 1.1: Average Inflation and Municipal Recycling Rates in the EU27 (2010–2023)

Source: Author's calculations based on Eurostat and World Bank data.

Figure 1.1 shows the average rate of inflation and the percentage of municipal recycling in the EU27 from 2010 to 2023. The growth of recycling appears to slow down during the period of elevated inflation after 2021, but this is a descriptive trend and does not imply that inflation caused changes in recycling performance. Other economic, institutional and policy-related factors which changed during the same era may also have been reflected in the observed patterns. The purpose of the figure is not to demonstrate a causal effect; instead, it is to spark the question for research.

1.2 Problem Statement

Although the circular economy and its benefits are well documented in literature and research, and the factors influencing recycling rates have already been studied, the direct and indirect

effects of macroeconomic inflationary pressure on the transition towards the circular economy, especially in European waste management systems, remains relatively underexplored (Holmen et al., 2025). In high inflation, consumers and businesses opt to save money in the short term and invest in sustainability in the long term, as per conventional economic theory (Jahrl & Mebrahtom, 2024).

This indicates that the "green premium" that sustainable products/services might provide could be eroded and a shift to cheaper, less sustainable alternatives (PWC, 2024). Although the price of sustainable products is not significantly higher, it can be an important barrier if prices for other key products such as energy and food have been rising and have become more of a burden on household budgets.

The EU27 offers an interesting empirical context in which to consider this, as it has a uniform regulatory framework and a range of economic development. The harmonised Eurostat data allows for a detailed macro-panel analysis, which gives a comprehensive picture of the various recycling capacities and institutional maturity of the various countries or regions analysed. This diversity provides a good empirical foundation for understanding how various macroeconomic shocks affect various economic structures, and provides information that can be used under a shared set of regulations in both more and less economically developed member states.

There is limited research that systematically investigates the relationship between inflationary pressures and municipal waste recycling performance across EU27 countries while accounting for country-specific heterogeneity and broader macroeconomic conditions. Existing studies generally focus either on the inflationary effects of environmental policies (greenflation) or on individual-level environmental behaviour. However, comprehensive macro-panel evidence

examining how sustained inflation influences recycling performance across diverse European economies remains scarce. This gap is particularly important given the recent inflationary shocks experienced across Europe and their potential implications for circular economy objectives.

Meanwhile, in less developed member countries, a trade-off between economic survival and environmental goals could be more apparent during the times of inflation. Policy makers need to understand these dynamics and create suitable and strong policies to enable transition towards circular economy even in an economic crisis situation. Policy reactions to economic crises can have unintended consequences if there is not this empirical evidence.

This thesis contributes to the literature by providing an updated macro-panel analysis of the association between inflation and municipal waste recycling performance across EU27 countries during a period characterised by substantial inflation volatility. This study does not restrict itself to the analysis of environmental policy or consumption behaviour, but also takes macroeconomic instability into account.

The research adds to the environmental economics literature by analysing the link between macroeconomic instability and the performance of the circular economy. It also contributes to the literature on the relationship between macroeconomic conditions and municipal waste recycling performance. This thesis introduces macroeconomic variables into sustainability analysis to create a more comprehensive analytical framework that encompasses the relationship between the macroeconomic and the environmental dimensions. Lastly, the findings contribute empirical evidence to ongoing policy debates in the EU regarding the relationship between macroeconomic conditions and municipal waste recycling performance.

Also, this discussion is linked to the broader discussion on “greenflation”, which refers to the inflationary pressures that can occur during a transition towards more sustainable production systems and technologies. While the present study does not directly measure greenflation mechanisms, the concept provides a broader context for understanding the interaction between inflationary pressures and sustainability transitions. This is usually linked to the increase in the demand for CRMs and the associated increase in their prices due to their sustainable production . These costs are associated with the circular transition, but also pose a challenge in terms of price stability and affordability for the consumer.

1.3 Research Questions and Objectives

The purpose of this thesis is to fill the identified research gaps in the understanding of the relationship between inflation and the transition of the EU27 countries towards the circular economy. Specifically, it aims to address the following research questions and to address the following objectives:

The main research question is: How is macroeconomic instability associated with municipal waste recycling performance across EU27 countries between 2010 and 2023?

Sub-Questions and Objectives:

1.Sub-Question 1: How is inflationary pressure associated with municipal waste recycling performance in EU27 countries?

Objective 1: To assess the relationship between inflation and municipal waste recycling performance in EU27 countries (2010–2023) using a panel data framework.

2. Sub-Question 2: How do structural socio-economic factors, particularly education and labour market conditions, influence recycling performance under varying macroeconomic conditions in EU27 countries?

Objective 2: To evaluate the extent to which structural socio-economic factors influence recycling performance under varying macroeconomic conditions in EU27 countries.

1.4 Research Hypotheses

H1: Inflationary pressure is associated with municipal waste recycling performance in EU27 countries.

H2: Structural socio-economic factors, particularly tertiary education attainment and labour market conditions, are associated with recycling performance in EU27 countries.

1.5 Significance of the Study

The study makes multiple contributions to the literature and policy making. Academically, it adds to the body of research on the macroeconomic determinants of the circular economy, in particular with its empirical findings on the association between inflation and municipal waste recycling performance. The majority of the previous studies have been at the micro level, either exploring the drivers of recycling behavior or the technology of the circular economy, but this thesis extends the discussion to the macroeconomic level.

A range of socio-economic and macroeconomic indicators enables a differentiated picture of the structural drivers of the recycling performance of EU27 member states. Moreover, the study uses a sound panel data approach in EU27 countries, offering comparative insights across EU27 member states. The emphasis is on the most recent data (2010-2023), making the results relevant to current economic and environmental issues and reflecting the impact of recent inflationary surges.

With the ongoing volatility of energy prices and economic uncertainty, it is becoming crucial to understand the link between inflation and recycling performance. With the sustainability transition in Europe increasingly under pressure, understanding whether macroeconomic headwinds are associated with environmental performance is essential to the supporting the long-term achievement of sustainability goals. This study offers the empirical evidence relevant to the integration of macroeconomic resilience into circular economy strategies, safeguarding environmental progress without sacrificing economic stability in the short-term.

On a policy level, the conclusions of this thesis will provide a valuable and informative contribution towards the issues and potential of the circular economy in times of economic turbulence to European policy-makers. Knowing about the link between inflationary pressures and recycling behaviour and material use in the circular economy can be used to shape the design of more resilient and effective environmental policies.

As an example, if macroeconomic conditions influence recycling performance, then during recessions policy-makers may want to introduce targeted support or subsidies for the recycling sector to avoid any 'backsliding' from environmental goals. This research can be used to identify and recommend interventions for specific countries/regions, such as financial incentives or

educational campaigns, to ensure continuity of the transition towards the goals of the European Green Deal. In the end, this study is intended to support and give evidence for the development of a more robust and sustainable circular economy in Europe, even in the presence of macroeconomic headwinds.

1.6 Research Scope and Limitations

The findings of this study are limited to the period 2010–2023 and to the EU27 Member States. This sample was selected because of the high degree of data standardisation provided by Eurostat, which ensures the quality and reliability of the panel data analysis. Other European countries, including EU candidate countries and non-EU countries, were excluded because they are not subject to the same reporting requirements and policy framework established under the European Green Deal.

One of the main challenges is data lag for some environmental indicators, requiring the most up-to-date data available up to 2023. Furthermore, the study acknowledges some academic and methodological limitations, such as omitted variable bias, endogeneity and problems with causal inference. Furthermore, the municipal waste recycling rate captures only one dimension of circular economy performance and thus does not reflect the overall complexity of the circular economy outcomes. In addition, the annual frequency of the data may limit the ability to capture short-term fluctuations and dynamic adjustments. Hence, the results are to be interpreted as evidence of the performance of municipal waste recycling, not overall circular economy performance.

1.7 Thesis Organization

This thesis consists of five main chapters, all of which are aimed to answer the research questions and objectives raised above in a systematic manner:

Chapter 1: Introduction - This chapter offers the overarching picture of research including a discussion on the global and European background of the inflation and circular economy. It explains the problem statement, defines the research questions and points out the relevance of the research.

Chapter 2: Literature Review – This chapter critically examines the academic literature that is relevant to the study of the circular economy, macroeconomic influences on environmental performance, and identifies gaps in the literature this thesis will address.

Chapter 3: Methodology and Data - It presents the research design used in the study which covers the Econometric Methodology, Data sources and Analytical approach.

Chapter 4: Results and Discussion -This chapter summarizes the empirical analysis performed in the econometric research, and discusses the results critically in the light of the research hypotheses.

Chapter 5: Conclusion and Recommendations - It summarizes the main findings, addresses policy implications and gives recommendations for future research.

2 CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to review literature related to the circular economy, waste management, inflation and their relationships within the European Union. The aim is to provide the theoretical and empirical foundations for the subsequent analysis, to ascertain the main gaps in the research and to situate the research of the present study. The review draws together views from other disciplines such as environmental economics, ecological economics, public policy and consumer behaviour to provide a comprehensive picture of the dynamics. Specific attention is paid to research which looks at macroeconomic factors influencing recycling rates, and the effects of economic shocks (such as inflation) on circular economy transitions. The purpose of this structured approach is to shed light on the theoretical background and empirical findings that feed into the research questions that will be tackled in this thesis. This review provides the theoretical and empirical background necessary to understand the relationship between macroeconomic conditions and municipal waste recycling performance within the European Union.

2.2 Theoretical Frameworks of Circular Economy and Waste Management

The shift from the "take-make-dispose" economy to a circular economy is a paradigm change in the management and utilization of resources and production systems. This section examines the theoretical underpinning of the CE concept and how it can be applied to waste management strategies. These theories offer valuable insights into the systemic changes needed for a transition to a circular economy. The concepts introduced in this section are derived from theoretical frameworks that help explain the role of macroeconomic and institutional factors in

municipal waste recycling performance across the EU27. These frameworks also provide theoretical support to the explanatory variables used in the empirical model.

2.2.1 Industrial Ecology and Cradle-to-Cradle Design

Industrial Ecology (IE) was a discipline that evolved a line of study that examines the flow of materials and energy in the industrial system and the ecological system and tries to use these with efficiency and to reduce the waste by mimicking natural systems, particularly in terms of waste management. The basic concept behind IE is to view systems as networks, and to consider the industrial waste produced in one process as an industrial feed for another process. This concept is closely related to the concept of the circular economy which is grounded in a scientific framework to design sustainable industrial systems (Geng & Doberstein, 2008). IE is based on the concept of 'dematerialization' and 'decarbonization' that seeks to reduce material and energy consumption in economic activities. The application of IE principles can be realized in different ways in practice, such as in the field of waste valorization, industrial symbiosis and eco-industrial parks. This framework is also useful in analysing the integration of industrial processes within EU policies to enhance the recycling infrastructure and promote material reuse, which is a key influence on the actual recycling rates measured for this study. The concept of Industrial Ecology is relevant in discussing how to use resource efficiency and waste reduction to assist in the development of municipal waste recycling systems. From the perspective of the empirical model, Industrial Ecology provides theoretical support for the inclusion of variables related to recycling systems and resource efficiency. The framework suggests that stronger institutional and economic conditions may facilitate the development of recycling infrastructure and material recovery systems, thereby contributing to higher municipal waste recycling performance.

Cradle-to-Cradle (C2C) design promotes the continuous circulation of materials within closed-loop production systems. While the framework aligns with the broader objectives of the circular economy, its relevance to the empirical model is limited because this study focuses on municipal waste recycling performance and macroeconomic factors rather than product design. Therefore, C2C is included only as a complementary theoretical perspective.

2.2.2 Theory of Planned Behavior and Consumer Engagement in Recycling

Consumer engagement and behaviour change is a key enabler for the success of circular economy activities, especially in the field of waste management and recycling. The Theory of Planned Behavior (TPB) was developed by Ajzen (1991) and offers a comprehensive model to explain and predict human behaviour including pro-environmental behaviour such as recycling. TPB suggests that three factors affect a person's intention to engage in a behavior: Attitude towards the behavior (personal evaluation of the behavior), subjective norm (perceived social pressure to perform or not perform the behavior), and perceived behavioral control (perceived ease or difficulty of performing the behavior). These intentions, in turn, are good predictors of actual behavior. This theory is used to explain different recycling rates between the EU27 countries because the economic situation can have a strong influence on the perception of control and attitudes of the consumers.

TPB has been extensively used to account for differences in consumers' engagement in recycling. Previous research has demonstrated that positive attitudes toward recycling (such as thinking it is good for the environment), perceptions of strong subjective norms (such as friends and family recycle), and high perceptions of behavioral control (such as it is easy to access a recycling facility) are important factors that can influence whether or not individuals will participate in recycling. However, the model also recognizes outside factors that can moderate

these relationships, including the characteristics of the people involved, economic incentive, and policy interventions. These behavioural drivers are important to understand when it comes to designing effective public awareness campaigns and infrastructure that will encourage consumers to adopt circular economy practices more, particularly in times of economic turbulence, such as inflation. Although TPB provides useful insights into individual recycling behaviour, the present study does not analyse household-level data. Instead, it examines macroeconomic determinants of municipal waste recycling performance at the country level. Therefore, TPB is used only to provide behavioural context rather than as a direct theoretical foundation for the econometric model.

2.2.3 Institutional Theory and Policy Frameworks for Circular Economy

Institutional Theory provides a useful framework for understanding how formal regulations, social norms, and governance structures influence the implementation of circular economy practices. It suggests that institutions, in the sense of policy, regulation and norms of culture play an important role in the process of legitimate and embed CE practices in economic systems. The theory distinguishes between regulative, normative and cultural-cognitive institutions, which all affect the implementation and success of CE initiatives. Institutional Theory provides a useful framework for explaining differences in the implementation and effectiveness of circular economy policies across EU member states. This study can shed light on the observed differences in recycling performance between EU27 countries in the institutional context, especially during economic transition periods like in periods of inflation.

In the EU, transition towards the circular economy is mostly represented by a holistic approach, in which a mix of directives, regulations and action plans play an important role. EU Circular Economy Action Plans (2015 and 2020) provide a strategic plan for the Member States to take

steps to reduce waste and increase the recycling rate and resource efficiency. These policies provide a regulatory structure that imposes and promotes some CE practices. However, because of different institutional, cultural and economic environments in the different countries, these policies may not be as effective. Institutional theory complements the above in helping to understand why certain countries have been more successful in implementing CE policies than others; this is because it recognizes the need to ensure congruence between formal policies and informal norms and capacities. The resilience and adaptability of these institutional mechanisms may influence the ability of countries to maintain circular economy progress during periods of economic stress. Institutional theory helps explain why recycling performance may differ across EU27 countries despite the existence of common EU policy objectives. The institutional differences between the EU member states, however, may present different challenges for implementing the directives on circular economy.

Education is frequently associated with environmental awareness, civic engagement, and the adoption of pro-environmental behaviours. Sallaku et al. (2019) identify environmental awareness, environmental concern, attitudes toward recycling, and social norms as important determinants of recycling behaviour in higher education settings. These findings suggest that higher levels of education may contribute to greater environmental awareness and stronger participation in recycling activities. Therefore, tertiary education attainment is included in the empirical model as a proxy for human capital, environmental awareness, and broader institutional capacity. Based on the existing literature, a positive relationship between education and municipal waste recycling performance is expected.

2.3 Macroeconomic Influences on Recycling and Waste Management

While circular economy solutions, such as waste management and recycling, must rely on technological innovations and individual actions, broader macroeconomic conditions also play a key role in their success. This section examines the relationship between other macro-economic variables (such as economic growth, unemployment, and inflation) and recycling rates and waste management in Europe. The result of this study is related to the macroeconomic determinants of recycling in the EU27 countries, which requires understanding of these influences. In this thesis, an overview of the macroeconomic influences is provided to serve as background for the empirical analysis.

2.3.1 Economic Growth and the Environmental Kuznets Curve (EKC)

The linkage of economic growth and environmental degradation is one of the most frequently discussed topics, which is mostly done with the help of the Environmental Kuznets Curve (EKC) hypothesis. It is suggested that environmental degradation would first rise with economic growth and then decline as the income level rises, as indicated by the inverted U shape in the EKC (Zheng et al., 2024). From a waste management perspective, this means that the more a country grows economically, it will produce more waste, and recycle less, because people are consuming more, and industries are growing more. After a certain level of income, however, there is a positive correlation between income and environmental awareness, the strength of the regulation and investment in waste management infrastructure, and the rate of waste recycling and reduction. The theoretical framework is relevant when analysing the potential impact of economic development on EU27 countries' recycling performance. The EKC hypothesis provides an important insight into the link between economic development and environmental outcomes over time, an important point to consider when making policy

recommendations based on this thesis. However, inflationary pressures may interrupt the expected environmental improvements associated with higher levels of economic development.

The EKC has been confirmed in waste management in some studies, for some waste types or areas, but has been found to be linear or N-shaped in others. For most of the countries in Europe, which are usually considered as representative of developed economies, many studies suggest that several European countries may already be in the declining phase of the EKC and that further economic development is likely to be related to better waste management and higher recycling rates (Knäble et al., 2022). This is often blamed on good environmental policies, sophisticated technology and high levels of public awareness. The EKC relationship isn't a foregone conclusion, though: policy decisions and investments in infrastructure for circular economy need to be made and carried out. The EKC framework provides a useful theoretical perspective for interpreting the role of economic development in municipal waste recycling performance. In the empirical model, GDP per capita is included as a proxy for economic development. According to the EKC framework, higher levels of development are generally associated with stronger environmental awareness, improved waste-management systems, and better municipal waste recycling performance. Therefore, a positive relationship would theoretically be expected.

2.3.2 Unemployment and its Impact on Recycling Behavior

The economic health of the communities that depend on recycling and waste management programs can be gauged by unemployment, which can also have several impacts. However, if there is an increase in unemployment, this could lead to an increase in waste because there is a decrease in consumption. On the other hand, economic hardship caused by a lack of

employment may cause households to abandon pro-environmental activities, which can be time consuming or involve extra effort. Understanding this relationship is important for assessing how labour-market conditions may be associated with recycling performance across EU27 countries. The theoretical foundation for including unemployment as a control variable in the empirical model, in case it impacts recycling rates, is discussed in this section.

In addition, unemployment can have an impact on the business readiness of waste management systems. One possible explanation discussed in the literature is that fiscal pressures associated with high unemployment may affect the resources available for environmental services. On the other hand, there are some research studies that indicate that in some cases the lack of employment could stimulate informal recycling or growth in demand for second-hand products, which is an indirect way of supporting the circular economy. Generally speaking, the literature reviewed tends to confirm that high unemployment rates appear to be a negative indicator of formal recycling participation, because environmental issues can take a back seat to immediate economic needs for households. Existing literature provides mixed evidence regarding the relationship between unemployment and recycling performance, which justifies its inclusion as a control variable in the empirical model. Consequently, unemployment is included in the empirical model as a control variable. Based on the existing literature, higher unemployment is expected to be associated with lower municipal waste recycling performance.

2.4 Inflation and Circular Economy: An Emerging Nexus

The interlinkages between inflation and circular economy practices, especially recycling, is a less-studied and emerging field of research. The macroeconomic effects of CE are well known, but warrant further consideration especially in the context of high rates of inflation. In this section, existing knowledge and theories on the relationship between inflationary pressures and

the shift towards circular economy are collected. A new connection is developing here, which is the starting point of the following empirical analysis and is fundamental to the present thesis. The analysis is built around the central question of this thesis and examines several theoretical mechanisms through which inflation may influence municipal waste recycling performance. However, existing literature provides mixed evidence regarding both the direction and magnitude of this relationship, making empirical testing necessary.

2.4.1 The Dual Impact of Inflation on Recycling Incentives

The effects of inflation on recycling incentives can be two-fold and sometimes counterintuitive. Inflation, in general, is likely to increase the price of raw materials and virgin resources, which may render recycled resources more economically. An increase in raw material prices and virgin resource prices, typical results of inflation, can make recycled resources more economically appealing. With the rising prices of new input materials, companies may choose to buy secondary raw materials from recycling value chains to make recycled content more competitive; this can foster demand for recycled content, and, as such, incentivize recycling activities (Nademi & Kalmarzi, 2025). This 'scarcity-induced efficiency' mechanism indicates that inflation could help drive more circular practices forward because the scarcity of resources could make efficiency in the use of resources a more urgent economic need. Existing evidence remains mixed, with some studies suggesting positive effects through resource scarcity mechanisms and others highlighting the negative consequences of reduced purchasing power. These arguments suggest a potentially positive relationship between inflation and recycling performance, although empirical evidence remains inconclusive.

But on the other hand, inflation reduces the purchasing power of the household, and only money needed for essential goods and services matters to the consumers. This change in consumer

behavior could lead to a decrease in the demand for higher quality items or services produced in a more sustainable way as these tend to come with a 'green premium'. In addition, households under economic stress may be less inclined to dedicate time and effort to waste sorting and recycling, particularly if the recycling services are not convenient or are viewed as expensive. Inflation can also drive up the cost to municipalities of operations for collecting and processing waste, and reduce the number of recyclables they collect or raise their fees, further discouraging participation. Existing literature does not provide a clear consensus regarding which of these mechanisms dominates in the EU context. To foster circularity during economic instability, it is important to understand these forces that run counter to circularity.

Based on the theoretical arguments discussed above, inflation is included in the empirical model as a key explanatory variable. However, the literature does not provide a clear prediction regarding the direction of the relationship, as both positive and negative mechanisms have been identified.

2.4.2 Greenflation: The Cost of Ecological Transition

Greenflation can be defined as the inflationary impact of transitioning to the green and/or circular economy. The reasons are linked to the higher demand for critical raw materials for green technologies, prices of renewable technologies, and the internalization of environmental externalities via carbon pricing or taxes. Although the longer-term effects of greening are well understood, the short- to medium-term effects can cause price pressure as industries react and supply chains re-configure. Greenflation provides a useful perspective for understanding the economic trade-offs associated with sustainability transitions. This section of the dissertation sets the theoretical context for the discussion of the implications of circular economy policies for inflation in the empirical context of the thesis.

Greenflation, from a circular economy perspective, is the expenses associated with creating the necessary infrastructure for recycling, new business models and eco-designed products that may make such outputs more expensive for consumers and producers. For instance, the price of recycled materials or products containing recycled materials rises, if new technology is developed for sorting products for advanced recycling or new chemical recycling plants are constructed. Policymakers are called on to balance these inflationary effects with a just transition to a circular economy and avoid negative effects on vulnerable groups. This discussion is part of the wider debate on how to handle the greenflationary pressures in the transition to the EU's circular economy. The greenflation literature provides additional context for understanding how inflationary pressures may interact with sustainability transitions.

2.5 Critical Comparison and Conflicting Findings

While a significant amount of literature exists, there are a number of points of conflicting results and ongoing debate, particularly around the exact mechanism that macroeconomic variables have on bottom line results of the circular economy. For instance, some research has revealed a positive relationship between waste management and economic growth, as in developed countries, waste management will improve as economic growth occurs (EKC hypothesis); but others argue that as a result of the economic growth, consumption will increase, which will eventually lead to an increase in waste production overall. The effect of unemployment on recycling actions is also not consistent and some studies show a decrease in pro-environmental behaviors during the recession, while others show an increase in informal recycling and/or greater demand for second-hand products. The multiple perspectives of the phenomena under investigation and the need for empirical analysis in a contextually appropriate way are reflected

in these conflicting viewpoints. This comparison of literature helps justify the need for further empirical investigation within the EU27 context.

Greater relevance for this thesis is the emerging body of literature that focuses on how inflation affects circular economy practices, which has conflicting perspectives. This increase in costs for virgin materials encourages recycling of secondary materials (Holmen & Söderholm, 2025), according to some scholars. On the other hand, other viewpoints focus on the fact that increases in inflation can affect household disposable income, which can result in a drop in ‘green' consumption, as well as in less recycling activities because of budget constraints or financial difficulties. The thesis in this field makes a contribution to this debate by providing empirical evidence from the EU27 countries, while this is a contrast between the different arguments found in the literature. This study aims to provide a more complex picture of the overall impact of inflation on recycling rates in a European context, which is diverse in many respects. The purpose of this section is to clarify the literature and to define the gap, in order to supply empirical evidence concerning these opposing views in this thesis.

2.6 Research Gaps and Contribution of the Current Study

Even though there is a growing number of literature on circular economy, waste management and macroeconomic factors, there are several research gaps, specifically: the link between inflation and recycling rates across a comprehensive European framework. While detailed study of these connections has already been addressed in various research studies, a comprehensive and thorough analysis, which is both current and detailed, of the characteristics of the EU's economies and policies is needed.

1. Macroeconomic Effects of Inflation on Municipal Waste Recycling Performance: Most of the studies available so far focus on static or linear approaches to studying the impact of economic variables on recycling performance. Research is needed that will reflect the more general macroeconomic impacts of inflation, including the differences in the effects of different inflation regimes (low vs. high inflation) and those differences on the behavior of consumers and industry. This paper attempts to rectify the situation by applying panel data econometric methods suitable for studying the macro-economic relationships between different countries.

2. Comprehensive European Panel Data Analysis: The use of a comprehensive panel data analysis across a large number of EU member states for a long time frame and recent time span (e.g., 2010-2023) is less common compared to some studies that focus on a few countries or smaller group of EU countries. This could increase the transferability of the results in the broad spectrum of economic and policy situations in the EU.

3. Policy Relevance in a High-Inflation Environment: In recent years, the global inflationary trend makes it a pressing demand for empirical evidence that can provide policy makers with guidance on how to keep circular economy transitions going through economic volatility. This research is timely and will bring important insights into the resilience of recycling systems in times of inflation to the policy debate in the EU member states.

The aim of this thesis is to contribute empirical evidence regarding the relationship between inflation and municipal waste recycling performance across EU27 countries.

2.7 Literature Summary Table

Table 2.1 below provides a summary of key empirical studies that are relevant to the circular economy, waste management and inflationary aspects of macroeconomics, in order to provide an understanding of the state of the evidence. A table summarizing the key methods, samples and results of these studies and comparing across the literature.

Table 2.1 : Summary of Key Literature

Author & Year	Methodology	Sample	Main Findings
Nademi & Kalmarzi (2025)	Markov switching panel data model, GMM	27 European countries, 2010–2019	Circular economy advancement significantly reduces inflation.
Knäble et al. (2022)	Panel data analysis	25 European countries, 2010–2019	CE impacts sustainable development; renewable energies and reuse reduce environmental impact; recycling has no effect.
Simion et al. (2025)	Panel fixed-effects regression with Driscoll–Kraay SE	EU member states	Private investment and resource productivity positively affect EGSS; recycling patents have insignificant short-term impact.
Zheng et al. (2024)	OLS, fixed effects, Granger causality, dynamic panel data	27 European countries, 2000–2019	Substantial correlation between CE indicators and macroeconomic conditions; no strong short-run causal effects.
Holmen & Söderholm (2025)	Econometric analysis, literature review	EU waste management system	Complex interplay between environmental and economic impacts; integrated policy approaches needed.
Geng & Doberstein (2008)	Literature review, case studies	Industrial ecology applications	Industrial ecology principles (waste valorization, symbiosis) crucial for resource optimization.
Ajzen (1991)	Theoretical framework	Human behavior	Theory of Planned Behavior explains pro-environmental actions through attitudes, norms, and perceived control.

2.8 Comparative Review of Empirical Findings: A Multi-Dimensional Analysis

Empirical findings differ considerably across geographic and economic clusters within the European Union. The work of Geng and Doberstein (2008) started the research field and was descriptive—not as strongly econometrically as the later panel data-based studies. Other, more recent studies (Knäble et al., 2022) have reached different findings; better quality of institutions and education is the key to higher recycling rates in Western European countries. These results, however, seem to diverge from research on Central and Eastern European (CEE) transition economies.

In addition, there have been conflicting results in the literature when comparing the methodological results of the static Fixed Effects model with the dynamic GMM model. Under static models, the contribution of country-specific factors, which are assumed to remain constant over time, is important for the recycling results, whereas under dynamic models, past recycling performance could influence future results.

The other debate is about the contribution of 'green consumption' to circularity. Some behavioural economists claim that it's consumer intent, but most macroeconomic studies show that it's price and income. The coexistence of behavioural and macroeconomic explanations highlights the complexity of recycling performance and justifies a multi-dimensional analytical approach.

2.9 Critical Discussion of Methodological Limitations in Existing Research

An in-depth review of the existing body of literature shows that there are a number of methodological weaknesses that impair the understanding of the inflation-recycling nexus. Firstly, ‘stable-state' economics has created a lack of research with a sole focus on extreme volatility periods. In the vast majority of macro-panel studies, data for the post-pandemic era with its unprecedented surge in inflation and the energy crisis are excluded. The situation in recent economic turmoil may be less predictable in the light of this temporal constraint, meaning that existing models will be less suited to interpret the results of the indicators.

Second, most of the EU-wide studies exhibit a high ‘aggregation bias’. Researchers who consider the EU27 as a whole usually overlook the differences in social structures across Member States. The impacts of recycling in countries with a developed system of EPR (Germany, for instance) will differ from those in other countries with a system that is only in its early stages of development (Bulgaria, for instance), when applying a 5% inflation rate. The current literature tends to overlook cross-country differences in structures and consequently end up with a one-size-fits-all set of policy recommendations, that could be ineffective or even counterproductive in different economic environments.

Last, there are still significant challenges with self-reported municipal data and with inconsistent circularity measures. At the macro level there is also a 'policy-performance gap' and a 'intent-behaviour gap' between the high-level targets and the operational capability to achieve them. A Fixed Effects model explicitly accounting for country-level heterogeneity, together with harmonized Eurostat data, addresses several of these concerns. Furthermore, the use of fixed effects is supported by the Hausman specification test reported in Chapter 3 (χ^2 =

27.04, $p < 0.001$), which indicates that the fixed-effects estimator is preferred to the random-effects alternative. These methodological choices are intended to improve the reliability of the empirical analysis and provide a more robust assessment of municipal waste recycling performance.

2.10 EU Circular Economy Policies: A Macro-Resilience Perspective

EU environmental policy has been progressing towards a greater understanding of the need for systemic change, from the Circular Economy Action Plan of 2015 to the European Green Deal currently being followed. However, academic discussions of these policies have often remained disconnected from macroeconomic considerations. The Green Deal is about climate neutrality by 2050, but it assumes a relatively stable macro-economic framework for reaching this aim. Problems with this assumption have emerged during the inflation crisis of 2022-2023. Some recycling and waste-to-energy plants in the Union have been impacted by the increasing prices of energy and materials.

This section argues for the inclusion of ‘macro-resilience’ mechanisms in EU circular economy policies to ensure they are effective. This includes the targets for recycling, as well as the financial and operational infrastructure necessary to meet them that can cope with the high inflation and economic uncertainty. While there are some existing studies on ‘Just Transition funds’ and ‘Recovery and Resilience Facilities', further research is required to better understand the conditions under which such funds can be particularly useful for ensuring the protection of circular economy investments during economic downturns. Long-term sustainability goals and short-term economic survival are a major policy tension in the EU's environmental governance over the next decade.

Through the study of the macroeconomic instability and environmental policy, this thesis will make a contribution to a more realistic and grounded understanding of the challenges facing the EU's sustainability transition. It highlights the need for coordination between policy ministries in the environmental and economic sectors, to ensure that the circular dimension is not put on the back burner even in periods of economic stress. These considerations highlight the importance of designing circular economy policies that remain effective under varying macroeconomic conditions.

2.11 Synthesis and Identification of Research Gaps

This literature review pinpoints three main gaps in the research. There is limited evidence on the relationship between inflation and municipal waste recycling performance of EU member states. Secondly, the majority of the current research literature is either on behaviour or on environmental outcomes, rather than on macroeconomic effects like inflation and unemployment. Third, relatively few studies examine these relationships with a full panel of EU27 countries from the ‘post-pandemic’ period, including the post-pandemic inflationary surge and energy crisis. These gaps are the main reason for the empirical analysis done in this thesis.

Based on the literature review, the hypothesized relationship between the explanatory variables and municipal waste recycling performance is as follows: education is expected to have a positive relationship with the municipal waste recycling performance , unemployment is expected to have a negative relationship, GDP per capita is generally expected to have a positive relationship within the Environmental Kuznets Curve (EKC) framework, and the hypothesized relationship between inflation and municipal waste recycling performance is still theoretically

ambiguous. The control variables capture broader sustainability and circularity conditions through renewable energy consumption and circular material use.

The main purpose of the study is to address the gap and contribute to empirical knowledge in both academia and policy-making. It contributes to the growing literature by extending the discussion of the circular economy beyond technical and behavioural dimensions to include macroeconomic factors. This can provide useful insights into the understanding of sustainability transitions in an economically uncertain world.

3 CHAPTER 3: METHODOLOGY

3.1 Data and Descriptive Statistics

This study is based on a panel data consisting of 27 European Union (EU27) countries for the period 2010-2023. The initial sample consists of 378 observations (27 countries by 14 years) providing a consistent basis for longitudinal analysis. The selection of EU27 countries is justified because the countries share comparable policy environments in terms of environmental regulations and waste management, as well as by the availability of harmonized data from reliable data sources, such as Eurostat (2024). The time frame 2010-2023 has been selected, corresponding to the aftermath of the financial crisis and the accompanying macroeconomic adjustments, including the inflationary surge observed after 2021. Although the initial panel contained 378 observations, the final regression sample was reduced to 375 observations due to missing values in the dependent variable (municipal waste recycling rate).

Table 3.1 : Descriptive Statistics of the Variables (N=375)

Variable	Obs	Mean	Std. Dev.	Min	Max
Recycling Rate (%)	375	35.9	15.5	4.1	71.4
Inflation Rate (%)	378	2.6	3.28	-1.6	19.4
GDP per Capita (USD)	378	44292	21603	14954	150508
Unemployment Rate (%)	378	8.33	4.6	2.0	27.8
Tertiary Education Attainment (%)	378	28.2	7.82	11.9	46.6
Renewable Energy (%)	378	21.3	12.0	0.979	66.4
Circular Material Use Rate (%)	378	9.00	6.40	1.20	32.0

As can be seen in Table 3.1, the EU27 average recycling rate was 35.90% with a wide range of values between 4.10% and 71.40%. This wide range reflects variations in waste management between MS, highlighting the differences in waste management practices and effectiveness of waste management policies between MS. The Harmonized Index of Consumer Prices (HICP)

annual rate of inflation has been 2.60% on average over the period, with a standard deviation of 3.28% indicating the variations in the inflation rates of the member states and over time.

Economic development (GDP per capita) averaged USD 44,292.00 with a minimum of USD 14,954.00, and a maximum of USD 150,508.00. The diversity is due to the economic power of the EU27 countries that could have a strong impact on their investment potential in infrastructure for the circular economy and recycling systems. The overall level of unemployment was 8.33%, in line with the average. The average of human capital and awareness indicator (Tertiary Education Attainment) was 28.20% and the average environmental commitment indicator (Renewable energy consumption) was 21.30% (Eurostat, 2024; World Bank, 2024).

Table 3.2: Correlation Matrix of the Main Variables

Variable	1	2	3	4	5	6	7
1. Recycling Rate	—						
2. Inflation Rate	.068	—					
3. GDP per Capita	.525***	.173***	—				
4. Tertiary Education Attainment	.370***	.078	.610***	—			
5. Unemployment Rate	-.387***	-.303***	-.381***	-.086	—		
6. Renewable Energy Consumption	.120*	.118*	-.067	.162**	-.027	—	
7. Circular Material Use Rate	.503***	.080	.297***	.176***	-.278***	-.228***	—

Note. N = 373–376 due to pairwise deletion of missing observations. Values represent Pearson correlation coefficients (r). Significance levels: * p < .05, ** p < .01, *** p < .001 (two-tailed).

The pairwise correlations among the main variables used in the regression analysis is presented in Table 3.2. The recycling rate is positively correlated with GDP per capita, tertiary education

attainment, and the circular material use rate, and negatively correlated with the unemployment rate. Inflation exhibits only a weak positive correlation with recycling performance. Overall, the correlation coefficients are relatively low, which is consistent with the VIF diagnostics reported in the methodology chapter and do not indicate serious multicollinearity concerns.

3.1.1 Advantages of Panel Data Analysis

There are several important benefits to be derived from the use of panel data, as compared to cross sectional analysis, in this study. The most important advantage is the ability to capture changes within the same country over time, allowing the analysis of how municipal waste recycling performance evolves in response to changing macroeconomic conditions. The model also controls for unobserved country-specific characteristics, such as stable cultural and regulatory differences. By doing so, the analysis will reflect the dynamic connections between macroeconomic conditions and municipal waste recycling performance over time. Moreover, panel data can be used to capture within-country variation over time and cross-country structural differences, which is crucial for separating the impact of macroeconomic variables such as inflation from the impact of time-invariant country characteristics.

3.2 Variable Definitions and Measurement

This section provides detail regarding the variables included in the econometric model; their definition, measurement and theoretical relevance for the study of recycling rates and macroeconomic fluctuations.

3.2.1 Dependent Variable

Recycling Rate (Dependent Variable): This variable reflects the percentage of municipal waste that is recycled, as a measure of performance of the circular economy and the effectiveness of waste management. Data from Eurostat were provided to get a comparability between the EU27 recycling rates. The higher the recycling rate, the more efficient the use of resources, and more circular economy oriented it is (Eurostat, 2024).

3.2.2 Independent Variables

Inflation Rate: Eurostat's Harmonized Index of Consumer Prices (HICP) change over the last 12 months. An important macroeconomic indicator that could alter consumer and production costs and the policy agendas for waste management is inflation. The increased costs of the recycling process can make it more difficult, while a higher price of new products can make recycled products more valuable to recycle (Nademi & Kalmarzi, 2025).

GDP per Capita: current USD; GDP per capita is a widely used indicator of economic development and prosperity, and is available from the World Bank (2024). In general, the higher the GDP per capita, higher-income countries are often associated with higher levels of environmental awareness and stronger environmental regulation and greater investment capacity in recycling infrastructure (Grossman & Krueger, 1991). To maintain consistency with the available dataset, GDP per capita is measured in current USD. This option can, however, give rise to distortions arising from exchange-rate fluctuations and inflation, and is therefore acknowledged as a limitation that is discussed later in the thesis.

3.2.3 Control Variables

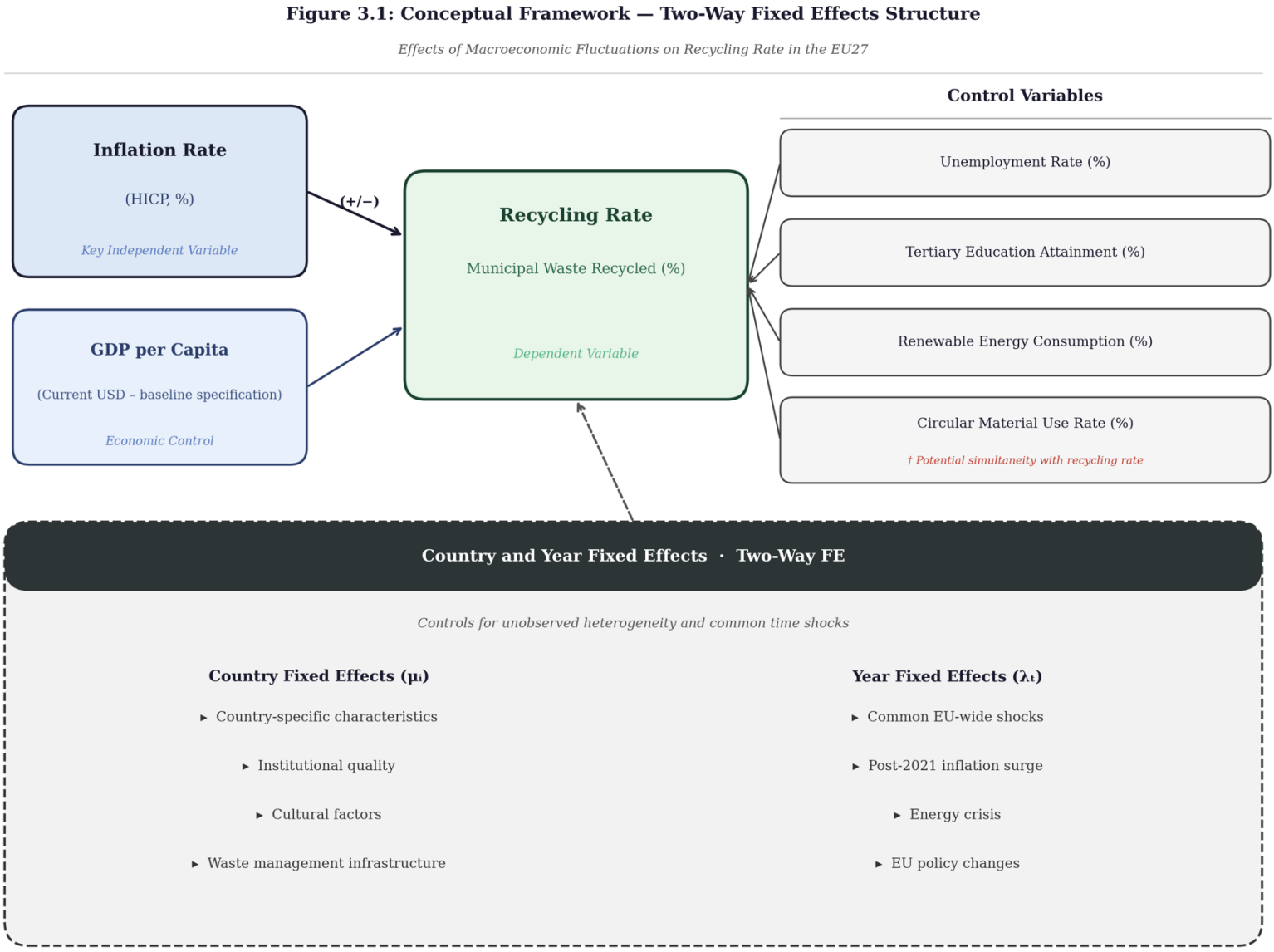

Figure 3.1: Conceptual Framework and Two-Way Fixed Effects Structure

Source: Author's own elaboration.

Unemployment Rate: Share of the labour force that is unemployed and seeking employment (Eurostat data). The impacts of high rates of joblessness on recycling can be mediated in several ways. From an economic perspective, the shortage of money can lead to reduced purchasing power, leading to a decrease in consumption and consequently waste. At the same time, it might help reduce the perceived opportunity cost of time for people to engage in recycling activities (Knäble et al., 2022). This variable is added to account for the macroeconomic stress conditions because the economic fluctuations in the labor market are often linked with wider economic cycles which have an impact on the priorities of the municipal budget and the household waste behavior.

Tertiary Education Attainment: Percent of the population aged 25-64 that have undertaken tertiary education. This measure is used in place of general enrolment ratios and more accurately reflects the level of human capital and environmental awareness of the productive population (Simion et al., 2025). Higher education and environmental awareness and sustainable waste management are strongly linked and are often mentioned as a proxy for Human Capital Development (HCD).

Renewable Energy Consumption: Expressed as a percentage of total final energy consumption, data from Eurostat It is a proxy indicator of a nation's level of environmental sustainability and green policies. Countries that have higher rates of renewable energy consumption could also be more advanced in their environmental infrastructures and their public perception of recycling (Eurostat, 2024). This indicator shows the extent of a country's overall environmental values and its state of the green infrastructure and recycling and resource recovery systems.

Circular Material Use Rate: Ratio of materials recycled and re-used in the economy, according to Eurostat. This factor shows the degree of circular economy and resource efficiency that is present in each country. Generally speaking, the greater the amount of material that circulates in the economy, the indicator is often associated with broader circular economy performance and resource efficiency. The recycling rate is a measure of how well municipal waste is recovered, while circular material use accounts for the general reintegration of secondary materials into the economy. Because recycling contributes directly to circular material use, the relationship between these variables may involve simultaneity. This potential endogeneity issue is discussed further in the limitations section.

3.3 Econometric Model and Estimation Strategy:

The empirical analysis is conducted in three steps. The first step is to fit a pooled OLS regression model as a baseline specification under the assumption that all observations are independent. Second, a linear mixed model (LMM) is used to estimate a random effects model, with country-specific intercepts as random effects, thereby capturing country-level heterogeneity and assuming that country-specific effects are uncorrelated with the regression variables. Third, a fixed effects model is estimated. The fixed effects specification initially includes country fixed effects, while the final specification adopts a two-way fixed effects structure (country and year fixed effects). This method accounts for common shocks affecting all EU member states in a particular year, and also allows for control of country-specific characteristics that remain constant over time. The last empirical model presented in Chapter 4 is the two-way fixed effects model with country and year fixed effects. This specification is preferred because it simultaneously controls for country-specific characteristics unobserved

country-specific characteristics and the macroeconomic shocks common to all EU member states over time.

The Hausman specification test ($\chi^2 = 27.04$, df = 6, p = 0.0001423) rejected the null hypothesis that the country-specific effects are uncorrelated with the regressors, thus, model selection between random effects and fixed effects was guided. This result indicates that the random effects estimator is not consistent and provides formal statistical support for the use of the fixed effects specification, as country-specific effects are likely to be correlated with the explanatory variables.

3.3.1 Model Specification

The econometric model is specified as follows:

$$Recycling_{\{it\}} = \beta_0 + \beta_1 Inflation_{\{it\}} + \beta_2 GDP_{\{it\}} + \beta_3 Education_{\{it\}} + \beta_4 Unemployment_{\{it\}} + \beta_5 Renewable_{\{it\}} + \beta_6 CircularUse_{\{it\}} + \mu i + \lambda t + \varepsilon_{\{it\}}$$

(1)

Where:

- $Recycling_{it}$ represents the recycling rate for country i at time t.
- $Inflation_{it}$ is the inflation rate for country i at time t.
- GDP_{it} is the GDP per capita for country i at time t.
- $Unemp_{it}$ is the unemployment rate for country i at time t.
- $Educ_{it}$ is the tertiary education attainment for country i at time t.
- $Renew_{it}$ is the renewable energy consumption for country i at time t.
- $CircularUse_{it}$ represents the circular material use rate for country *i* at time *t*.
- ε_{it} is the idiosyncratic error term.
- t denotes the time period (years 2010–2023).
- μ_i represents the unobserved country-specific fixed effects, capturing all time-invariant characteristics unique to each country, including institutional quality, cultural factors, and long-standing waste management infrastructure
- λt represents year-specific effects that capture common shocks affecting all EU27 countries in a given year, including EU-wide inflationary pressures, energy crises, regulatory changes, and macroeconomic conditions.

The inclusion of year fixed effects is especially relevant in the context of this study because of the incorporation of year fixed effects. Omitting year fixed effects may bias coefficient estimates if there are common EU-wide developments like the inflation surge after 2021, energy market shocks and policy reactions.

The final empirical specification is a two-way fixed effects model with both country fixed effects (μi) and year fixed effects (λt). Country fixed effects control for the unobserved time-invariant differences across EU member states, and the year fixed effects capture macroeconomic shocks common to all the countries in a particular year, such as changes in inflation, energy market disruptions, regulatory developments and other economic shocks.

3.3.2 Model Comparison and Specification Choice

To estimate the random effects specification a linear mixed model with random intercepts at country level was used, with both within-country and cross-country variation taken into account. This is an efficient way if country-specific effects are not correlated with explanatory variables. All country specific variables that do not change over time are accounted for in the fixed effects specification, using country dummy variables. All specifications were estimated and compared to assess the robustness of all results to alternative model specifications. The Hausman test result provides formal statistical justification for preferring fixed effects over random effects in the final specification.

Moreover, in macro-level panel studies, it is crucial to take into consideration the potential omitted-variable concerns. These risks can be addressed by using the Fixed Effects estimator, which can account for the unobserved time-invariant factors that may be influencing the

relationship between the variables being estimated and that are specific to a country. This approach will help make the estimates more reliable by focusing on the variation in the country rather than across countries.

The fixed effects specification was selected based on the results of the Hausman test ($\chi^2 = 27.04$, df = 6, p = 0.0001423), which rejects the null hypothesis that the random effects estimator is consistent. This finding indicates that country-specific effects are correlated with the explanatory variables and therefore the fixed effects estimator is preferred. Given the importance of common EU-wide macroeconomic shocks during the study period, the final specification adopts a two-way fixed effects model including both country and year effects. Therefore, the two-way fixed effects specification is treated as the preferred model throughout the empirical analysis and serves as the basis for the interpretation of the main results presented in Chapter 4.

The final model incorporates both country and year fixed effects. The inclusion of year effects is particularly important in the context of this study because EU member states were exposed to common macroeconomic shocks, including the post-2021 inflation surge, the energy crisis, and EU-wide policy responses. Year fixed effects reduce the risk that estimated coefficients capture common time trends rather than country-specific variation.

For fixed effects estimations, the reported coefficient of determination should primarily be interpreted as within R^2, reflecting the explanatory power of the model with respect to variation within countries over time rather than variation between countries.

3.3.3 Robustness Considerations

Several complementary checks are used to assess the robustness of the main findings. The first step is to compare coefficient estimates across three alternative model specifications: pooled OLS, random effects and fixed-effects models. Second, the baseline fixed effects model is re-estimated using Driscoll–Kraay standard errors, which are robust to serial correlation and cross-sectional dependence. Third, a two-way fixed effects model is fitted with both country and year dummy variables to check the robustness of the results to common time trends. The findings, particularly with respect to tertiary education attainment and unemployment, are consistent across all the specifications, which helps to support the robustness of the main findings. The robustness analysis is particularly important since the panel is simultaneously serial correlated and cross-sectionally dependent. Therefore, in cases where the conventional standard errors are used for inference, this uncertainty might be underestimated. The key results are robust in each of the three types of specification (pooled OLS, random effects, and two-way fixed effects). Tertiary education has a consistently positive relationship with recycling performance and unemployment has a consistently negative relationship. The main conclusions are reinforced by the fact that inflation is not statistically significant in any of the specifications. The consistency of coefficient signs and statistical significance across alternative specifications increases confidence that the main conclusions are not driven by model selection.

3.3.4 Diagnostic Tests and Validation

The reliability and validity of the regression results were tested with several diagnostic tests. These tests have been carried out to assess violations of classical linear regression assumptions often found in panel data situations.

To test the reliability of the regression estimates, model validity checks (residual analysis, autocorrelation and multicollinearity tests) were conducted.

Heteroskedasticity: Heteroskedasticity refers to situations in which the variance of the error term is not constant across observations. Because panel data frequently exhibit heteroskedastic disturbances, robust inference procedures are required. To address potential heteroskedasticity together with serial correlation and cross-sectional dependence, Driscoll–Kraay standard errors were employed in the robustness analysis. This estimator provides heteroskedasticity-consistent standard errors and is considered appropriate for macro-panel datasets.

Autocorrelation: Panel data can often exhibit autocorrelation, where error terms are correlated across time for the same entity. To check serial correlation, a Durbin-Watson test was performed as an initial diagnostic test for the pooled OLS specification. Because the Durbin–Watson statistic is primarily designed for pooled regressions, the Wooldridge/Breusch–Godfrey panel test is considered the principal diagnostic test for serial correlation in this study. The Breusch–Godfrey/Wooldridge test for serial correlation in panel models confirms the presence of autocorrelation in the idiosyncratic errors ($\chi^2 = 158.8$, df = 12, $p < .001$). The presence of serial correlation implies that conventional standard errors may be biased downward, potentially overstating statistical significance. Therefore, robust inference procedures are necessary. To address this, the main fixed effects model is re-estimated using Driscoll–Kraay standard errors, which are robust to both serial correlation and cross-sectional dependence. The Driscoll–Kraay estimator is particularly appropriate for macro-level panel data with a relatively small number of cross-sectional units and a moderate time dimension, as is the case in this study (Driscoll & Kraay, 1998).

Cross-Sectional Dependence: The Pesaran CD test for cross-sectional dependence yields a test statistic of $z = 2.198$ ($p = .028$), indicating the presence of statistically significant cross-sectional dependence in the panel. This result is consistent with the expectation that EU27 member states share common macroeconomic shocks, policy frameworks, and business cycle fluctuations. The use of Driscoll–Kraay standard errors directly addresses this concern, as this estimator produces consistent inference under both serial correlation and cross-sectional dependence. Since EU member states are exposed to common policy initiatives and macroeconomic shocks, cross-sectional dependence is expected rather than exceptional. Ignoring this issue may lead to inconsistent standard errors and misleading inference.

Multicollinearity: Multicollinearity occurs when the independent variables are highly correlated; it can cause these coefficients to be overestimated, thus obscuring the effect of each regressor. Variance Inflation Factors (VIFs) of all the independent variables examined. All Variance Inflation Factor (VIF) values were below the commonly accepted threshold of 10, indicating that multicollinearity is not a serious concern in the model.

3.3.5 Statistical Software

All statistical analyses were conducted using **Jamovi (Version 2.7)** and **R (Version 4.5)**. Jamovi was used for descriptive statistics, pooled OLS estimation, random effects estimation, fixed effects estimation, and two-way fixed effects modelling. Additional panel-data diagnostics and robustness analyses were performed in R using the *plm* package, including the Hausman specification test, the Wooldridge/Breusch–Godfrey test for serial correlation, the Breusch–Pagan test for heteroskedasticity, the Pesaran CD test for cross-sectional dependence,

and Driscoll–Kraay robust standard errors. The combined use of Jamovi and R enabled both model estimation and diagnostic evaluation of panel-data assumptions.

3.3.6 Data Limitations

However, several limitations of the data and methodology should be acknowledged. Eurostat recycling indicators may be affected by differences in reporting practices and waste classification across EU member states. Furthermore, using macro level data does not allow the analysis of individual recycling behaviour and the data at the household level. Thus the results must be interpreted in terms of macro-level structural relationships rather than the extent to which individual behaviours are changed. Moreover, using annual macroeconomic measures can also restrict the model's capacity to reflect short-term behavioral changes and policy reactions.

Another condition of limitation is the measurement of GDP per capita. GDP per capita is in current USD which could include effects of exchange-rate variability and nominal prices. This is especially significant as the study period covers some periods of high inflation and currency volatility in EU member states. A preferable approach for cross-country comparisons would be to use real GDP per capita in constant prices or Purchasing Power Standards (PPS). The small and not significantly different coefficient for GDP per capita ($\beta = -9.44 \times 10^{-5}$, $p = .071$ under standard errors; $p = .114$ under Driscoll–Kraay standard errors) indicates that this variable's role in the model is small, and that a future model should, at least in principle, be re-estimated with data based on PPS-adjusted or constant-price GDP.

It is also important to note that municipal waste recycling rate is one of the aspects of the performance of the circular economy. While recycling is a proxy for circularity, it does not

reflect a range of circular economy activities like product reuse, repair, remanufacturing, and resource productivity. Therefore, the empirical results should be read as evidence of the performance of the municipal waste recycling system and not as evidence of the overall performance of the circular economy.

Potential endogeneity issues arise due to the fact that circular material use rate is controlled. Municipal waste recycling is directly related to the circular use of materials, so the two can be determined together. This is confirmed by the negative and non-significant coefficient for circular material use rate ($\beta = -0.026$, $p = .801$), which does not appear to have the direct structural effect in this model. Circular material use rate could also be used as an alternative dependent variable in the future, instrumental variable techniques could be employed to overcome potential endogeneity.

4 CHAPTER 4: RESULTS AND FINDINGS

4.1 Introduction to Empirical Results

The results of the empirical analysis by panel regression are presented in this chapter. The main purpose is to analyse the factors driving the municipal waste recycling rate at EU27 member states in the period 2010-2023. The analysis is organized in three steps: A first section gives an overview of the overall regression results, a second section elaborates on the meaning of the individual variables, and a third section discusses the overall policy implications of the EU sustainability agenda.

One of the major methodological integrity features of this study is that it employs a Fixed Effects (FE) model. The FE model also accounts for the differences between the member countries of the EU27, which are not observed but vary over time (discussed in Chapter 3). In the waste management sector, this manifests in the longstanding national cultures of the environment, the geographical constraints and structural abilities that are present for decades and affect the recycling infrastructure. These features are accounted for in the model, allowing to separate out the impact of time-varying macroeconomic and socio-economic variables from long-lasting structural differences between countries.

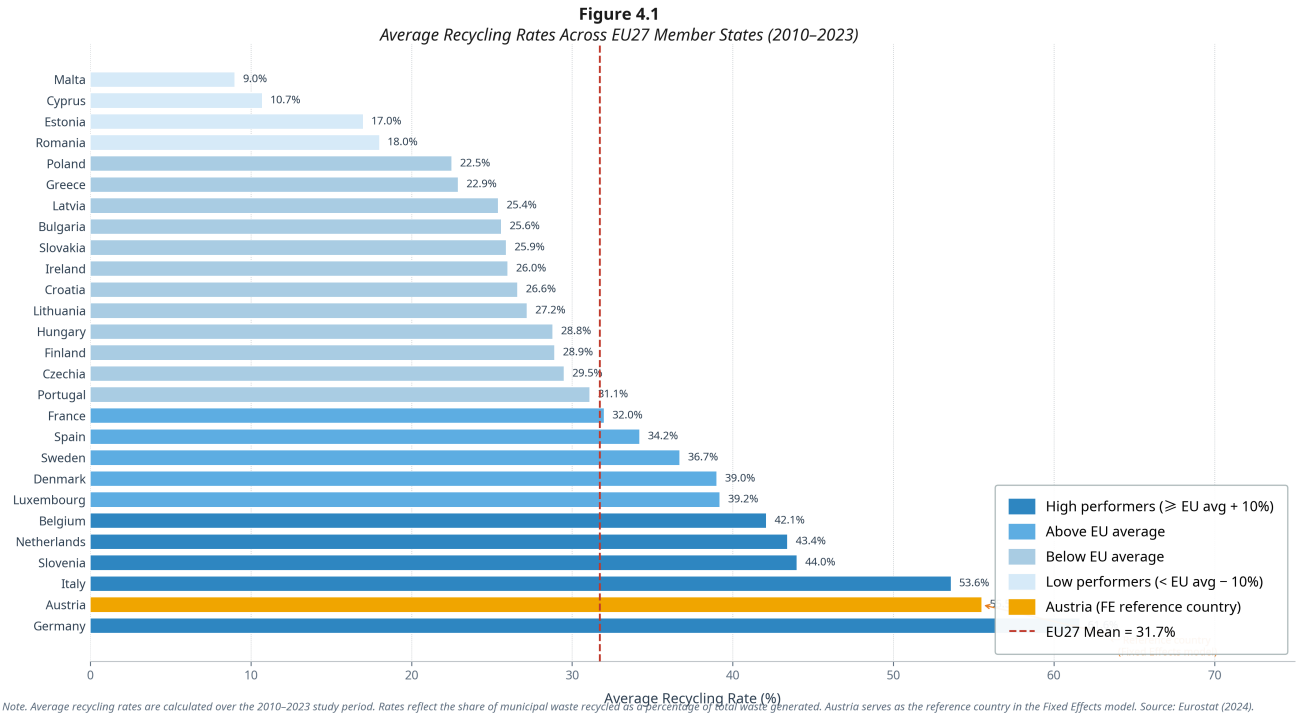

Figure 4.1: Average Recycling Rates Across EU27 Member States (2010–2023)

Note. Average recycling rates are calculated over the 2010–2023 study period. Rates reflect the share of municipal waste recycled as a percentage of total waste generated. Austria is visually highlighted in the figure for reference purposes.Source: Eurostat (2024).

As can be seen in Figure 4.1, there are large differences in the performance of municipal recycling across the EU27 member countries during the period 2010-2023. The average rates are generally higher in countries in Northern and Western Europe, while several countries in Southern and Eastern Europe are still below the EU average. This variation reinforces the use of the Fixed Effects framework, as structural differences across countries appear to be an important determinant of municipal waste recycling performance.

4.2 Econometric Model Presentation

Table 4.1 reports the results of the two-way fixed effects panel model. The model includes both country and year fixed effects and uses Driscoll–Kraay standard errors to account for heteroskedasticity, serial correlation, and cross-sectional dependence. The selection of the fixed effects specification is supported by the Hausman test ($\chi^2 = 27.04$, $p < 0.001$), which rejects the random effects alternative.

Table 4.1: Two-Way Fixed Effects Regression Results with Driscoll–Kraay Standard Errors

Variable	Coefficient (β)	Robust SE	95% CI	t-statistic	p-value
Inflation Rate	0.0633	0.0987	[-0.129, 0.255]	0.641	0.522
GDP per Capita	−0.000094	0.000060	[-0.000210, 0.000022]	−1.583	0.114
Tertiary Education Attainment	0.9514***	0.1772	[0.607, 1.296]	5.370	<0.001
Unemployment Rate	−0.8780***	0.1533	[-1.176, -0.580]	−5.727	<0.001
Renewable Energy Consumption	−0.0779	0.0719	[-0.218, 0.062]	−1.084	0.279
Circular Material Use Rate	−0.0258	0.1022	[-0.224, 0.173]	−0.252	0.801
Observations (N)	375				
Countries	27				
Within R^2	0.436				
F-statistic	44.04***				
Hausman χ^2	27.04***				
Country FE / Year FE	Yes / Yes				
Driscoll–Kraay SE	Yes				

Note. Dependent variable: municipal waste recycling rate (%). Standard errors are Driscoll–Kraay robust standard errors, which are robust to cross-sectional dependence, heteroskedasticity, and serial correlation. The model includes both country fixed effects (μ_i) and year fixed effects (λ_t) — a two-way fixed effects specification. The Hausman test ($\chi^2 = 27.04$, $p < .001$) confirms the consistency of the fixed effects estimator over random effects. Within R^2 refers to the proportion of within-country variance explained by the model. *** $p < .001$. Robust standard errors reported in Table 4.1 correspond to Driscoll–Kraay estimators.

The Within R^2 of the fixed effects model is 0.436, indicating that the model accounts for about 43.6% of the variation in municipal waste recycling rates within countries over time This suggests that the explanatory variables explain a substantial share of the within-country variation in recycling rates over time, while a considerable proportion of the variation remains unexplained by the model.

The findings indicate that in the estimated specification socio-economic structural variables rather than inflation have a stronger relationship with recycling performance. However, the model does not identify causal mechanisms.

To evaluate the robustness of the main results, pooled OLS, random effects, fixed effects, and two-way fixed effects models were estimated.. The direction of the key coefficients remained consistent across alternative specifications. Especially, tertiary education attainment continued to be positively related to recycling performance, and unemployment continued to be negatively related. These findings support the robustness of the main results, as inflation was not statistically associated under any of the specifications.

Table 4.2: Diagnostic and Model Selection Tests

Diagnostic Test	Test Statistic	p-value	Interpretation
Hausman Test	$\chi^2 = 27.04$	< 0.001	Fixed effects model preferred over random effects
Wooldridge Serial Correlation Test	$\chi^2 = 158.80$	< 0.001	Serial correlation detected
Breusch–Pagan Test	$\chi^2 = 27.29$	< 0.001	Heteroskedasticity detected
Pesaran Cross-Sectional Dependence Test	z = 2.20	0.028	Cross-sectional dependence detected

Note. The Hausman test supports the use of the fixed effects specification. Diagnostic tests indicate the presence of serial correlation, heteroskedasticity, and cross-sectional dependence. Therefore, Driscoll–Kraay standard errors were employed in the final two-way fixed effects model to obtain inference robust to these econometric issues.

The diagnostic tests support the methodological choices adopted in this study. The Hausman test supports the fixed effects model over the random effects model while the presence of serial correlation, heteroskedasticity, and cross-sectional dependence justifies the use of the use of Driscoll–Kraay standard errors. Thus, the final two-way fixed effects model provides more

reliable statistical inference than a conventional fixed effects specification based on standard errors.

4.3 Analysis of the Inflation-Recycling Nexus

The results show that inflation has no statistically significant direct impact on the performance of municipal recycling in the EU27 member states. While the market value of materials that are recyclable may rise due to the inflation, the economic efficiency of recycling systems may be decreasing due to an increase in the operational and energy costs of recycling systems.

The coefficient for inflation is positive but statistically insignificant ($\beta = 0.063$, $p = 0.522$). Therefore, the analysis does not provide evidence of a direct association between inflation and municipal waste recycling performance once country effects, year effects, and control variables are taken into account.

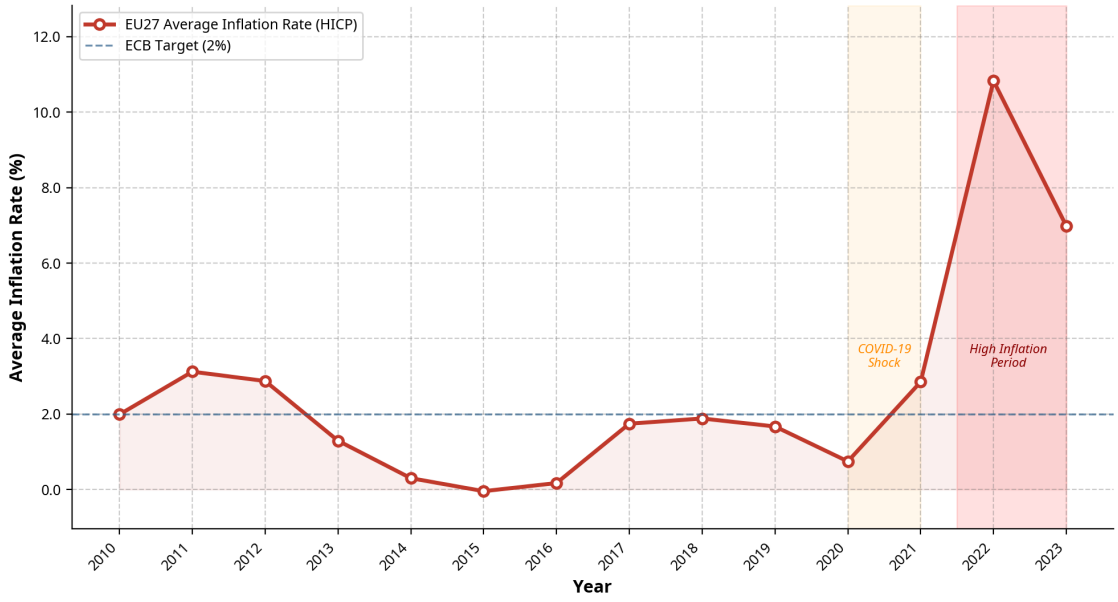

Figure 4.2: Average Inflation Trends in EU27 (2010–2023)

Source: Author's calculations based on Eurostat data (2024).

Despite the macroeconomic shocks observed during 2020–2023, recycling performance in the EU27 generally continued to increase gradually throughout the study period.

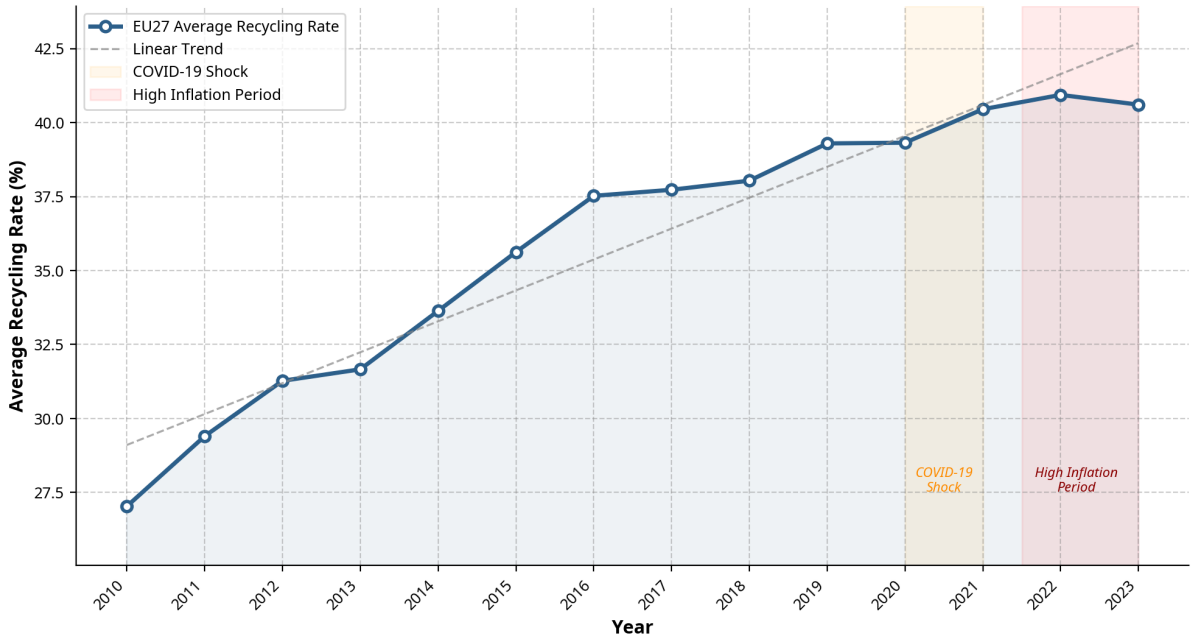

Figure 4.3: Average Recycling Rate Trends in EU27 (2010–2023)

Source: Author's calculations based on Eurostat data (2024).

Looking at the overall trend over time, however, there is some indication that the recycling rate in EU27 member states is increasing gradually, suggesting that structural and institutional factors, including policy measures, waste management infrastructure and public environmental awareness, are more likely to influence recycling rates in the long term than short-term fluctuations in the inflation rate. Although recycling rates continued to increase during the 2020–2023 period, this descriptive pattern should not be interpreted as evidence that inflation had no effect on recycling performance. The regression analysis provides the formal basis for assessing this relationship and indicates no statistically significant direct association between

inflation and municipal waste recycling performance after controlling for country effects, year effects, and other explanatory variables.

Although recycling rates remained relatively stable during periods of elevated inflation, the regression analysis does not identify the mechanisms responsible for this outcome. Consequently, no conclusions can be drawn regarding institutional resilience or the ability of national systems to absorb macroeconomic shocks.

4.4 Economic Development and Institutional Capacity

GDP per capita exhibits a negative coefficient but is not statistically significant when robust Driscoll–Kraay standard errors are applied ($\beta = -9.44 \times 10^{-5}$, $p = 0.114$). Therefore, the analysis does not provide strong evidence that income levels are directly associated with municipal recycling performance after controlling for country and year fixed effects. Note that GDP per capita is measured in current USD in the baseline specification. As discussed in Chapter 3, this measure may capture exchange-rate and inflation-related effects. Future research could employ real GDP per capita or logarithmic transformations to improve interpretability.

GDP per capita is included as a control variable representing the structural economic capacity of EU27 member states. The lack of statistical significance suggests that income level alone is insufficient to explain differences in municipal recycling performance once country and year fixed effects are accounted for.

4.5 Structural Determinants: Education and Unemployment

The most statistically significant variables at the EU27 member state level in the model are tertiary education and the unemployment rate. These findings illustrate the need to take structural socio-economic conditions into account when examining how the performance of the circular economy is impacted by short-term macroeconomic fluctuations.

In the fixed-effects model, the statistical significance of the education and unemployment variables suggests that structural socio-economic factors are important correlates of long-run recycling patterns. By contrast, short-term macroeconomic fluctuations, such as inflation, do not appear to be significantly associated with recycling performance in the final specification. The results indicate that education and unemployment are statistically associated with recycling performance. However, the model does not identify the precise causal mechanisms underlying these relationships.

4.6 Analysis of Socio-Economic Controls

In the fixed-effects model, a statistically significant negative association was found between the unemployment rate and recycling performance ($\beta = -0.8780$, $p < 0.001$). This result should be interpreted as an association between labor-market stress and lower recycling performance. Potential mechanisms such as reduced household participation or lower municipal resources are plausible but are not directly observed in the model.

The education rate is the strongest statistically significant and explanatory variable for recycling performance. In the fixed effects model, the coefficient for tertiary education attainment is positive and highly significant ($\beta = 0.9514$, $p < 0.001$), and it is the strongest positive predictor

of recycling performance. This result is generally consistent with the environmental literacy hypothesis, which links tertiary education to increases in environmental awareness, pro-environmental attitudes, and participation in recycling and waste separation programs. Education should be interpreted as a structural correlate of recycling performance rather than direct evidence that education itself causes higher recycling rates. It may also capture broader factors such as institutional quality, civic engagement, and environmental awareness.

Renewable energy consumption and circular material use rate were not statistically significant in the final two-way fixed effects model with Driscoll–Kraay standard errors ($\beta = -0.0779$, $p = 0.279$; $\beta = -0.0258$, $p = 0.801$, respectively). There was some variation in the sign of the coefficients across alternative specifications, but neither variable was the most significant in the final model. The coefficients for these variables were not statistically significant; therefore, the results indicate that other institutional and structural mechanisms in EU27 member states have a stronger impact on recycling performance than these variables do. Interpreting the circular material use rate requires particular caution because recycling performance and circular material use are conceptually related and may be jointly determined. This potential simultaneity issue represents a limitation of the specification.

4.7 Discussion: Macroeconomic Stability and the EU Green Deal

The empirical findings may provide insights relevant to ongoing EU sustainability discussions, including the Circular Economy Action Plan (CEAP). The CEAP's goals are ambitious and will need sustained progress to be met, such as a 60% recycling rate of municipal waste by 2030. Our findings indicate that macroeconomic conditions may indirectly influence recycling systems through operational costs, institutional capacity, and policy implementation challenges, rather than through strong, direct statistical effects. The 2022-2023 inflationary impact is a

reminder that times of economic uncertainty can present opportunities (material value) and challenges (operational costs) for circularity.

Moreover, the statistical significance of the education and unemployment variables indicates the importance of accounting for country heterogeneity across the EU27. There are significant differences in labor market conditions and human capital endowments across EU27 countries, which imply that a fully uniform circular economy policy framework does not necessarily have the same effects on all member states. To reach the EU's ambitious recycling goals, tailored measures that address the socio-economic vulnerabilities of lower-income EU27 Member States, in particular through investment in education and employment stability, are required.

The policy implications discussed in this chapter should be interpreted as being informed by the broader literature and descriptive evidence rather than derived directly from the regression results. The econometric findings primarily support the relevance of structural socio-economic factors, particularly education and labor-market conditions, rather than providing direct evidence regarding the effectiveness of specific EU policy interventions.

4.8 Model Fit and Limitations

This study has some limitations that should be considered, despite its methodological advantages. Omitted-variable bias is possible because some potentially important socio-economic, policy, or cultural factors may not have been measured or may not have been available due to data limitations or measurement difficulties. Furthermore, differences in local recycling outcomes across EU27 Member States at the municipal level are not accounted for in national-level macroeconomic data, so they should be given due consideration, as they may have a significant impact on recycling outcomes. Comparative environmental research is

hampered by challenges related to waste management data consistency and quality at the EU level, particularly across member states, as well as by challenges in overall data harmonization within the EU. These granular aspects of policy and data could be a subject of future study to gain a more complete understanding.

The diagnostic analysis shows that there is no multicollinearity because all the Variance Inflation Factor (VIF) values are less than the commonly accepted values of VIF 1.12 to 2.06. Autocorrelation is another characteristic of macro-panel data, as indicated by the Durbin-Watson statistic (0.880, $p < 0.001$). This issue is addressed in the final specification through the use of Driscoll-Kraay standard errors, which provide inference robust to serial correlation, heteroskedasticity, and cross-sectional dependence.

Additional diagnostic tests confirmed the presence of heteroskedasticity (Breusch–Pagan test, $p < 0.001$), serial correlation (Wooldridge test, $p < 0.001$), and cross-sectional dependence (Pesaran CD test, $p = 0.028$). These findings further support the use of Driscoll–Kraay standard errors in the final specification.

There are also limitations due to data availability and potential omitted-variable bias that should be noted in the model. Several factors may constrain the results, such as municipal waste policies and data constrained at the regional level. These results should thus be analyzed with some caution because only partially causal mechanisms are observed, and the estimated relationship is principally the statistical association. The major strength of the model is its ability to capture the complex relationship between inflation and recycling performance, which warrants further exploration in the future. Municipal-level datasets and policy-specific indicators would be beneficial for future research to explore the relationship between inflation

and recycling. Overall, the model can offer some insight into the circular economy performance of EU-27 member states and the link between macroeconomic instability and that performance.

4.9 Summary of Findings

The chapter suggests that recycling performance in the EU27 appears to be more strongly associated with structural socio-economic conditions than with short-term macroeconomic fluctuations. The panel model regression analysis for 375 observations covering the period 2010-2023 across 27 EU27 countries shows that the most statistically significant factors influencing recycling performance are the unemployment rate and tertiary education attainment, with the former negatively and the latter positively influencing recycling performance. Although there were several pathways by which inflation could influence recycling, a direct association was not found in the fixed-effects model ($\beta = 0.0633$, $p = 0.522$), as noted in recent literature, which shows the relationship between the two to be complex and context-specific. GDP per capita displayed a negative coefficient but did not remain statistically significant under robust inference.

The results highlight the importance of human capital development and the stability of the labor market to transition to a circular economy. The results could contribute to the design of more sector-specific circular economy policies, as they highlight the key role of structural socio-economic factors in explaining recycling performance across EU27 Member States. The findings are consistent with the view that education, human capital development, and labor-market stability may be relevant contextual factors in designing policies to support the EU Green Deal and the Circular Economy Action Plan.

5 CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Synthesis of Empirical Findings and Theoretical Context

This study provides a detailed analysis of the macroeconomic and socio-economic drivers of municipal waste recycling rates in the EU27 over 2010–2023. The investigation began by identifying that the EU's circular economy objectives were among the highest in the world and that the macroeconomic context in which they were implemented was much more volatile. The study has covered the link between the macroeconomic environment and environmental performance, indicating that broader economic dynamics could also drive the transition towards the circular economy.

One of the important empirical results of this study is that socio-economic factors play a key role in the performance of recycling. More specifically, in the fixed-effects model, the highest β (0.9514) and the most significant positive relationship ($p < 0.001$) were observed between tertiary education attainment and recycling performance across the EU27 member states. This positive association should be interpreted as a structural correlation rather than evidence of a direct causal effect. Education may capture broader dimensions of institutional quality, environmental awareness, civic engagement, and human capital development. The model does not directly observe household behavior, municipal budgets, or institutional capacity, and therefore cannot identify the precise mechanism underlying this relationship. A macroeconomic model was used to examine the direct relationship between inflation and recycling performance, using a fixed-effects model; no statistically significant relationship was found ($\beta = 0.0633$, $p = 0.522$). This suggests that the inflationary shocks in energy-related costs experienced in 2022-2023 have resulted in mixed trends in material value and operational costs (including energy and transportation), affecting recycling rates. This finding suggests that the relationship

between inflation and municipal waste recycling performance may be more complex than a simple direct association and warrants further investigation.

Furthermore, GDP per capita exhibited a negative coefficient (β = -9.44e−5) but was not statistically significant after applying Driscoll–Kraay standard errors (p = 0.114). This suggests that income differences alone are not strongly associated with municipal waste recycling performance, once country- and year-fixed effects are taken into account. Contrary to the theoretical expectations derived from the Environmental Kuznets Curve framework, GDP per capita was not positively associated with municipal waste recycling performance in the final specification.

5.2 Strategic Policy Recommendations

The following policy recommendations should not be interpreted as direct conclusions derived from the econometric model. Rather, they are broader implications informed by the empirical findings, the literature reviewed in Chapter 2, and the descriptive evidence presented throughout the thesis. The regression analysis primarily supports the relevance of structural socio-economic factors, particularly education and labor-market conditions, while the wider policy discussion reflects the broader circular economy and sustainability literature.

The findings presented in this thesis are highly relevant to the EU's sustainability agenda, including the EU Circular Economy Action Plan (CEAP) and the goals set out in the Green Deal. The following strategic interventions are recommended to enable the transition to become resilient and equitable towards climate neutrality:

Furthermore, a good circular economy system can help to increase EU strategic autonomy. They use fewer virgin raw materials and, because of this, provide resource security – a factor crucial when energy shortages or geopolitical turbulence occur. The transformation of the sector's approach will help mitigate supply chain risks, reinforce the EU's position as a leader in sustainable resource use, and enhance its economic resilience and self-sufficiency.

Sustainable financing and green investment are also key to keeping recycling systems sustainable in the long run and to the resilience of the circular economy. There are a variety of tools that can help attract additional investment for new solutions in waste management, circular business models, and scaling up markets for secondary raw materials, such as green bonds, EU transition funds, and financing aligned with ESG criteria. Financial instruments are vital for de-risking investments and sustaining a steady funding flow during the transition.

Social is another important element of circularity to consider, along with the economic and environmental. The transition creates green jobs, both nationally and in local communities, helping build regional cohesion. All this contributes to the creation of long-term economic resilience by promoting job diversification and reinforcing sustainability initiatives at the community level.

5.2.1 Differentiated Policies and Regional Tailoring

The EU should recognize the variability and aim towards regionally specific policy arrangements. The diversity of economic situations across the EU27 member states makes a 'one-size-fits-all' approach to recycling mandates less effective. The level of institutional capacity and infrastructure in a given country should be taken into account when designing policy interventions. For countries with less developed recycling systems, the first step is to

build the basic infrastructure, such as expanding separate collection systems and regional recycling centers, and securing investment from the EU's Just Transition Fund to sustain recycling momentum even amid inflation.

This regional tailoring should also be made applicable to the setting of interim targets. Although the 2030 targets are national in scope, the path towards them should take into account the different macroeconomic sensitivities identified in this study. EU27 member states that have yet to reach systemic maturity for recycling need more flexibility in timelines and/or technical assistance to achieve this.

5.2.2 Enhancing Infrastructure Resilience and Energy Decoupling

The price volatility in energy was evident during the 2022-2023 inflation crisis, underscoring the need for a more resilient waste management system. Energy prices are important to the recycling sector because of the energy required for collection, transport, or processing. EU27 member states need to encourage the use of renewable energy in waste processing, such as on-site solar or wind energy. Additionally, the electrification of waste collection technology should help mitigate fluctuations in diesel fuel prices and stabilize the economics of waste collection, thereby maintaining a positive economic incentive for material recovery.

Resilience may also be strengthened through investment in advanced waste management infrastructure, including automated sorting technologies and more efficient collection systems. However, technological developments could help to mitigate increasing labor and energy prices, making recycling more economically sustainable even in high inflation.

5.2.3 Macro-Resilient Environmental Budgeting and EPR Strengthening

Microeconomic stabilization policies need to better incorporate environmental policies. EU27 member states are advised to set up ‘Environmental Resilience Funds', which could be triggered in times of extreme inflation to support the recycling industry in the short term. This would help keep recycling viable when recovery is more expensive than the material's value, while still ensuring circularity remains on track.

EU27 Member States should also improve and nudge extended producer responsibility (EPR) schemes. The adoption of eco-modulation of fees that incentivizes producers to pay lower prices for highly recyclable packaging should be uniform, so that producers have a clear long-term economic advantage to designing for recyclability. The flexibility of this signal provides a balanced economic message in the absence of short-term macroeconomic volatility that would otherwise reduce the incentive to design in a circular manner.

5.2.4 Infrastructure Financing and Public-Private Cooperation

Innovative infrastructure financing models should be made easier to implement through EU action to meet the 2030 recycling targets. This includes promoting Public-Private Partnerships (PPPs) to reduce the costs of large waste-processing factories by providing private funding. The adoption of sustainable finance instruments such as green bonds to finance the shift towards high-tech solutions for recovery should be promoted. The EU27 can also further boost public-private cooperation to more efficiently use resources and accelerate the uptake of the technology needed for sustainable solutions.

5.3 Contributions to the Field

5.3.1 Contribution to Environmental Economics and Circular Economy Literature

The thesis represents a new avenue in the field of environmental economics, examining the relationship between inflation and waste circularity, a parameter that is not commonly taken into account in environmental studies. The research also suggests that socio-economic factors, such as education and unemployment, are important correlates of recycling performance and deserve greater attention in the circular economy literature. It presents an empirical analysis of environmental performance during the early 2020s inflationary shock, recognizing the limitations of macro-level panel analysis, while also pointing to the resilience of European sustainability transitions.

5.3.2 Contribution to Sustainability Transitions Literature

This study adds to the body of research on sustainability transitions by analyzing the ‘circularity divide' in the EU. The study shows that socio-economic capacity is a key determinant of environmental convergence, underscoring the importance of a more in-depth understanding of how socio-economic conditions affect the effectiveness of sustainability policies. A discussion of ‘decoupling' economic growth from environmental degradation raises the question of whether macroeconomic conditions and national structural capacities can affect the effectiveness of sustainability transitions.

5.3.3 Contribution to Macro-Panel Research and EU Policy Debate

On the methodological side, the study is important for the EU27 literature because it uses a fixed-effects panel approach to separate unobserved time-invariant factors (such as

environmental cultures and historical institutional capacities) from the analysis. The additional depth and dimension to the macro-panel research is also provided by the use of a non-balanced panel of 375 observations, suggesting that socio-economic stability is an important determinant of policy effectiveness.

Last but not least, this research brings a contribution to the policy debate of the EU on a circular economy on the basis of empirical evidence for context-specific and macro-resilient circular economy strategies. It highlights the relevance of considering both macroeconomic and socio-economic conditions when analyzing municipal waste recycling performance across EU Member States. The findings suggest that structural socio-economic factors may play a more important role than short-term inflationary fluctuations in explaining differences in recycling performance.

5.4 Limitations and Future Research Directions

While the study has contributed to the research literature, certain limitations should guide future academic research. The fixed effects specification accounts for a significant share of the variation in recycling performance, but unobservables can still affect recycling outcomes at the EU27 level. However, other factors such as the quality of the local governance system, cultural attitudes towards waste, and the actual design of the local waste collection system need to be explored at a more granular level.

5.4.1 Expanding the Data and Methodological Scope

Future studies can use more detailed, municipal data to reflect local policy success and the effect of interregional economic differences. In this instance, a country-level analysis is strong but may mask important differences across countries in infrastructure and policy

implementation. Furthermore, other econometric models could be used to account for potential endogeneity, such as Dynamic panel models (GMM), as well as for cross-country spillover effects, such as Spatial econometrics.

Further studies beyond 2023 would be useful to determine if the energy crisis-induced inflationary shocks had long-term or short-term impacts on recycling systems. The more information that becomes available, the clearer it will be if the inflationary shocks caused an "eventual" change in recycling markets or were only short-term "interruption" events.

5.4.2 Behavioral Economics and Sectoral Recycling Analysis

The application of behavioral economics in macro panel studies could help understand how inflationary expectations and economic concerns affect households' waste separation behavior.

It is important to comprehend the psychological effects of macroeconomic instability to create effective public awareness campaigns.

A sectoral recycling analysis (which looks at the effects of macroeconomic shocks on different materials (plastic, glass, paper, and metals)) may also provide more specific policy guidance.

Comparative studies with countries outside the EU can also be used to assess whether the findings of this study reflect the European regulatory context or a global trend.

Studying the relationship between inflation and recycling cross-culturally would be very interesting, as it would allow exploration of the influence of various regimes on this relationship.

5.5 Final Concluding Remarks: Toward a Resilient and Sustainable Future

The shift towards a circular economy is one of the challenges the European Union is facing and implies a break with the value of resources. This thesis examined whether macroeconomic conditions, particularly inflation, were associated with municipal waste recycling performance across the EU27 countries.

Policy action is needed to ensure a resilient circular economy that is sound and supports the EU Green Deal and climate neutrality, despite macroeconomic uncertainty. This needs differentiated regional policy, institutional development and technological innovation to build recycling systems' resilience in times of economic instability. Incorporating considerations of macroeconomic resilience into circular economy strategies may contribute to more sustainable and adaptive policy frameworks across the EU27.

The empirical results suggest that municipal waste recycling performance is more strongly associated with structural socio-economic factors than with short-term inflationary fluctuations. In particular, education attainment is positively associated with recycling performance, while unemployment is negatively associated with it. These findings highlight the importance of long-term socio-economic conditions in shaping recycling outcomes across EU Member States.

The absence of a statistically significant relationship between inflation and recycling rates does not imply that macroeconomic conditions are irrelevant. Rather, the results indicate that short-term inflationary changes were not directly associated with municipal waste recycling performance once country-specific characteristics and control variables were considered.

The findings suggest that policy approaches combining environmental objectives with broader socio-economic considerations may contribute to improved municipal waste recycling performance across EU Member States. Acknowledging the diversity of the Member States' structures can contribute to the effectiveness and equity of sustainability strategies. The shift towards climate neutrality is a complex process, but a macro-resilient approach could support the European Union's long-term sustainability and circular economy goals. The results should be interpreted with caution because recycling rate represents only one dimension of circular economy performance. Future research could examine alternative circular economy indicators and explore the role of common EU-wide shocks using additional robustness analyses.

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Declaration on the Use of Artificial Intelligence (AI) Tools

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Degree Programme: Sustainable Finance

Title of the Thesis: Inflationary Pressure and Municipal Waste Recycling Performance: Evidence from EU27 Recycling Systems (2010–2023)

Supervisor: Prof. Diana BARRO

DECLARES

☐ that he/she has NOT used generative artificial intelligence technologies to support various aspects of the research and writing of the final paper/degree thesis;

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