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FINAL REPORT //

Indicators on a Circular Economy

CIRCTER update

Report // 29 November 2024

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Coordination:
TECNALIA

Authors
Marco Bianchi, Jorge Ortigosa, TECNALIA; Carlos Tapia, Kamila Dzhavatova, Nordregio

Technical Support
Martin Gauk, ESPON EGTC

Advisory group
Marjan van Herwijnen, Martin Gauk, ESPON EGTC; Philipp Gareis, Sina Redlich, BBSR

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This document is a final report.

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The final version of the report will be published as soon as approved.

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Abbreviations

CE	Circular Economy
CF	Consumption footprint
DE	Domestic extraction
DMC	Domestic material consumption
EC	European Commission
EF	Environmental Footprint
EU	European Union
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GVA	Gross Value Added
LCA	Life Cycle Assessment
MF	Material footprint
OLS	Ordinary Least Squares
PPS	Purchasing power standards
RMC	Raw material consumption
RME	Raw Materials Equivalent
RP	Resource productivity

Executive Summary

Transitioning to a circular economy is a key strategy for achieving climate neutrality, as it directly addresses the environmental impacts due to material use and waste generation. In a circular economy, resources are utilised more sustainably by designing products to last longer, promoting reuse, and prioritising recycling over disposal. This shift reduces the demand for new materials, thus lowering the need for resource extraction, production, and transportation—all of which contribute significantly to greenhouse gas emissions. By minimising the volume of materials entering and exiting the economy, a circular economy curbs emissions associated with these activities, directly supporting efforts to mitigate climate change.

Monitoring progress towards this transition is essential for assessing the effectiveness of circular economy practices and identifying areas for improvement. In January 2018, the European Commission adopted the first EU monitoring framework for the circular economy, aimed at tracking the progress of the EU and the Member States. Following the launch of the new circular economy action plan for a cleaner and more competitive Europe, a revised framework has been adopted to capture the circular economy focus areas and the interlinkages between circularity, climate neutrality and the 'zero pollution' ambition. However, the EU monitoring system largely functions at the national or EU-aggregated level, limiting the granularity of insights available to policymakers working within diverse regional realms.

In this context, the former CIRCTER project (2017-2019) achieved a significant milestone in overcoming data limitations by creating a comprehensive and harmonised dataset on circular economy indicators at the regional NUTS 2 level. This was made possible through advanced downscaling techniques, which modelled the relationships between circular economy indicators and their drivers, leveraging these relationships to regionalise national indicators and provide insights at a more granular territorial scale.

This CIRCTER update revises key circular economy indicators, equipping academia and policymakers with timely and detailed data to support the design of targeted, place-based strategies for climate-neutral development across Europe. The updated framework includes:

- **Granular Data**: Indicators are provided at the regional NUTS 3 level, offering higher resolution insights to address regional disparities and specific needs.
- **Extended Time Series**: Data spans from 2006 to 2023, enabling long-term trend analysis and the evaluation of progress over nearly two decades.
- **New Footprint Indicators**: Includes material footprint and consumption footprint, capturing the environmental impacts of resource use and consumption across regions.

CIRCTER update - Indicators overview
Domestic material consumption
Resource productivity
Domestic extraction
Material imports dependency
Total waste generation, excluding major mineral waste
Waste intensity
Total waste generated by households
Food waste
Generation of municipal waste
Material footprint
Consumption footprint

Key findings show that regions across Europe are progressing toward a circular economy at varying speeds and directions. Urban areas, with their less material-intensive tertiary sectors, are generally better positioned for economic dematerialization compared to rural and intermediate regions. However, some material-intensive regions are making significant progress in narrowing the resource efficiency gap.

Waste reduction remains a greater challenge. While minor gains have been observed relative to economic growth, decoupling economic expansion from waste production is still elusive. Urban areas bear a higher share of waste-related impacts due to dense populations and concentrated consumption.

The analysis also highlights the distinct roles and challenges of urban and rural areas in the circular economy. Rural regions, as primary suppliers of raw materials, bear the environmental impacts of extraction and processing, while urban areas benefit from downstream consumption. This imbalance can be addressed by fostering interregional circular supply chains that connect industrial producers with urban consumers. Policies should promote the reintegration of urban waste streams back into the economy. Strengthening these reciprocal exchanges can reduce environmental impacts and ensure equitable economic and ecological benefits, fostering an inclusive and sustainable circular economy.

1 Introduction

The transition to a circular economy is essential for achieving climate-neutral territories by decoupling economic growth from resource depletion. This shift reduces material extraction and consumption, which in turn helps to mitigate greenhouse gas emissions. Monitoring progress towards this transition is essential for assessing the effectiveness of circular economy practices and identifying areas for improvement. In this line, the European Commission (EC) has advanced its circular economy monitoring framework, which now includes a new thematic area, "Global sustainability and resilience," along with indicators such as consumption footprint and material import dependency. However, the EU monitoring system largely functions at the national or EU-aggregated level, limiting the granularity of insights available to policymakers working within diverse regional contexts.

The former CIRCTER project[1] (2017-2019) achieved a significant milestone in overcoming data limitations by creating a comprehensive and harmonised dataset on circular economy indicators at the regional NUTS 2 level for years 2006 and 2014. This was made possible through advanced downscaling techniques, which modelled the relationships between circular economy indicators and their drivers, leveraging these relationships to regionalise national indicators and provide insights at a more granular territorial scale.

A decade has passed since the last data points, underscoring the need for refreshed information that reflects the current state of regional circular economy efforts. The CIRCTER update aims to revise key circular economy indicators, equipping policymakers with timely and detailed data to support the design of targeted, place-based strategies for climate-neutral development across Europe.

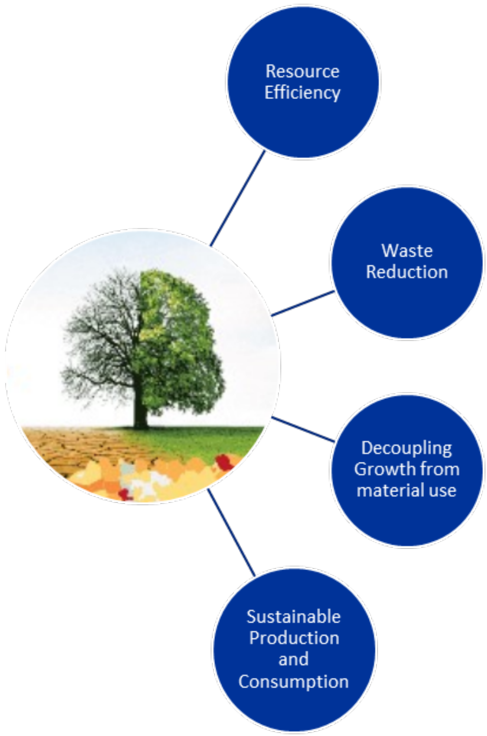
1.1 Background and context

Climate change is one of the most urgent challenges of our time, with the European Union recognising it as a top priority. Scientific evidence shows that greenhouse gas (GHG) emissions have already increased global temperatures by approximately 1.1°C since the late 19th century, and projections indicate further warming of 1.5°C or more in the coming decades without strong intervention. In response, the EC has set an ambitious goal: achieving climate-neutral territories across Europe. This objective involves reaching net-zero GHG emissions by balancing the levels of emissions produced with those removed or offset.

Achieving climate neutrality requires systemic changes across society and the economy, with a focus on sustainable practices that reduce resource consumption and environmental impact. A transition to a circular economy is central to this goal, as it seeks to decouple economic growth from resource depletion. In a circular economy, resources are utilised more sustainably by designing products to last longer, promoting reuse, and prioritising recycling over disposal. This shift reduces the demand for new materials, thus lowering the need for resource extraction, production, and transportation—all of which contribute significantly to GHG emissions.

By minimising the volume of materials entering and exiting the economy, a circular economy curbs emissions associated with these activities, directly supporting efforts to mitigate climate change.

Figure 1: How circular economy support climate neutral territories



[1] https://archive.espon.eu/circular-economy

Monitoring progress towards this transition is essential for assessing the effectiveness of circular economy practices and identifying areas for improvement. In January 2018, the EC adopted the first EU monitoring framework for the circular economy, aimed at tracking the progress of the EU and the Member States. Following the launch of the new circular economy action plan for a cleaner and more competitive Europe, a revised framework has been adopted to capture the circular economy focus areas and the interlinkages between circularity, climate neutrality and the 'zero pollution' ambition. The enhanced framework includes the thematic area of "Global sustainability and resilience," with new indicators like consumption footprint and material import dependency.

However, the EU framework largely focuses on national and EU-level data, leaving a gap at the regional level. This data gap poses challenges for regional and local policymakers, who operate in diverse socio-economic contexts and require specific, harmonised data to tailor circular economy strategies effectively.

The CIRCTER project (2017–2019) addressed the need for granular regional data on circular economy progress by developing a downscaling methodology that generated a harmonised dataset for European regions in 2006 and 2014. This downscaling approach, or spatial disaggregation, transforms large-scale data into region-specific insights, facilitating more targeted and territorially tailored analyses. CIRCTER's method is one of the few existing tools for producing sub-national material and waste flow data that covers all European regions while ensuring consistency across regions over time and recognising territorial diversity (Li et al., 2024[2]). The dataset and method also enabled comparative regional analyses that were previously unfeasible (Bianchi et al. 2023[3]).

Since CIRCTER's data generation for 2014, national circular economy indicators have evolved, and new indicators have been integrated into the EU's monitoring framework. This underscores the need to refresh the CIRCTER indicators and the downscaling models, incorporating the latest data to provide up-to-date insights on circular economy progress at the regional level across Europe.

1.2 Objectives of the study

This study provides critical insights to support the European Union's climate-neutrality ambitions by delivering granular, region-specific data that enables policymakers to monitor and analyse progress toward a circular economy at the regional level.

A set of circular economy indicators focusing on key aspects such as material consumption, waste generation and consumption footprint are provided at the NUTS 3 regional level, filling important gaps in the EU's monitoring framework. These new indicators offer deeper insights into the progress of European regions towards circular economy goals. The full list of indicators is presented in Chapter 2, along with an overview on the methodological approach applied.

Chapter 3 summarises key findings. First, it describes material consumption trends. By combining resource use with economic growth, the study also offers a lens on current decoupling patterns, which is essential for understanding the shift toward more sustainable, resource-efficient economic models. Waste regional trends are analysed in section 3.2. Tracking waste indicators, including total municipal waste and food waste, highlights areas for reducing waste at its source, which is critical for reducing landfill use, cutting emissions associated with waste management, and fostering sustainable consumption. Material and consumption footprints are addressed in section 3.3. These indicators capture the broader impact of a region's material usage and consumption levels, accounting for the entire life cycle of goods consumed. These indicators provide a holistic view of how consumption drives environmental impact, offering valuable insights to help regions address resource dependencies and align their consumption with related sustainability targets.

In summary, the new indicators explored in this study represent both direct and indirect enablers of the net-zero emissions objective. By combining these regional indicators with existing climate and sustainability data, the study not only provides a comprehensive assessment of regional progress toward a circular economy but also examines how circular territories can contribute to achieving climate neutrality.

[2] Li, S., Xu, C., Su, M., Lu, W., Chen, Q., Huang, Q., & Teng, Y. (2024). Downscaling of environmental indicators: A review. Science of The Total Environment, 170251

[3] Bianchi, M., Cordella, M., & Menger, P. (2023). Regional monitoring frameworks for the circular economy: implications from a territorial perspective. European Planning Studies, 31(1), 36-54

2 Methodology

This Chapter first presents the circular economy indicators regionalised in the project, followed by an overview of the downscaling methodology and, finally, it concludes with a specification of the description of the models applied for each indicator.

2.1 Indicators

Table 1 presents the list of the indicators downscaled at NUTS 3 level, together with their definitions and relevance for the circular economy.

Indicator	Definition
Domestic Material Consumption (DMC)	The DMC indicator measures the total amount of materials (tonnes) directly used by an economy and is defined as the annual quantity of raw materials extracted from the domestic territory, plus all physical imports minus all physical exports. It is important to note that the term "consumption" as used in DMC denotes apparent consumption and not final consumption. In fact, DMC does not include "hidden" flows related to imports and exports of raw materials and products.
Resource productivity (RP)	The RP indicator is part of the EU circular economy monitoring framework, and it monitors progress on the thematic area of 'production and consumption'. RP represents the economic value generated per unit of material consumed and it is calculated as the ration of GDP/DMC. A higher RP indicates that an economy is generating more economic value while using fewer resources, which is a desirable outcome from a sustainability perspective. RP analysis over time provides insights into whether decoupling between the use of natural resources and economic growth is taking place.
Domestic extraction (DE)	The DE indicator measures the input from the natural environment to be used in the economy. DE is the annual amount of raw material (except for water and air) extracted from the natural environment. The ratio DE/DMC can inform on material import dependency, i.e. the extent to which an economy relies on domestic resources to meet its materials needs.
Material footprint (MF)	The MF indicator is part of the EU circular economy monitoring framework and it monitors progress on the thematic area of 'production and consumption'. MF, also referred to as raw material consumption (RMC), represents the global demand for the extraction of materials induced by consumption of goods and services within a geographical reference area. MF indicators are very relevant in the current policy context as they give visibility to the EU responsibility for environmental pressures elsewhere as consequence of products exported to the EU.
Consumption footprint (CF)	The CF indicator is part of the EU circular economy monitoring framework and it monitors progress on the thematic area of 'global sustainability and resilience'. CF addresses domestic and spill-over/transboundary environmental impacts through imported goods. Current trends of increasing consumption intensities and changes of patterns among areas of consumption result in an increasing EU consumption footprint. Circular economy strategies, changing consumption patterns and the environmental profile of products might decrease EU's consumption footprint.
Total waste generation,	Total waste generated by all economic activities and households, excluding mineral and soil waste[4]

[4]Over 90% of waste comes from the mining and construction sectors, which tend to fluctuate significantly over time. By excluding major mineral wastes, this indicator provides a clearer view of general waste trends than total waste statistics.

excluding major mineral waste	
Generation of waste excluding major mineral wastes per GDP unit	The indicator is part of the EU circular economy monitoring framework and it monitors progress on the thematic area of 'production and consumption'. A circular economy aims at decreasing waste generation while maintaining or increasing economic output. Comparing waste generated to GDP reflects the waste intensity of the economy and provides a measure of 'eco-efficiency'. Observation of its change from year to year permits to assess whether the economy is able to produce more wealth while at same time generating less waste.
Total waste generated by households	The indicator covers the waste produced locally by households' activities, including both hazardous and non-hazardous waste; this category also includes mineral wastes or soil.
Food waste	The indicator is part of the EU circular economy monitoring framework and it monitors progress on the thematic area of 'production and consumption'. The indicator measures food waste generated in the production, manufacturing, distribution, food services and households' stages of the food supply chain. Under the EU's Farm to Fork Strategy, the Commission will propose legally binding targets to reduce food waste. These targets will help limit the food supply chain's impact on the environment and climate, thereby creating a more sustainable food system.
Generation of municipal waste	The indicator is part of the EU circular economy monitoring framework and it monitors progress on the thematic area of 'production and consumption'. In a more circular economy, the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of material waste is reduced quantitatively and improved qualitatively. Waste prevention is closely linked with improving manufacturing methods and influencing consumers to demand greener products and less packaging. Reducing the amount of waste generated is stated as the highest priority under the Waste Hierarchy established in the Waste Framework Directive (Article 4).

Table 1: Circular economy indicators downscaled at the regional NUTS 3 level

2.2 Overview of the downscaling methodology

The CIRCTER downscaling methodology follows three key steps: 1) OLS regression, 2) Optimisation, and 3) Extrapolation (Bianchi et al. 2020[5]). All the steps described have been carried out using R programming language.

2.2.1 Step 1: OLS Regression

The first step involves applying Ordinary Least Squares (OLS) regression to identify the best regression model for describing the behaviour of a circular economy indicator, Y_i, at the European country level. This involves selecting the most relevant explanatory variables and quantifying their relationship (i.e., elasticity) with the indicator.

To achieve this, 58 regional variables were analysed, spanning domains such as:

- **Economy**: Employment, gross value added, and gross fixed capital formation by economic activity.
- **Demography**: Population, population density, and household income, among others.
- **Productivity**: Labour productivity

The selection of explanatory variables for model definition is contingent upon their availability at both the country level and the regional (NUTS 3) level. Only variables consistently reported at these scales are considered, ensuring that the relationships identified during the global OLS regression step can be effectively applied during the extrapolation step.

[5] Bianchi, M., Tapia, C., & del Valle, I. (2020). Monitoring domestic material consumption at lower territorial levels: A novel data downscaling method. Journal of Industrial Ecology, 24(5), 1074-1087.

The output of this step includes the global regression parameters, $\boldsymbol{\beta_{gn}}$, which quantify the relationships between the indicator and its explanatory variables XN at country level i.

$$Y_i = const + \boldsymbol{\beta_{g1}} X1_i + \boldsymbol{\beta_{g2}} X2_i + \cdots + \boldsymbol{\beta_{gn}} XN_i + e$$

Additionally, this step provides insights into the magnitude of socio-economic drivers and territorial factors influencing circular economy dynamics (see section 2.3).

2.2.2 Step 2: Optimisation

The estimated parameters $\boldsymbol{\beta_g}$ from the OLS regression step are global, meaning they apply uniformly across all countries without accounting for country-specific variations. Applying these global parameters directly would result in unrealistic regional estimates.

To address this, the regression coefficients of the explanatory variables obtained in the global model are optimised for each country by means of an augmented Lagrange multiplier method. This approach allows to find the optimal values of the regression coefficients under an equality constraint, and hence adjust the global parameters to account for country-specific socio-economic and spatial regimes[6].

The country-specific parameters ($\boldsymbol{\beta_{cs}}$) are calculated by the algorithm as follows:

$$L(\beta_g, \lambda, \rho) = f(x) + \sum_{i=1}^{m} \lambda_i \, g_i(x) + \frac{\rho}{2} \sum_{i=1}^{m} g_i\,(x)^2 \qquad (1)$$

Subject to:

$$l_{\beta_g} \leq \beta_g \leq u_{\beta_g}$$

Where:

- $L(\beta_g, \lambda, \rho)$ is the augmented Lagrangian function.
- β_g is the vector of regression coefficients in the global econometric model.
- $f(x)$ is the objective function to be minimised or maximised, using the regression coefficients in the global model.
- λ_i are the Lagrange multipliers for the equality constraints.
- ρ is the penalty parameter.
- $g_i(x)$ represents the equality constraint functions.
- $[l_{\beta_g}, u_{\beta_g}]$ are the lower and upper confidence intervals bound for β_g, based on standard errors.

The augmented Lagrange method iterates between updating the variables β_g, the Lagrange multipliers λ, and the penalty parameter ρ to find the optimal solution while satisfying the constraints. This process allows the parameters β_g to vary within their confidence intervals to align the estimated indicator value with the observed country-level value. In doing so, the resulting parameters, β_{cs}, better capture country-specific territorial contexts.

2.2.3 Step 3: Extrapolation

The final step applies the country-specific parameters, β_{cs}, to regional-level explanatory variables, XN_j, observed at the NUTS 3 level, enabling the generation of regional indicators. The relationship is expressed mathematically as:

$$Y_j = const + (\beta_{cs1})_i \, X1_j + (\beta_{cs2})_i \; X2_j + \cdots + (\beta_{csn})_i \; XN_j + e$$

[6] Country-specific profiles refer to the notion of metabolic regimes, i.e. the structural coupling of a socioeconomic system with the natural environment from which resources are drawn. For more information refer to Bianchi, M., Tapia, C., & del Valle, I. (2020). Monitoring domestic material consumption at lower territorial levels: A novel data downscaling method. Journal of Industrial Ecology, 24(5), 1074-1087.

Where:

- $i = 1,2, \dots n$: represents the country.
- $j = 1,2, \dots m$: represents the regions within each country.

This substitution ensures that the explanatory variables measured at the NUTS 3 level account for regional contexts, allowing the model to produce granular, region-specific indicators.

Robustness check: Before the final reconciliation, the robustness of the regional estimates is assessed by analysing the deviation between the sum of regional estimates and the observed national value for each country. If the deviation is below 20%, the regional estimates are considered of high quality and validated.

If the deviation exceeds 20%, the methodology returns to Step 1 to refine the regression model by identifying alternative combinations of explanatory variables. This iterative process continues until a model satisfies the robustness criterion or until all possible combinations of explanatory variables are exhausted. In cases where no model meets the threshold, the "least-worst" model is used, and this limitation is explicitly indicated in the results.

Reconciliation: Once the regional estimates are generated, they are reconciled to ensure consistency with national figures. Reconciliation adjusts regional indicators, so their aggregated values match the observed national totals, maintaining coherence across scales. Mathematically:

$$\tilde{y}_j = \frac{\hat{y}_i * Y}{\sum_{i=0}^{n} \hat{y}_i}$$

Where:

- $\tilde{y}_j$: Final rescaled regional indicator.
- $\hat{y}_i$: Initial regional estimate from the extrapolation step.
- Y: Observed national value.

  $\sum_{i=0}^{n} \hat{y}_i$: Sum of initial regional estimates for all regions in the country.

This reconciliation ensures the regional indicators are proportionally adjusted to align with the national totals, maintaining consistency and reliability of the results.

A detailed description of the downscaling approach, including the procedures for model selection and variable identification, is provided in the methodological Annex. This annex also includes deviation plots for the indicators, offering further insights into the robustness and accuracy of the regional estimates relative to observed national values for each country.

2.3 Description of models used

Table 2 presents the models used to downscale the CIRCTER indicators, i.e. the results from step 1 OLS regression of the downscaling methodology. Since the variables in the models were log-transformed prior to estimation, the coefficients shown in Table 2 should be interpreted as elasticities. That is, a1% increase in the explanatory variable corresponds to a proportional percentage change in the dependent variable (i.e., the respective circular indicator of interest) as indicated by the coefficient value. This approach allows for a clearer understanding of the relative relationships between variables within the downscaling framework.

The model used for material consumption indicators, specifically domestic material consumption (DMC) and domestic extraction (DE), identified labour productivity as a key explanatory variable for both. The negative relationship observed between material consumption/extraction and productivity likely reflects differences in economic structure and underlying economic activities. Regions with high labour productivity often have a greater presence of high value-added sectors, such as services requiring specialised skills, expertise, or technology, which are typically less material-intensive. Conversely, areas with lower productivity tend to rely more on material-intensive activities like extraction or manufacturing. This economic composition explains why regions with higher productivity levels generally exhibit lower material consumption or extraction rates even if exceptions may occur.

For DMC, additional drivers such as GDP and land area emerged as significant factors, reflecting the link between material consumption and the scale of economic activity and territorial extent. These variables effectively capture the overall size and economic capacity of a region.

In contrast, DE models incorporated variables such as population density and gross value added in NACE[7] activities "B-E", which include mining and quarrying, manufacturing, electricity, gas, and water supply. These indicators relate directly to the availability and exploitation of natural resources in specific regions. While these factors proved robust across most European regions, they occasionally generated outliers. For instance, Norway exhibited a high deviation in the DE model. This deviation is largely attributed to its unique characteristics, including exceptionally low population density and a high industrial gross value added, driven primarily by oil production. These distinctive traits are not fully captured by the explanatory variables used in the model, highlighting the limitations of generalising across diverse territorial contexts.

For material footprint, total employment emerged as a strong predictor, reflecting the dual role it plays in shaping material demand. On one hand, it indicates the scale of economic activity in a region, directly correlating with material consumption. On the other hand, it is also a proxy for household income and purchasing power, which drives demand for goods and services. Unlike population, which includes inactive individuals with reduced purchasing capacity, total employment provides a more targeted measure of economic activity and its material implications.

In addition to total employment, the share of employment in the construction sector was identified as a significant explanatory factor. This relationship underscores the pivotal role of construction, a sector responsible for approximately 50% of total material use in an economy. Regions with a higher share of employment in construction typically exhibit a larger material footprint, driven by the substantial material demands for infrastructure and building projects. These findings highlight the importance of sectoral composition in determining material consumption patterns at the regional level.

In the case of consumption footprint, the key predictor is total population. Population size is a direct driver of material consumption because more people mean more demand for goods, services, and infrastructure. The more people living in a territory, the more raw materials are required for housing, transportation, energy, and consumer goods. The effect of total population size is nuanced by nominal labour productivity, which proxies income levels and purchase power of households in each region. When it comes to modelling consumption footprint, labour productivity yielded more stable results than other indicators proxying household wealth, such as GDP or GVA per capita. Finally, gross fixed capital formation (GFCF) was included to account for how much of the new value added in an economy is invested and therefore not consumed, implicitly controlling for firm and corporate consumption in a given economy.

The development of regression models for waste-related indicators proved to be particularly challenging, largely due to the complexities and limitations inherent to these statistics and the variability in data quality across countries. Differences in national accounting practices and periodic updates to waste reporting methodologies raise concerns about the harmonisation of waste statistics, especially in cross-country comparisons. Additionally, the multifaceted nature of waste generation, influenced by diverse economic, social, and cultural factors, complicates the identification of universally robust explanatory variables.

Despite these challenges, GDP per capita and population consistently emerged as statistically significant predictors for most waste indicators across the years examined. This consistency underscores the relevance of GDP per capita as a proxy for consumption intensity and population as a measure of scale. Both variables demonstrated a positive relationship with waste generation. Population showed an elasticity close to 1, meaning a 1% increase in population generally leads to a 1% increase in waste generation. GDP per capita exhibited a smaller elasticity, around 0.2%, reflecting the influence of economic output per person on living standards and consumption patterns. As GDP per capita rises, increased demand for goods and services typically results in higher household waste due to greater reliance on disposable items and packaging.

An exception to this general pattern was observed for municipal waste generation, where employment in NACE G-I (covering retail, hospitality, and related sectors) outperformed population as a predictor. This relationship is likely due to the significant amount of waste generated by these sectors, which is often classified as municipal waste. Retail and hospitality activities, for example, produce substantial volumes of packaging, food waste, and other disposable materials, making this sector a key driver of municipal waste generation, particularly in urban and commercial areas.

[7] The term NACE is derived from the French "Nomenclature statistique des activités économiques dans la Communauté européenne" - Statistical classification of economic activities in the European Community

Indicator	Unit	Explanatory factors	Unit	Source	Coefficient Value[8]	Rationale
Domestic material consumption (DMC)	Thousand Tonnes	GDP	Million PPS	ARDECO: SUVGD	0.739 (0.062)***	GDP represents the total economic output of a country and is closely linked to consumption patterns and resource use. As GDP increases, material consumption rises due to greater demand for goods and services. Larger economies tend to consume more resources for infrastructure development, industrial production, and overall consumption, reflecting their scale and economic activity.
		Total land	Square kilometre	EUROSTAT: *reg_area3*	0.205 (0.056)**	The physical size of a region influences its resource consumption patterns, with land-extensive economies naturally exhibiting higher absolute DMC values. In addition, regions with extensive land areas frequently host activities such as agriculture, forestry, and mining, which inherently require significant resource inputs and result in higher material consumption.
		Nominal Labor Productivity per person employed	Million EUR 2015	ARDECO: *SUVGDE*	-0.665 (0.207)**	Labour productivity is negatively related to material consumption, as higher productivity tends to be related to knowledge-intensive industries or high-value services, which produce more value per unit of material consumed. Contrarywise, lower labour productivity is usually associated to material-intensive sectors, such as agriculture, mining, or manufacturing.
Domestic extraction (DE)	Thousand Tonnes	Population density	Persons per square km	Own elaboration: Population (ARDECO: SNPTD) /total land (EUROSTAT: *reg_area3)*	-0.298 (0.077)***	Population density is a key explanatory factor for domestic material extraction, as regions with lower population densities are often dominated by resource-intensive activities such as agriculture, mining, and forestry. These activities require extensive land use, making them more prevalent in sparsely populated areas. Conversely, densely populated regions allocate most of their land to urban infrastructure and services, leading to a reduced emphasis on local material extraction.
		Labor productivity	Nominal Labour Productivity per person employed in PPS	ARDECO: *SUVGDE*	-1.319 (0.278)***	Labour productivity is negatively related to domestic extraction, as higher productivity tends to relate to knowledge-intensive industries or high-value services, which produce more value per unit of material consumed. Contrarywise, lower labour productivity is usually associated to material-intensive extractive sectors, such as agriculture, and/or mining.

[8] Coefficient values refer to the latest year available.

		Gross Value Added (GVA) in NACE B-E	Million PPS	ARDECO: *SUVGZ*	0.937 (0.054)***	GVA is positively related to DE because resource-intensive sectors, such as those in NACE B-E (mining, manufacturing, and utilities), rely heavily on raw material inputs to generate economic output.
Consumption footprint (CF)	Index (single weighted score)	Average annual population	Number of persons	ARDECO: *SNPTD*	1.039 (< 2e-16) ***	Population is the primary predictor of material consumption. More people mean greater demand for goods, services, and infrastructure. Increased population levels drive total consumption, irrespective of economic status. As the number of people in a territory rises, the need for raw materials for housing, transportation, energy, and consumer goods also increases.
		Nominal Labor Productivity per person employed	Million EUR 2015	ARDECO: SUVGDE	0.676 (<2e-16) ***	The variable proxies economic output, income levels and purchase power in each region. As household income rises, households tend to consume more and the environmental footprint grows.
		Gross Fixed Capital Formation	Million EUR PPS	ARDECO: *RUIGT*	-0.072 (0.0162) *	GFCF indicates how much of the new value added in an economy is invested and therefore not directly consumed, hence moderating the effect of the previous variables on the final consumption footprint. The effect is small but still statistically significant at 5% significance level.
Material footprint (MF)	Thousand Tonnes	Total employment	Thousands of persons	ARDECO: *SNETD*	0.968 (0.054)	Total employment reflects the general economic activity and demand for materials across sectors. More employment typically correlates with higher production and consumption, thus increasing the material footprint.
		Construction employment share	Percentage	Own elaboration: Construction employment/ Total employment	0.792 (0.382) *	Construction employment share captures the influence of the construction sector, a major driver of material consumption since construction materials represent around 50% of the total material use in an economy. The higher the share of employment in construction, the larger the material footprint, given the sector's significant material demands for infrastructure and building projects.
Total waste generation, excluding major mineral waste	Tonnes	GDP per capita in Purchasing Power Standards	PPS/person	ARDECO: *SUVGDP*	0.122 (0.158)	GDP per capita is a measure of economic output per person and reflects living standards and consumption patterns. As GDP per capita increases, so does waste generation due to higher demand for goods and services, leading to more disposable items and packaging. This aligns with the idea that greater economic activity drives resource use and, consequently, waste production.

		Average annual population	Number of persons	ARDECO: *SNPTD*	1.053 (0.049) ***	Population is a key driver of waste generation, as more people directly lead to higher consumption of goods and services, resulting in increased waste production. The relationship is nearly proportional across all waste types.
Total waste generated by households	Tonnes	GDP per capita in Purchasing Power Standards	PPS/person	ARDECO: *SUVGDP*	0.228 (0.077) **	GDP per capita is a measure of economic output per person and reflects living standards and consumption patterns. As GDP per capita increases, so does household waste generation due to higher demand for goods and services, leading to more disposable items and packaging.
		Average annual population	Number of persons	ARDECO: *SNPTD*	0.997 (0.023) **	Population is a key driver of waste generation, as more people directly lead to higher consumption of goods and services, resulting in increased waste production. The relationship is nearly proportional across all waste types.
Food waste	Tonnes	GDP per capita in Purchasing Power Standards	PPS/person	ARDECO: *SUVGDP*	0.285 (0.180)	GDP per capita is a measure of economic output per person and reflects living standards and consumption patterns. As GDP per capita increases, food waste rises even more sharply due to higher purchasing power, over-purchasing, and stricter quality preferences. Wealthier economies also generate more food waste across production, retail, and household consumption.
		Average annual population	Number of persons	ARDECO: *SNPTD*	0.979 (0.045) ***	Population is a key driver of waste generation, as more people directly lead to higher consumption of goods and services, resulting in increased waste production. The relationship is nearly proportional across all waste types.
Generation of municipal waste	Thousand tonnes	GDP per capita in Purchasing Power Standards	PPS/person	ARDECO: *SUVGDP*	0.240 (0.103) *	GDP per capita is a measure of economic output per person and reflects living standards and consumption patterns. As GDP per capita increases, so does municipal waste generation due to higher demand for goods and services, leading to more disposable items and packaging.
		Employment in NACE G-I	Thousands of persons	ARDECO: *SNETZ*	1.006 (0.029)***	Employment in NACE G-I, which covers activities related to the sale of goods and services, is a key predictor of municipal waste generation, as the waste produced by economic activities in retail, hospitality, and similar sectors is generally classified as municipal waste.

Table 2: Models used to downscale the CIRCTER indicator

3 Results and key findings

The following sections summarise key results derived from the new data and their analysis. While the complete set of indicators, including absolute and per capita values, is available at https://www.espon.eu/projects/circter-update-indicators-circular-economy, this report focuses primarily on relativised indicators, expressed per capita or per unit of GDP. These metrics provide a more relatable and comparable perspective across countries and regions. Absolute values for indicators such as material consumption and waste generation are largely influenced by the size of a region's population and its economic scale. Consequently, regions with larger populations or economies tend to report higher absolute values. By contrast, normalising these indicators by population or GDP offers more meaningful insights into regional performance and disparities.

It is also important to note that the maps and analyses presented in this report use 2022 as the reference year, despite the availability of data for 2023 and earlier years. This choice reflects the fact that 2022 data were the most complete and reliable, whereas much of the 2023 data available from Eurostat remain provisional estimates. For further details and access to the full database, including the complete list of indicators and methodologies, readers can refer to the project website.

3.1 Material consumption patterns

3.1.1 Domestic material consumption

Domestic material consumption (DMC) measures the total amount of materials (in tonnes) directly used or consumed within a country's economy. It is a key indicator for monitoring the circular economy, as it tracks resource consumption over time. DMC is particularly relevant for assessing resource efficiency and exploring whether decoupling between GDP and material consumption is occurring, a fundamental goal of circular economy principles. By analysing DMC, policymakers can identify opportunities to optimise resource use and develop strategies to minimise the environmental impacts associated with extraction, processing, and consumption.

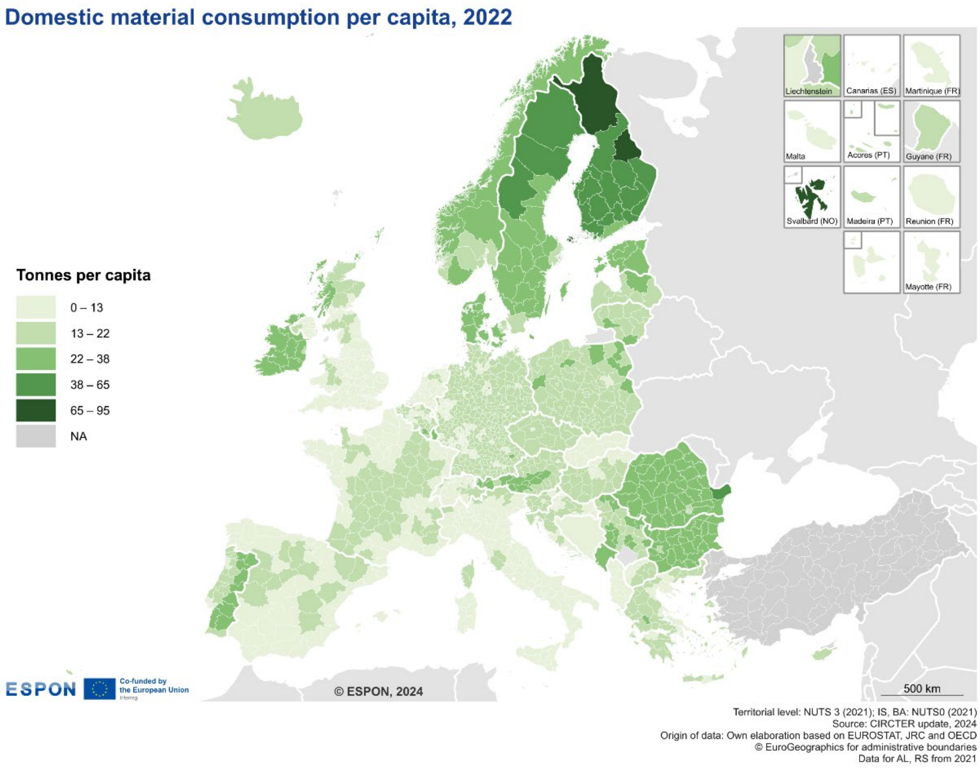
Map 1 shows DMC per capita, representing the average amount of materials consumed per person in each region. High DMC per capita values often signify intensive resource consumption, highlighting potential areas for policies that promote sustainable consumption and production patterns. These values are closely tied to the nature of regional economies. Regions with material-intensive, export-oriented economies—often reliant on primary and secondary activities such as agriculture, mining, or manufacturing—tend to exhibit higher DMC per capita. Conversely, regions dominated by tertiary sectors, such as services, generally show lower values.

This economic differentiation is evident in the territorial patterns displayed in Map 1. Regions with high DMC per capita are predominantly located in Nordic and Eastern Europe, as well as Ireland, Estonia and Denmark, and, to a lesser extent, parts of Portugal and Austria. In these areas, agricultural or mineral extraction activities are central to the regional economy, driving higher material consumption.

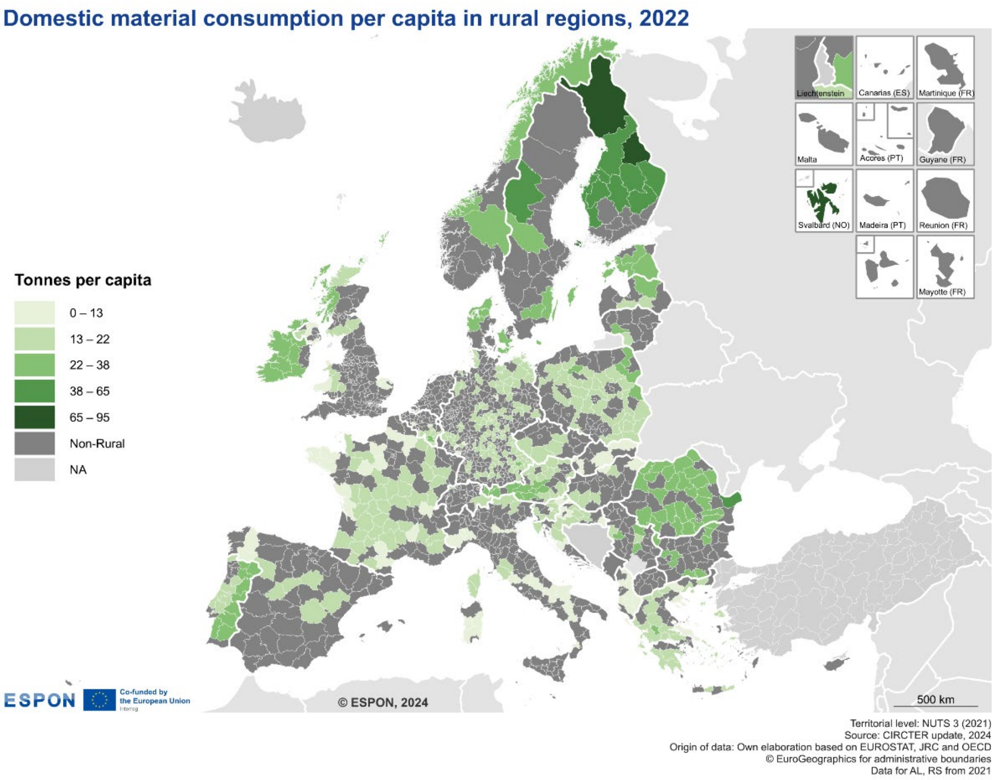
In general, the type of regional economy closely aligns with the region's territorial typology—whether rural, intermediate, or urban. Rural economies, often rich in natural resources such as agricultural products, minerals, and timber, exhibit the highest average DMC per capita values (20 tonnes). In contrast, urban areas, which are primarily focused on service sectors, have significantly lower DMC per capita values (10 tonnes). Falling in between, intermediate regions (15 tonnes) typically present a mix of activities, combining elements of both rural and urban economies.

From a material consumption perspective, rural regions, shown in Map 2, generally bear the burden of material extraction and raw material production. These resource-intensive activities drive higher DMC values in rural areas, even though the end-use of the extracted materials is predominantly concentrated in urban regions. While this dynamic highlights the critical role of rural areas in supporting broader economic systems, it also indicates the limitations of relying solely on DMC as an indicator for resource efficiency. This limitation arises from DMC's focus on direct consumption, which does not capture the entire lifecycle of goods, including their final use. Consequently, rural regions may appear to consume significantly more materials, even though much of this material is extracted and processed to support urban economies. To provide a more comprehensive understanding of the environmental impacts borne by different regions, it is necessary to complement DMC analysis with raw material consumption indicators such as the material footprint. This indicator, analysed in section 3.3, considers raw material use throughout the entire lifecycle of goods, offering a more balanced perspective on environmental burdens generated by material consumption.

Map 1: Domestic material consumption per capita (2022)



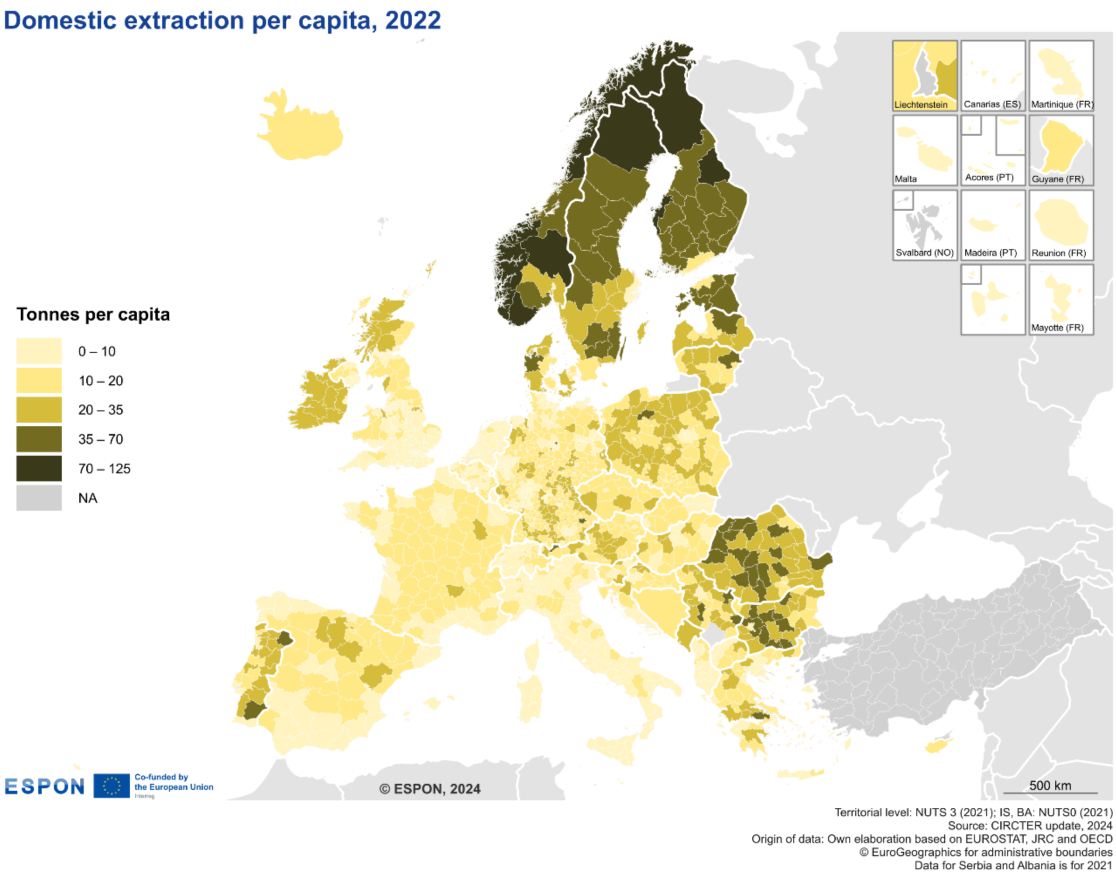
Map 2: Domestic material consumption per capita in rural regions (2022)



3.1.2 Domestic material extraction

In terms of domestic material extraction (DE), disparities across territorial typologies are, as expected, even more pronounced compared to DMC. On average, urban regions extract 6.4 tonnes per capita, while rural areas extract over three times as much, at 21 tonnes per capita. Map 3 shows that regions with the highest per capita natural resource extraction are located primarily in Nordic and Eastern countries, with some representation in Portugal. These spatial patterns largely reflect the distribution of natural endowments, such as fossil fuels, timber, and agricultural land, across the European territory.

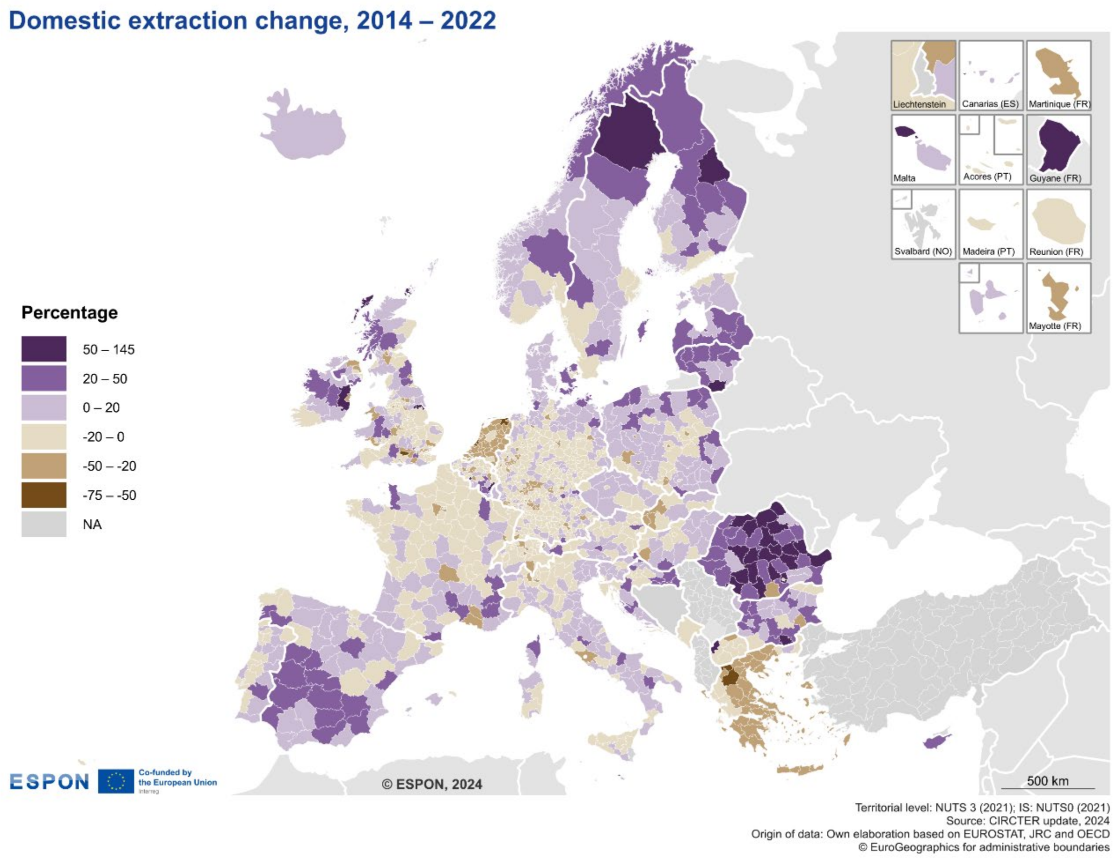
Map 3: Domestic material extraction per capita (2022)



From a temporal perspective, the rate of change in domestic extraction between 2014 and 2022, as shown in Map 4, reveals diverging trends across urban, rural, and intermediate regions. Urbanisation trends, characterised by increasing population concentration in cities, have driven a 12% reduction in domestic extraction in urban areas during this period. In contrast, rural regions experienced an increase of nearly 7%, while intermediate regions showed no significant change. This dynamic increasingly polarises final consumption zones from areas of material extraction and production of consumer goods, which are often the least populated regions. As we will explore further through additional indicators, including footprint and waste metrics, this spatial separation between the key actors in the value chain—producers and consumers—has significant strategic implications.

On the one hand, urban areas, as major centres of final consumption, are becoming concentrated hubs for waste generation, necessitating efficient waste management strategies to address the mounting pressures. On the other hand, the environmental impacts of primary material extraction and refinement, such as land degradation, water pollution, and biodiversity loss, are increasingly concentrated in less populated rural regions. This growing disconnection may complicate efforts to address environmental justice between regions and underscores the need for integrated approaches that consider the spatial distribution of environmental impacts across the entire lifecycle of materials and products.

Map 4: Domestic material extraction change (2014 - 2022)



3.1.3 Resource productivity and decupling patterns

Resource productivity (RP) measures how efficiently an economy generates economic value while minimising natural resource consumption. It reflects the economic value produced per unit of material consumed, with higher RP values indicating that an economy is producing more with fewer resources—a cornerstone of sustainability. Recognised as a key indicator of sustainable development, RP has been adopted by the European Union as a benchmark for policy evaluation[9], enabling Member States to monitor progress toward a more resource-efficient economy. RP is also a key component of the EU's Circular Economy monitoring framework[10], emphasising its role in advancing a regenerative and environmentally conscious economic model.

RP analysis over time provides insights into whether decoupling between the use of natural resources and economic growth is taking place. The term decoupling refers to breaking the link between an environmental and an economic variable. As defined by the Organisation for Economic Cooperation and Development[11], decoupling occurs when the growth rate of an environmental pressure (for example, DMC) is less than that of its economic driving force (for example, GDP) over a given period. Decoupling can be either absolute or relative. Absolute decoupling is said to occur when the environmental variable is stable or decreases while the economic driving force grows. Decoupling is said to be relative when the rate of change of the environmental variable is less than the rate of change of the economic variable.

The territorial distribution of RP, illustrated in Map 5, shows a similar regional dynamic to that of DMC per capita, with urban regions generally outperforming rural areas. Leading regions in RP performance include major urban centres such as London (United Kingdom), Paris and Hauts-de-Seine (France), Basel-Stadt

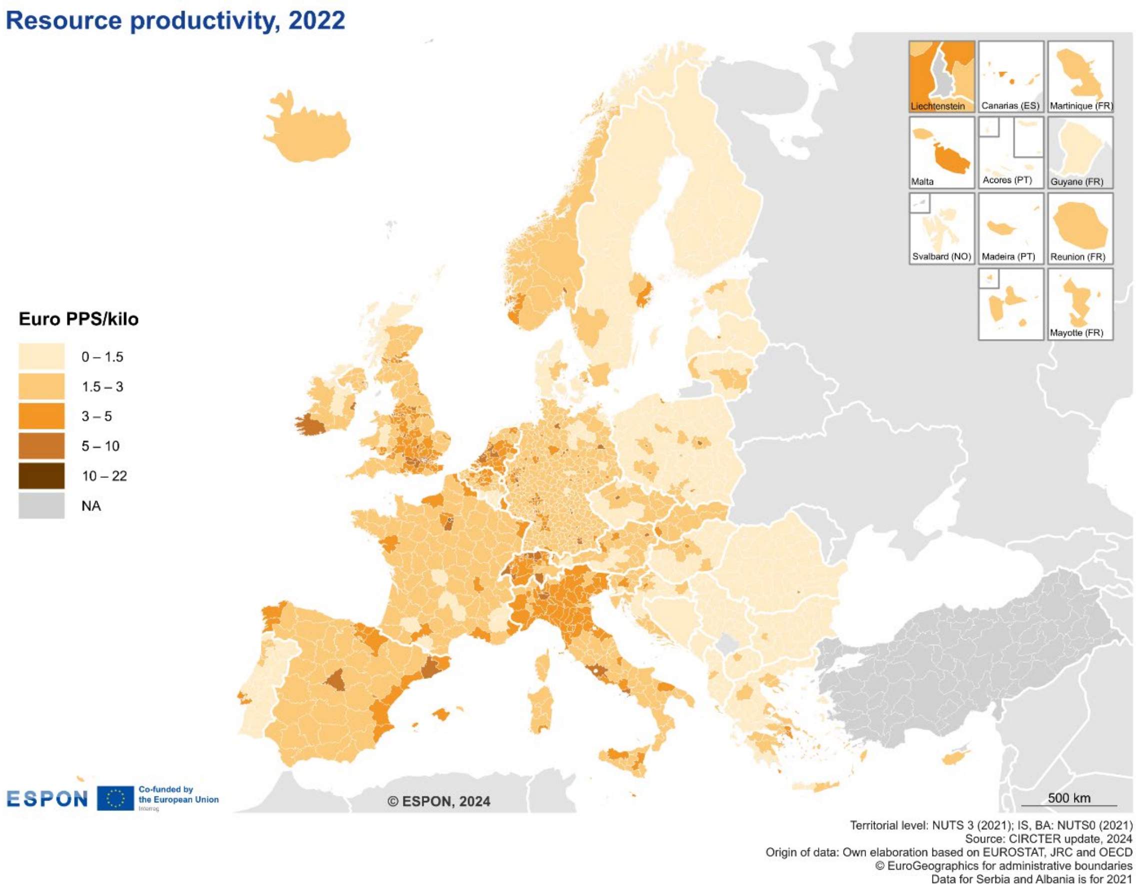
9 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Sustainable_development_indicator_(SDI)

10 https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework

11 OECD (2019), Waste Management and the Circular Economy in Selected OECD Countries: Evidence from Environmental Performance Reviews, OECD Environmental Performance Reviews, OECD Publishing, Paris, https://doi.org/10.1787/9789264309395-en.

(Switzerland), Milan (Italy), and Groot-Amsterdam (Netherlands). These regions exemplify the ability of urban economies to achieve high levels of efficiency in resource use, aligning with their strong focus on service-oriented and high added value activities.

Map 5: Resource productivity in Euro Purchasing Power Standards (PPS) (2022)



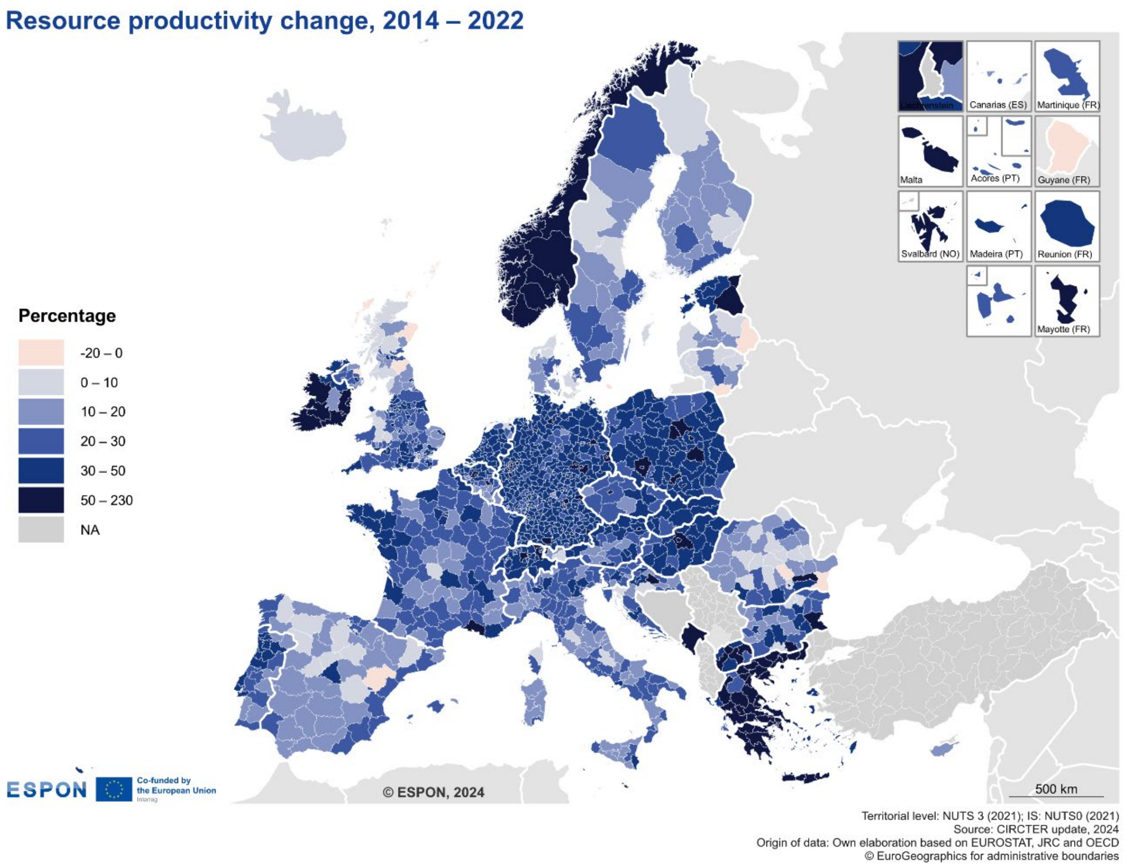
However, a closer look at the data also reveals notable exceptions where rural regions have also achieved RP levels comparable to urban areas[12]. Examples include Mid-West (IE053) in Ireland, Oberbayern (DE222) and Oberpfalz (DE221) in Germany, and Trento (ITH10) in Italy. According to the data, these rural regions demonstrate that it is possible to bridge the productivity gap traditionally associated with rural economies. Their success may stem from strategic investments, innovative practices, or specific economic structures that enable efficient resource use. Further investigation of the driving factors of these outliers might provide valuable insights into how rural regions can overcome the typical challenges of achieving high RP. They may also serve as models for other rural areas seeking to enhance their resource productivity, offering practical examples of policies and practices that support a more resource-efficient and sustainable economic trajectory.

Map 6 shows that, between 2014 and 2022, Europe experienced a notable overall improvement in RP, with 99% of analysed regions showing a positive change. This reflects a significant shift toward more resource-efficient economies across the continent. Notably, 175 out of the 1.392 regions examined recorded increases in RP of over 50%. Examples of such substantial improvements include regions in Norway, most regions in Greece and Ireland, as well as several areas in Eastern Europe and Germany.

Contrarywise, a small subset of regions exhibited concerning patterns, with RP deteriorating over the same period. The most alarming cases, where RP decreased by over 10%, include the Romanian regions of Constanța and Prahova, as well as several Nordic islands in the United Kingdom. These declines warrant further investigation to understand the underlying factors, which may range from structural economic shifts to challenges in adapting to resource efficiency measures.

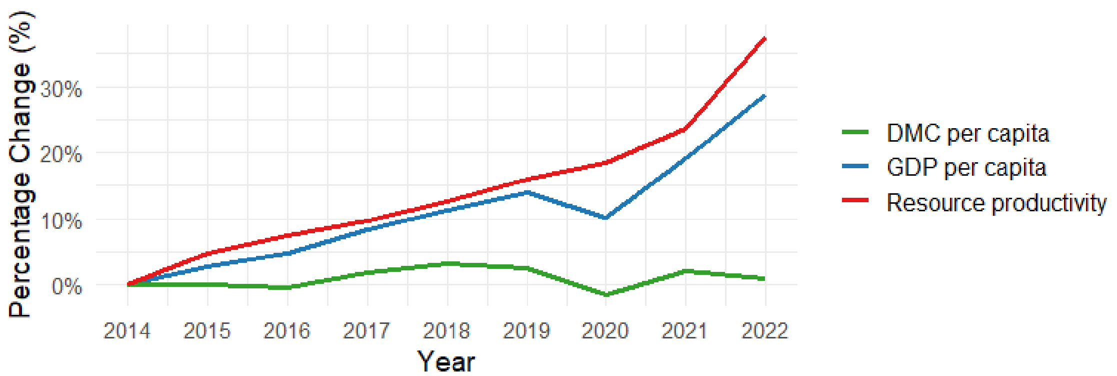
[12] The reader can refer to the interactive data story *Circular rural regions* to navigate RP across territorial typologies.

Map 6: Resource productivity change (2014 – 2022)



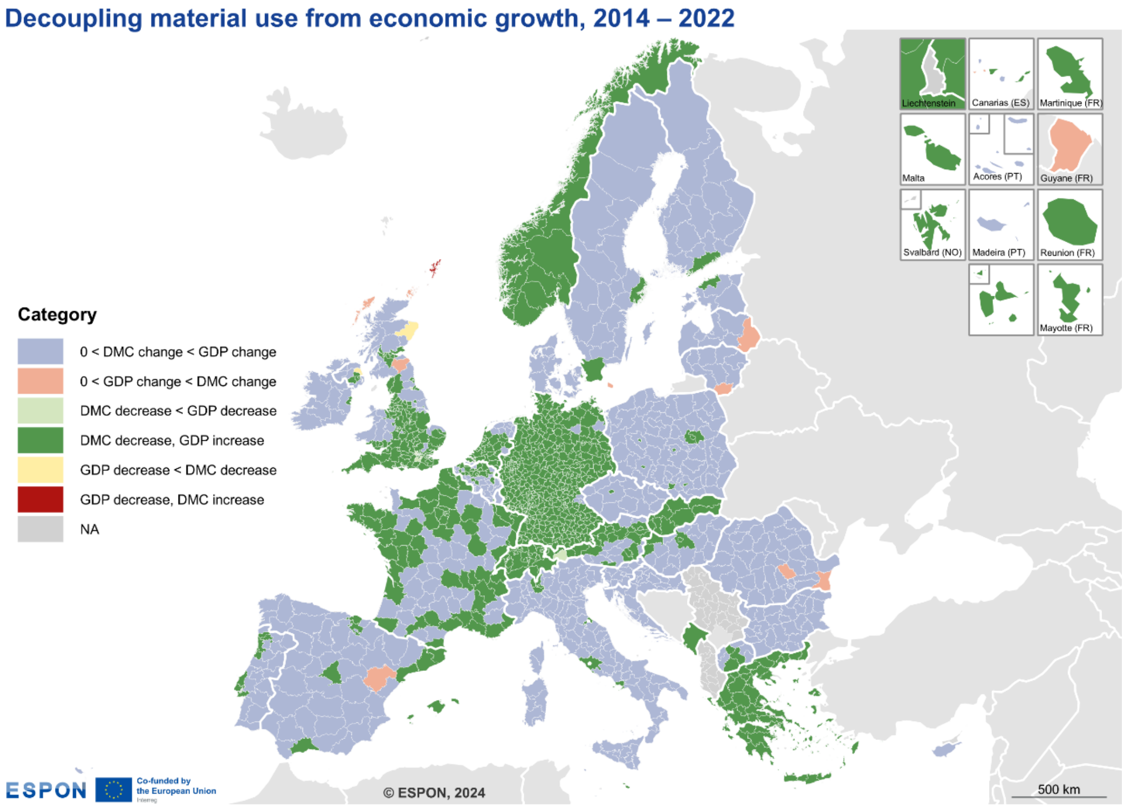
If we shift the focus to the change in DMC per capita over the same period (Figure 2), the data reveals a more modest picture of resource savings compared to the significant improvements suggested by RP. Most regions experienced reductions in DMC within the range of 0–15%, with the notable exception of Greece, where reductions exceeded 15%. These insights indicate that much of the progress in RP has been driven by increased economic output (i.e., GDP growth) rather than substantial reductions in material use.

Figure 2: Trends in GDP per capita, domestic material consumption per capita and resource productivity per capita (2014-2022)



To provide a more nuanced understanding of decoupling patterns, we developed a regional classification based on the rate of change in both GDP and DMC, presented in Map 7. This approach allows us to identify and compare decoupling patterns across European regions, shedding light on varying levels of progress toward sustainable growth.

Map 7: Decoupling material use from economic growth (2014-2022)



Territorial level: NUTS 3 (2021)
Source: CIRCTER update, 2024
Origin of data: Own elaboration based on EUROSTAT, JRC and OECD
© EuroGeographics for administrative boundaries

Regions achieving **absolute decoupling (Strong Green)** are exemplary models for sustainable development, showcasing that it is possible to reduce material dependency while maintaining robust economic growth. This pattern is primarily observed in Greece, Germany, and Norway, as well as in several regions of Italy, Spain, France, and the United Kingdom. The strategies and innovations implemented in these regions—such as investments in circular economy initiatives, technological advancements, or shifts toward high-value, low-impact economic activities—should be analysed to identify best practices that can be adapted and replicated in other contexts.

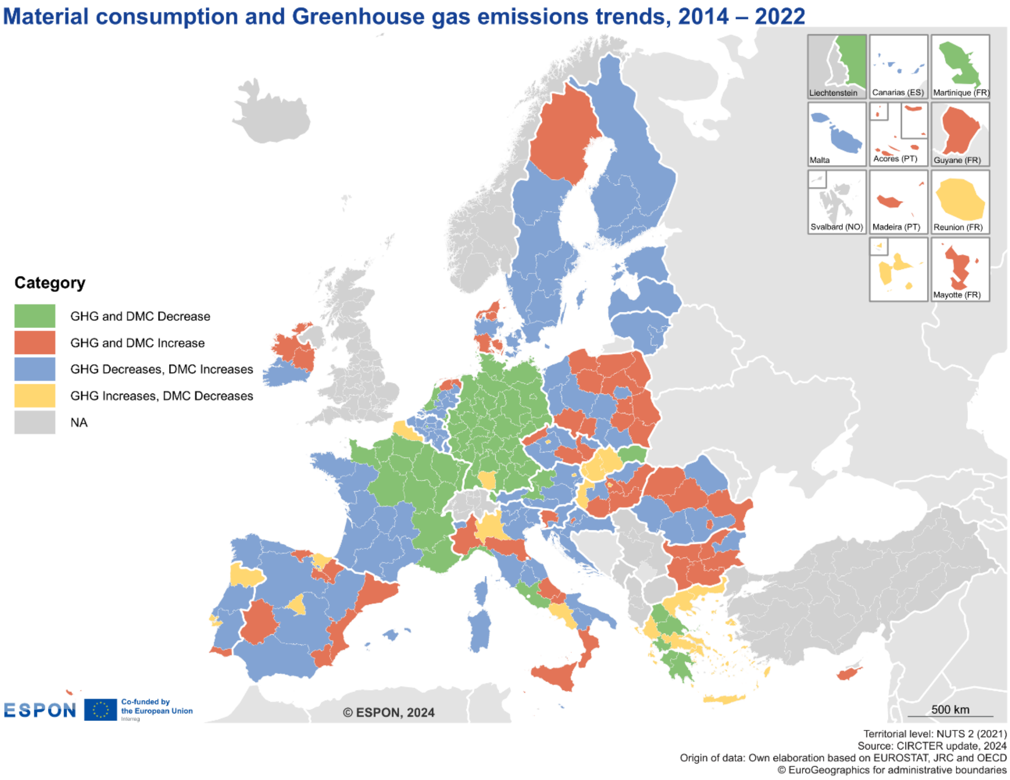
Relative decoupling (Light Blue) is the most common trend across European regions. Regions in this category demonstrate progress but reveal untapped potential for achieving absolute decoupling. For these regions, policies that accelerate the transition to resource efficiency, such as incentivising eco-innovation, strengthening resource-saving technologies, and promoting material reuse and recycling, could help bridge the gap.

Regions classified as experiencing **no decoupling (Orange)** or **negative decoupling (Red)** face significant challenges in aligning economic performance with resource efficiency. Examples include Shetland Islands (UKM66), Teruel (ES242) and Alytus County (LT021). In these areas, material use is either increasing faster than GDP or rising alongside economic decline, reflecting systemic inefficiencies and structural vulnerabilities. Addressing these challenges require targeted interventions, diversifying economies away from material-intensive activities, enhancing resource recovery systems, and fostering local innovation as critical steps. These regions may also benefit from partnerships with more advanced regions or transnational initiatives, leveraging shared expertise and resources to support their transition toward sustainable development.

Overall, this decoupling classification not only underscores the varied regional progress toward sustainable growth but also highlights the critical need for differentiated and context-sensitive strategies. While the frontrunners may represent good examples for sustainable economic models, lagging regions emphasise the need for sustained and targeted support to ensure that the benefits of decoupling are equitably distributed across Europe. Achieving this balance is essential for the EU's overarching goal of fostering a resource-efficient, climate-neutral economy.

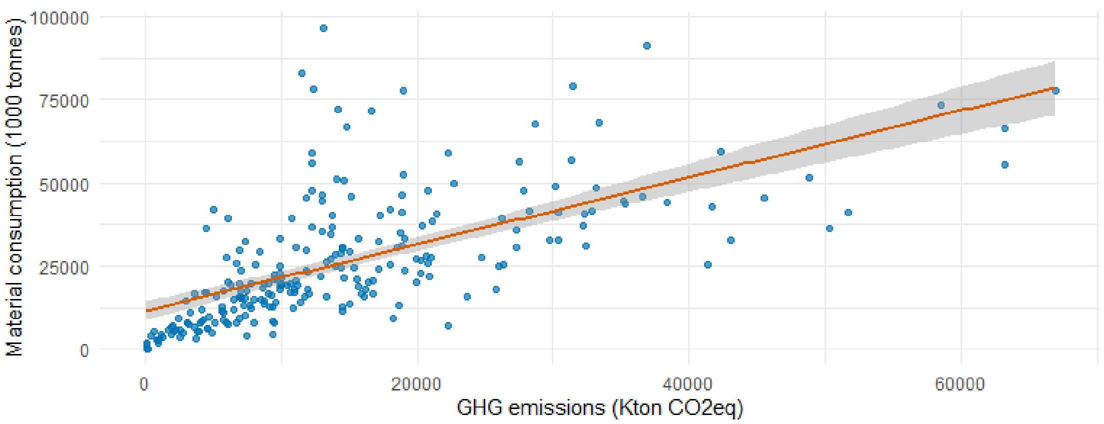
To conclude, Map 8[13] illustrates the trends in material consumption and GHG emissions, providing key insights into areas advancing toward more sustainable production and consumption systems, while also highlighting the key role of the circular economy in achieving climate neutrality.

Map 8: Material consumption and greenhouse gas emissions trends (2014-2022)



Regions that have successfully reduced material consumption (Map 7) also tend to demonstrate corresponding reductions in GHG emissions. This relationship is further corroborated by looking at the correlation between resource use and GHG emission (Figure 3): higher material consumption levels go hand in hand with higher emissions – the correlation is exceeding 60%. This dynamic indicates that transitioning to more resource-efficient practices enables regions to simultaneously reduce emissions—key objective for achieving climate neutrality.

Figure 3: Scatterplot of GHG Emissions vs. domestic material consumption (2022)



[13] Map 8 is presented at the NUTS 2 level because GHG emission data, sourced from the JRC-EDGAR database, are only available at this regional scale

3.2 Waste generation patterns

3.2.1 Total waste generation, excluding major mineral waste

Monitoring waste generation is essential for evaluating progress towards a circular economy. Circular economy principles seek to minimise waste by optimising resource use, promoting recycling, and designing products for durability and reuse. Reducing waste generation serves as an indicator of improved resource efficiency while reflecting broader societal and economic shifts towards sustainable production and consumption patterns.

At the regional level, waste generation patterns display significant variation. In 2022, waste generation (excluding major mineral waste) ranged from more than 6 tonnes per inhabitant in Estonia to approximately 1 tonne per inhabitant in regions such as Liechtenstein, Malta, Romania, and Latvia. These disparities highlight the impact of regional economic structures and waste management systems. Estonia's exceptionally high waste generation per capita is largely attributable to its reliance on oil shale energy production, a resource-intensive process that produces considerable waste. This underscores the environmental challenges faced by regions with extractive or energy-intensive industries.

On average, waste generation per capita (excluding major mineral waste) across analysed European regions in 2022 was 1.7 tonnes, the same as in 2014. This stagnation indicates that, at an aggregated scale, no progress has been made in improving waste efficiency over the past eight years, despite growing attention to circular economy principles.

A closer look to territorial patterns in waste generation reveals divergent trends across Europe, as shown in Map 9. Many regions, particularly in Greece, parts of Central Europe (e.g., Germany and Slovenia), and Nordic regions (e.g., Denmark and Finland), achieved significant reductions in waste generation. Conversely, regions within Sweden, Luxembourg, Lithuania, the Czech Republic, Slovakia, Portugal, Hungary, Bulgaria, Serbia, and Croatia showed notable deteriorations in waste generation per capita.

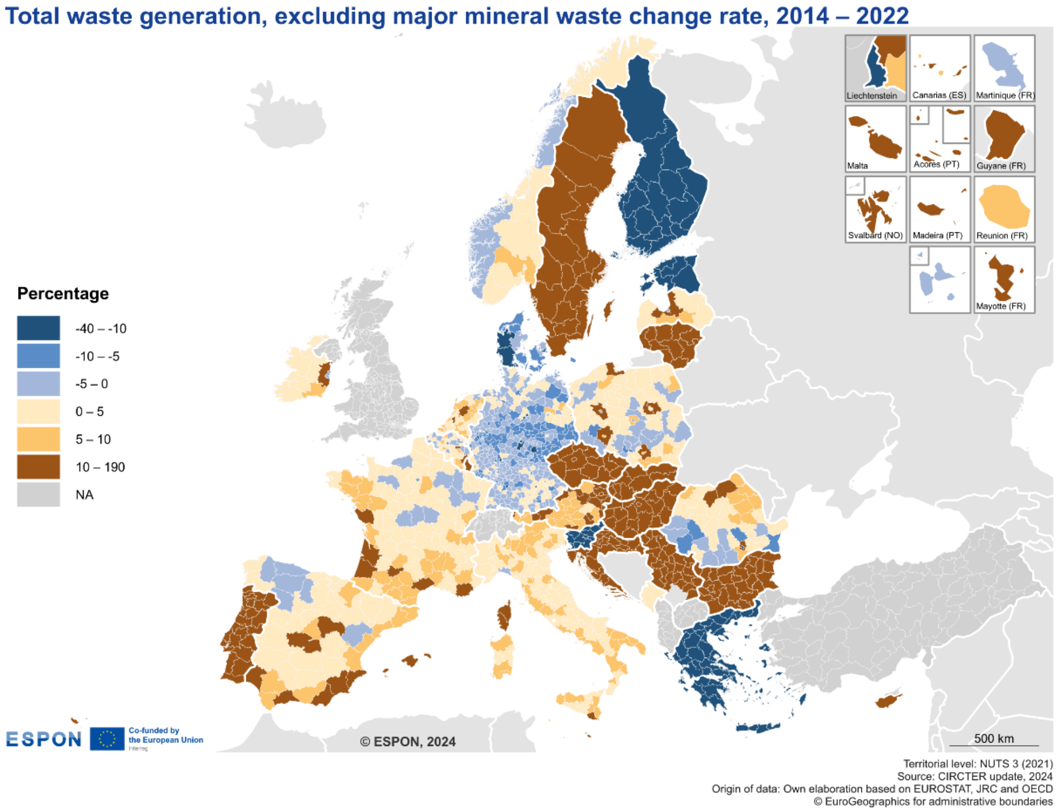
While waste generation per capita provides a snapshot of resource efficiency relative to population, it does not account for the economic context driving waste production. This is where waste generation per GDP becomes crucial, offering insights into the eco-efficiency of regional economies—whether regions are capable of decoupling economic growth from waste generation. A circular economy seeks not only to reduce waste but also to achieve sustainable economic expansion, making this indicator central to understanding progress.

Map 10 highlights the territorial patterns of waste generation per GDP. Most regions demonstrate improvement, indicating progress in decoupling waste generation from economic growth. However, a few regions—primarily located in Croatia, Serbia, Slovakia, Czechia, Luxembourg, and Cyprus—have worsened. These regions exhibit increased waste intensity relative to economic output, raising concerns about the efficiency of their production and consumption systems.

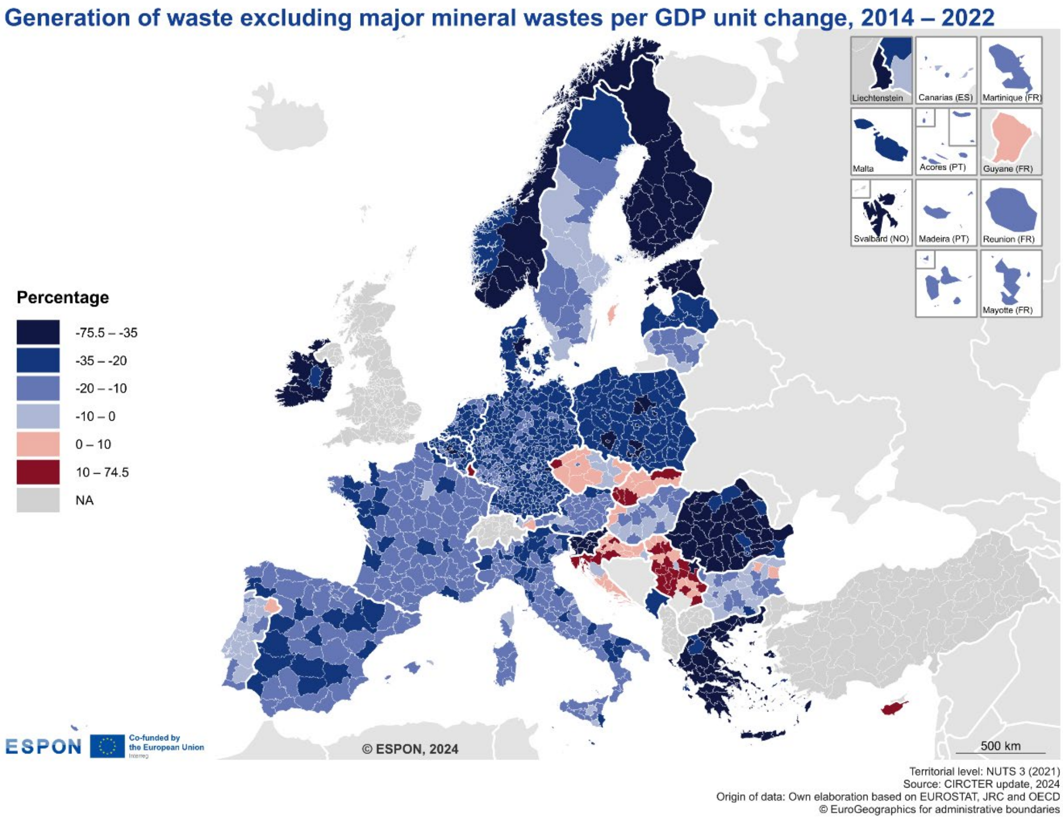
Comparing changes in waste per capita with waste per GDP reveals critical dynamics. Some countries—such as Bulgaria, Portugal, Hungary, Sweden, and Lithuania—have seen increases in waste generation per capita but improved their waste efficiency relative to economic output. This suggests that their higher waste levels may be partially justified by the expansion of their economies, which have outpaced waste growth, reflecting progress in relative decoupling.

In contrast, countries like Luxembourg, Croatia, Serbia, Slovakia, and Czechia face a worsening situation on both fronts. These areas exhibit increases in waste per capita alongside deteriorations in waste generation per GDP, highlighting challenges in both waste management and economic efficiency. Such trends suggest structural inefficiencies or limited adoption of circular economy principles, emphasising the need for targeted interventions to address these dual challenges.

Map 9: Total waste generation, excluding major mineral waste change (2014-2022)



Map 10: Generation of waste excluding major mineral waste per GDP unit change (2014-2022)



3.2.2 Municipal waste, household waste and food waste generation

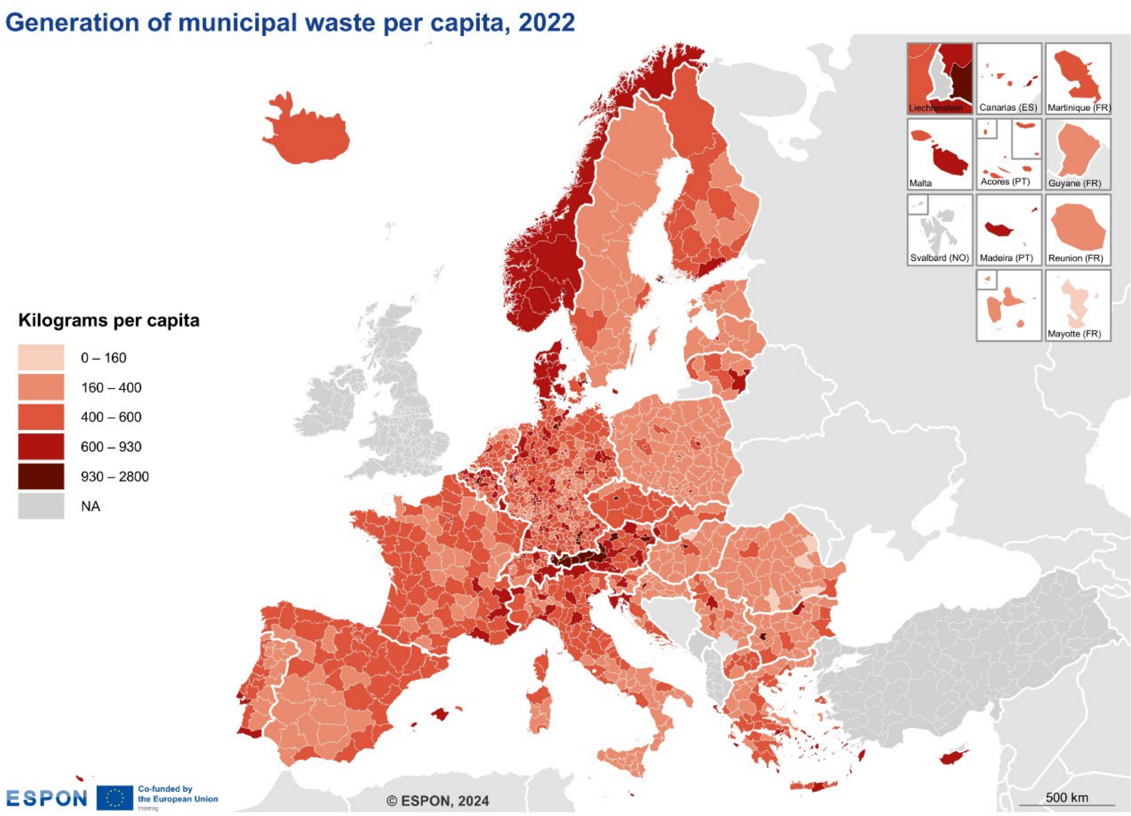
Municipal waste refers to the waste collected by or on behalf of municipal authorities and managed through the waste management system. It primarily includes waste generated by households but may also encompass similar waste from commercial activities, offices, and public institutions. Household waste, which arises from activities within households, represents the largest share of municipal waste. On the other hand, food waste is predominantly generated by households, which account for more than half of the total food waste in the EU (54%)[14]. As a result, food waste constitutes a significant portion of both household waste and, consequently, municipal waste. However, food waste also originates at various stages of the food supply chain, such as production, manufacturing, distribution, and food services, extending its contribution beyond household sources.

For local decision-makers, municipal waste, household waste, and food waste are particularly relevant indicators due to the direct influence of local infrastructure and regulations on their management. Unlike total waste, often governed by national or supranational policies, these waste types are typically under the jurisdiction of local authorities, making regional-level data essential for designing and implementing effective strategies. Both municipal waste and food waste are included in the EU's Circular Economy Monitoring Framework, underscoring their importance in tracking progress in the "production and consumption" thematic area.

Map 11 and Figure 4 highlights the distribution of municipal waste generation across regions, showing distinct differences between urban, intermediate, and rural areas. In 2022:

- Urban regions generated the most municipal waste per capita, averaging 608 kg per inhabitant.
- Intermediate regions followed, with an average of 480 kg per inhabitant.
- Rural regions produced the least, averaging 422 kg per inhabitant.

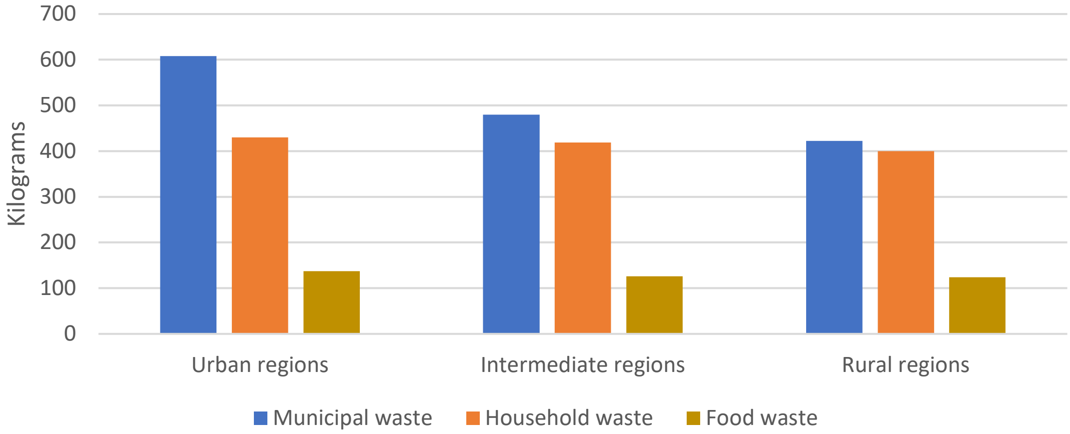
Map 11: Generation of municipal waste per capita (2022)



Territorial level: NUTS 3 (2021); IS: NUTS0 (2021)
Source: CIRCTER update, 2024
Origin of data: Own elaboration based on EUROSTAT, JRC and OECD
© EuroGeographics for administrative boundaries
Data for CZ, GR from 2021

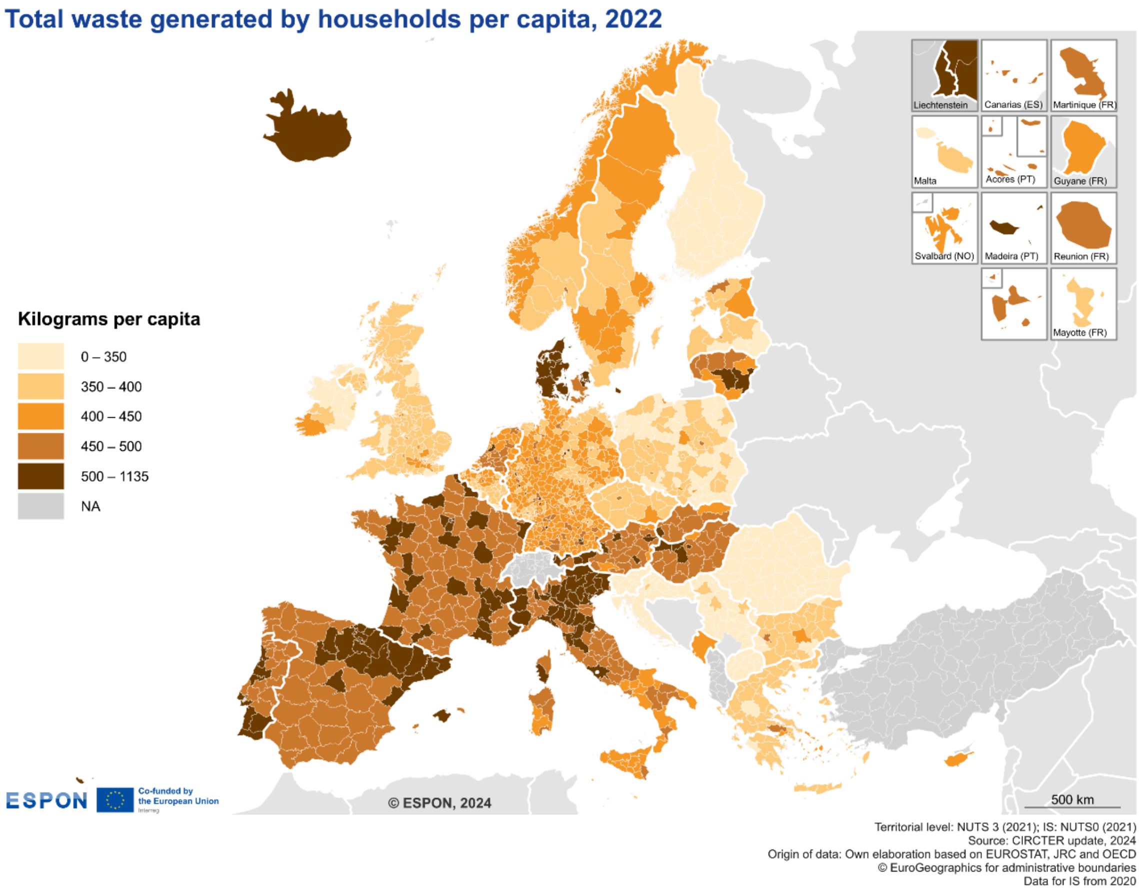
[14] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

Figure 4: Average waste generation between territorial typologies



The significant gap between urban and rural areas can largely be attributed to the higher concentration of small commercial activities in urban settings, which contribute substantially to municipal waste generation. This observation is further supported by the share of household waste in municipal waste. In urban areas, household waste constitutes roughly 70%, while in rural areas, it accounts for up to 95% of municipal waste. This discrepancy reflects the predominance of household-generated waste in less commercialised rural areas. Map 12 show the regional distribution of household waste generation per capita.

Map 12: Total waste generated by household per capita (2022)

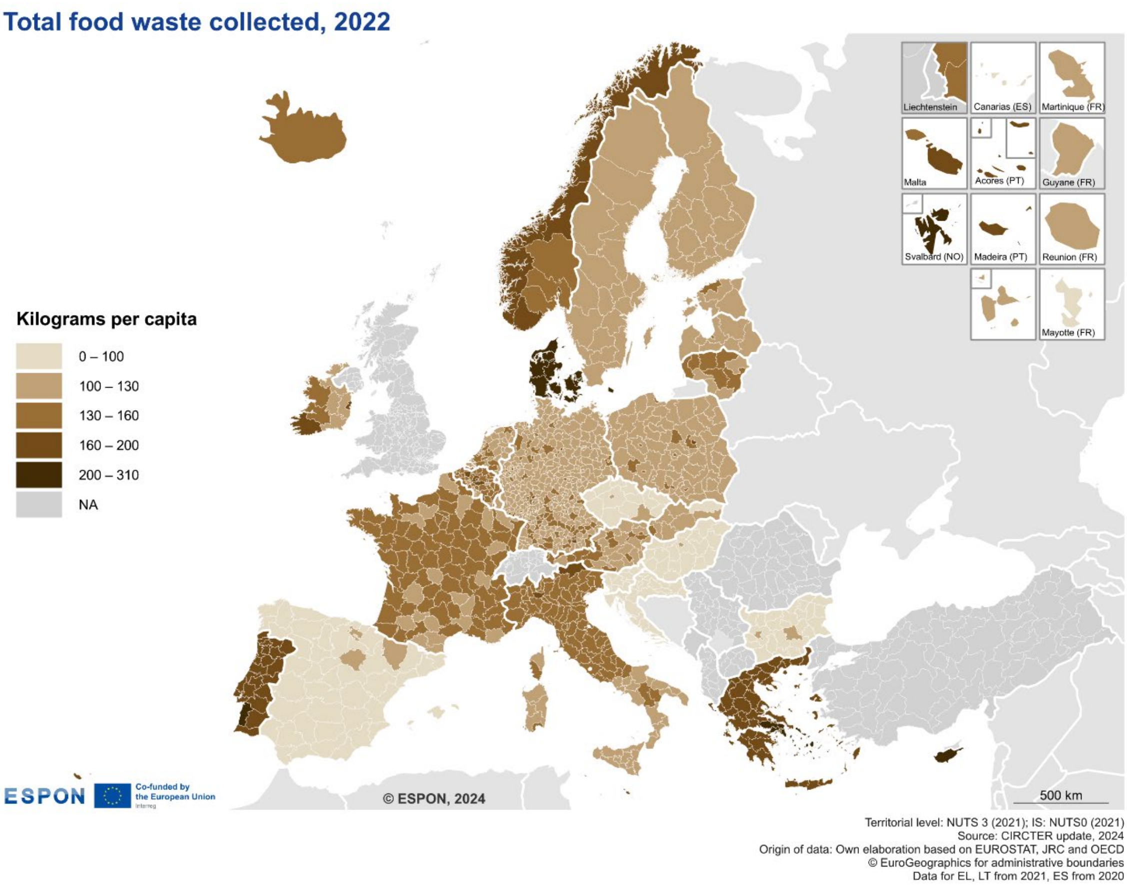


Food waste, Map 13, displays a similar territorial pattern, with urban areas generating more food waste both in absolute terms and on a per capita basis compared to intermediate and rural regions. However, unlike the household waste patterns, the proportion of food waste relative to total municipal or household waste remains relatively consistent across territorial typologies (23%-29%, for urban and rural regions, respectively).

These patterns carry clear policy implications. Urban and intermediate areas should adopt a balanced approach, targeting both household and non-household waste streams to enhance waste management efficiency. In particular, efforts should focus on addressing waste generated by commercial activities, such as promoting sustainable business practices and improving recycling infrastructure tailored to non-household sources. On the other hand, rural areas should concentrate on household waste reduction initiatives, emphasizing educational campaigns and infrastructure improvements.

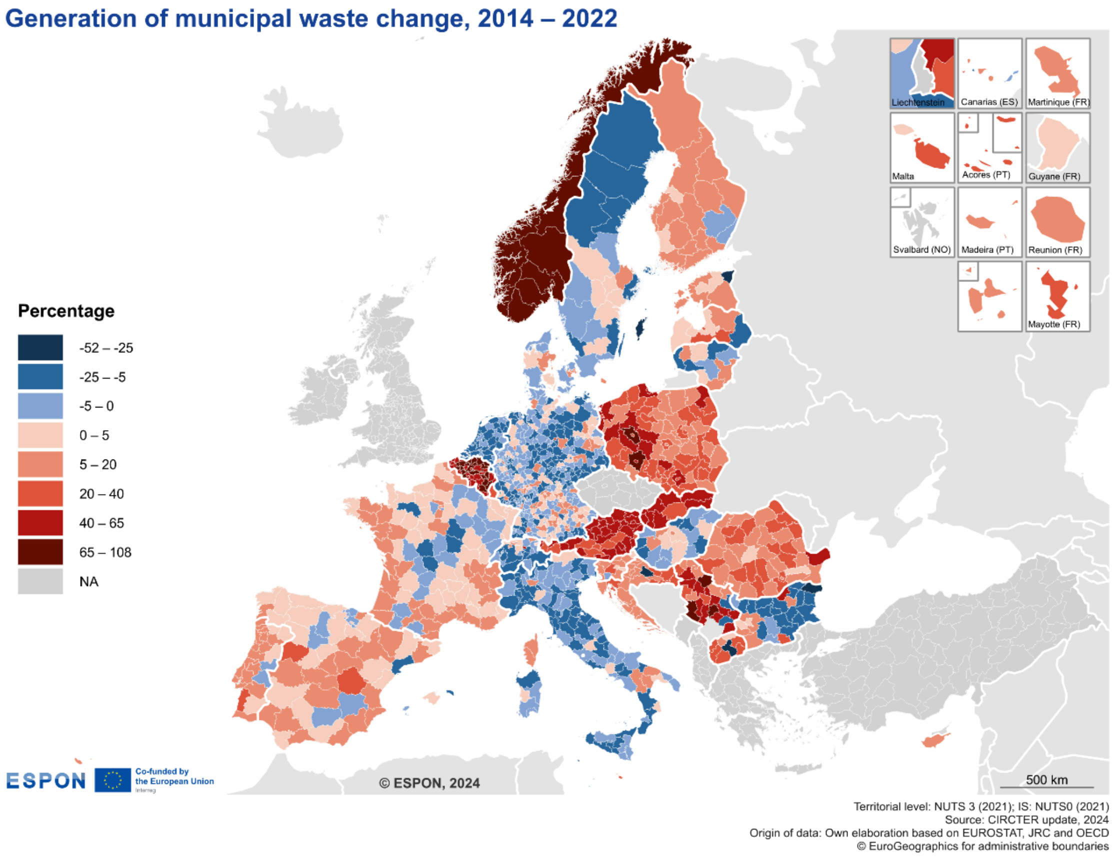
From a temporal perspective, regional data indicates that municipal waste generation per capita increased by 4% between 2014 and 2022. While this increase occurred relatively evenly across regional typologies, Map 14 indicates that this trend was especially experienced in Eastern regions[15]. A similar pattern is also observed in numerous regions across Nordic countries such as Norway and Finland, as well as in Belgium, Luxembourg, Austria, and Slovakia. However, the reliability of these findings is partly affected by changes in statistical accounting methodologies. In particular, countries like Belgium, Austria, Czechia, Luxembourg, Norway, Portugal, Slovenia, and Sweden reported breaks in time series data, as flagged by Eurostat, suggesting shifts in their accounting approaches over time. These changes highlight the need for careful interpretation of temporal trends, particularly when comparing across regions and countries with evolving data practices.

Map 13: Total food waste collected (2022)



[15] The rate of change in Map 14 has been calculated using absolute values for municipal waste generation. Similar results were observed when the rate of change was calculated using per capita values for municipal waste generation.

Map 14: Generation of municipal waste, rate of change (2014-2022)



3.3 Material and consumption footprint patterns

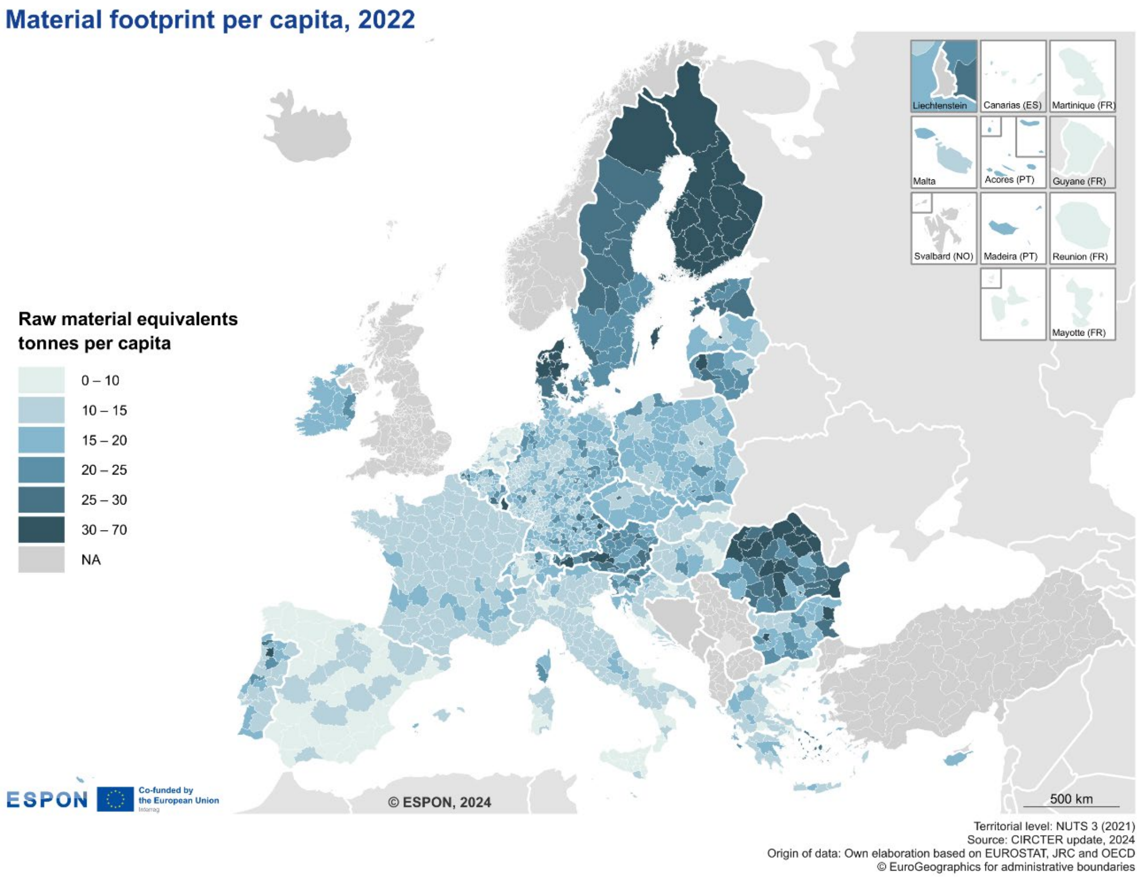
3.3.1 Material footprint

The material footprint (MF) indicator, included in the EU Circular Economy Monitoring Framework, offers a comprehensive measure of the global material extraction required to satisfy the consumption and investment patterns of households, governments, and businesses within Europe. Unlike domestic material consumption (DMC), MF accounts for the entire supply-chain material requirements, encompassing biomass, metal ores, non-metallic minerals, and fossil energy materials. This broader perspective allows for a more accurate allocation of environmental responsibilities by highlighting the true material demands associated with EU consumption and investment.

Map 15 shows the regional distribution of MF per capita in 2022, revealing distinct patterns when compared to DMC:

- Regions with high MF and DMC per capita: Countries like Sweden, Finland, Austria, Romania, Bulgaria, Estonia, Denmark, and Lithuania exhibit heavy material use per capita in both metrics. This suggests that, beyond material consumption due to satisfy foreign demand, these countries are also responsible for significant material extraction globally to meet their consumption needs.
- Regions with lower MF per capita and high DMC per capita: Conversely, countries such as Ireland, Portugal, and Latvia show lower environmental burdens from an MF perspective relative to their DMC. This discrepancy is likely due to their economies' export-oriented nature. For example, Ireland and Portugal may extract or import raw materials, process them domestically, and then export finished goods, thereby transferring part of the material burden to other regions.

Map 15: Material footprint per capita (2022)



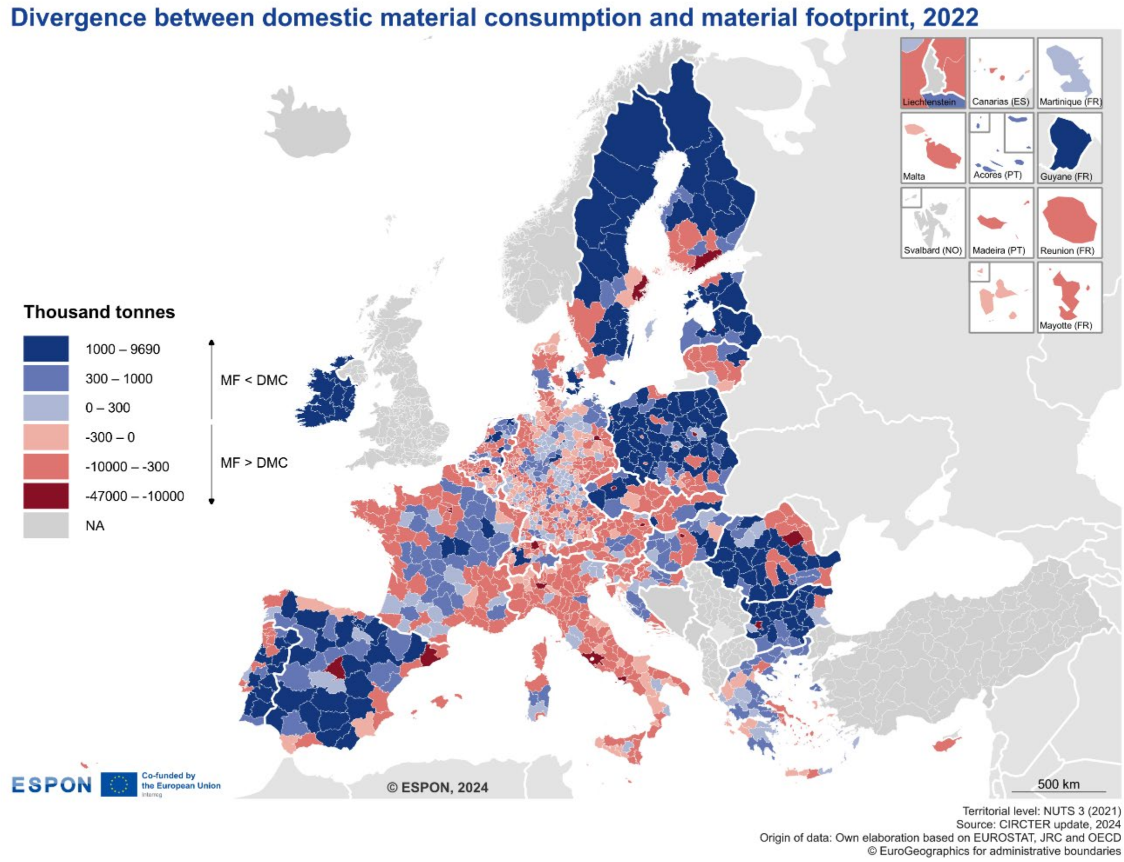
A closer look at regional patterns reveals notable differences between MF and DMC, particularly in urban areas. On average, urban regions show an MF of 13.2 tonnes per capita, compared to a significantly lower DMC of 9.66 tonnes per capita. This divergence highlights the globalised nature of urban economies, which rely heavily on imported goods and services. Much of the material consumption in urban regions is tied to external supply chains, with resources extracted and processed abroad. As a result, while their domestic consumption appears relatively low, their overall material demand, as captured by MF, is significantly higher.

Map 16, which illustrates the difference between DMC and MF in thousand tonnes, clearly depicts this trend. Urban regions with the largest discrepancies include Bucharest (RO321), where the difference exceeds 40,000 tonnes, as well as Madrid (ES300), Helsinki (FI1B1), Sofia (BG411), and Vienna (AT130), which show increases of around 20,000 tonnes. These data underscore the indirect environmental impacts of urban consumption patterns, emphasizing their heavy reliance on imported resources.

Interestingly, the gap between rural and urban areas is much narrower when comparing MF rather than DMC. Rural regions have a slightly higher MF average (17 tonnes per capita) compared to urban regions (13.2 tonnes per capita), but the difference is smaller than the gap observed in DMC (17.9 vs. 9.66 tonnes per capita). This indicates that while rural areas still consume more materials per capita, the true environmental impacts of consumption in urban and rural regions are more similar than DMC figures alone suggest.

These findings highlight the importance of addressing the indirect impacts of consumption in urban areas to advance sustainable resource use. Urban regions, with their advanced and service-oriented economies, must not only reduce their direct material consumption but also consider the environmental costs of imported goods and services within their supply chains. By focusing on both direct and indirect impacts, regions can better align their consumption patterns with the principles of a circular economy.

Map 16: Divergence between domestic material consumption and material footprint (2022)



3.3.2 Consumption footprint

The national distribution of the CF indicator reflects the impacts of EU consumption, accounting for the entire life cycle of locally consumed products and services. Regions that import a significant amount of goods may exhibit higher consumption footprints, as the environmental impacts of material extraction, production, transport, and decommissioning are attributed to the importing country.

Generally, the more resources and energy a region consumes, the greater its environmental impact. Consequently, areas with higher consumption levels tend to have larger environmental footprints. However, regional consumption footprints also depend on the composition of consumption baskets. Influential factors driving regional consumption footprints include population size, economic development, trade patterns, lifestyle and consumption habits, environmental policies and regulations, and technological levels.

Map 17 shows the consumption footprints per capita in NUTS-3 regions in 2022 obtained from our modelling approach. The spatial coverage includes all European regions within countries that have national CF values. Typically, consumption footprints are greater in regions with high consumption of energy and consumer goods. This can be linked to (1) higher levels of industrial activity and living standards, (2) greater dependence on material-intensive activities (like mining, forestry, and agriculture), and (3) high reliance on imports to satisfy local demand for consumption goods, such as food and transport.

The highest consumption footprint per capita are found in regions of South-West in IE, Delfzijl en omgeving in NL, Wolfsburg, Kreisfreie Stadt in DE, Byen København in DK and Ingolstadt, Kreisfreie Stadt in DE. In contrast, Eastern Europe exhibits substantially lower consumption footprints per capita, with the lowest values in Romanian regions such as Vaslui, Neamţ, Suceava, Botoşani and Bacău.

When examining the degree of urbanisation, the NUTS 3 regions with the highest consumption footprints per capita are typically the most affluent mid-sized urban and intermediate areas. This pattern reflects high economic output and labour productivity. However, relatively smaller populations prevent these regions from benefiting from consumption efficiency potentials, as seen in larger metropolitan areas. Meanwhile, some remote rural areas with strongly material-dependent economies, like Norrbotten in Sweden, demonstrate comparatively higher consumption footprints than other areas with similar conditions.

The evolution of the absolute consumption footprint shown in Map 18 reflects changes in the drivers of consumption footprint statistics, including total demand and the composition of the consumption basket. These aspects are influenced by co-evolving economic and socio-economic processes, such as economic development, trade dynamics, technological advancements, demography, lifestyles, and regulations. The map clearly shows a divide in the evolution of consumption footprints across three broadly defined groups of regions.

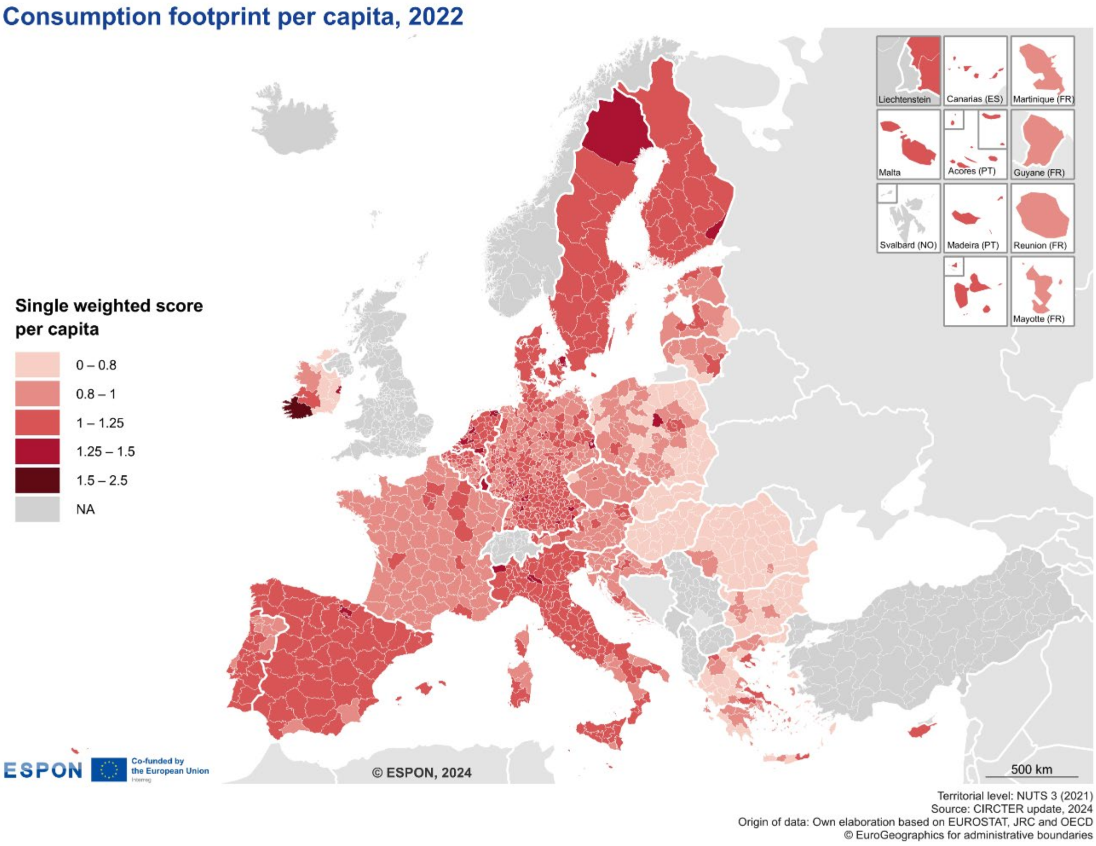
The first group consists of regions that experienced an increase in consumption footprints greater than 5 percent over the five-year period from 2017 to 2022. This category includes 259 regions representing 22 percent of the total. Most regions experiencing an absolute increase in consumption footprints are located in Eastern European countries and the Iberian Peninsula. The increase in consumption footprints in Eastern regions can be attributed to the expansion of the economic cycle over the analysed period, which led to higher environmental footprints driven by increased final household consumption. Notably, this growth in economic activity seems to have offset the population stagnation or declines observed in many Eastern regions, which typically reduce consumption levels. In contrast, in other areas like the Iberian Peninsula, while the rise in household income during the 2017-2022 period was less pronounced compared to Eastern regions, the surge in consumption footprint could have been driven by a boom in tourism, particularly after the COVID-19 pandemic. Mass tourism can have a great impact on consumption footprints. For instance, it is estimated that tourist flows in Spain contributed to a total carbon footprint of 47 825 ktCO2e in 2019, 62% of which is directly attributable to international tourism (Osorio et al., 2023[16]). Additionally, population growth driven by immigration further exacerbates the trend in Spain, as both local residents and visitors contribute to increased resource consumption.

The second group includes 115 regions (10 percent) where the consumption footprint declined by more than 5 percentage points between 2017 and 2022. This group is led by several regions in Ireland and Bulgaria. In Ireland, the reduction reflects the national CF's evolution rather than predictor behaviour. From 2017 to 2022, the national Irish consumption footprint declined from 6.81 to 5.72 million pt. In Bulgaria and many other regions across Europe in this category, the decrease is primarily due to demographic decline or stagnation. In most cases, population decline was coupled with modest economic growth.

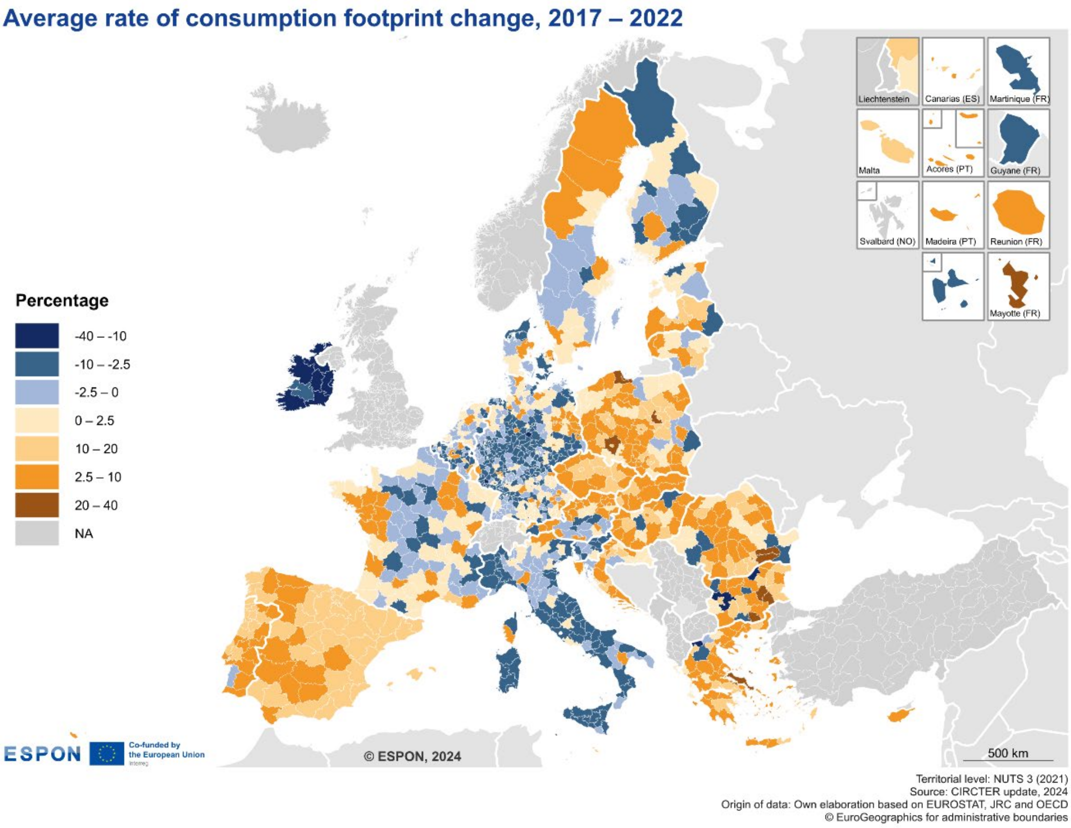
The third group comprises regions where consumption footprints remained relatively stable from 2017 to 2022. This is the largest group, including 794 regions, or 68 percent of the total. The regions in this intermediate group reflect the average behaviour in most EU countries, which experienced a modest 2.4 percent increase in the global CF between 2017 and 2022.

[16] Osorio, Pilar, María-Ángeles Cadarso, María-Ángeles Tobarra, och Ángela García-Alaminos. 2023. "Carbon footprint of tourism in Spain: Covid-19 impact and a look forward to recovery". Structural Change and Economic Dynamics 65 (juni):303–18. https://doi.org/10.1016/j.strueco.2023.03.003.

Map 17: Consumption Footprint per capita (2022)



Map 18: Variation on regional Consumption Footprint (2017-2022)



4 Conclusions

4.1 Monitoring circular economy: diverse challenges and multi-dimensional progress across European regions

Monitoring progress towards a circular economy is inherently complex due to its multidimensional nature. This complexity stems from the diverse aspects involved, including resource management, waste reduction, and sustainable consumption and production. Additionally, monitoring progress at the regional scale presents further challenges, as data gaps and inconsistencies often hinder comprehensive and comparable analysis. To address these limitations, the CIRCTER project has developed a robust framework of indicators designed to capture the intricate dynamics of circular economy practices across European regions.

The analysis of CIRCTER's indicators reveals that regions across Europe are progressing towards a circular economy at varying speeds and in different directions. Regions in highly industrialised and economically advanced countries, such as Italy, Switzerland, and the Netherlands, often lead in the transition to greater resource efficiency. However, the analysis also highlights rapid progress in countries such as Greece, Ireland, or Norway, which are successfully narrowing the resource efficiency gap with these frontrunners. Generally, urban areas are better positioned for economic dematerialisation due to their dominant tertiary sectors, which are less material-intensive compared to primary and secondary activities typical of rural areas. Moreover, several circular business models are more feasible in urban contexts, due to economies of scale.

Progress in waste reduction, however, appears to have been more modest. On average, European regions have shown limited improvement in reducing waste generation since 2014. While some marginal gains have been observed when waste generation is measured relative to economic growth, significant decoupling of economic expansion from waste production remains elusive. Urban areas bear the burden of waste-related environmental impacts, given their dense populations and concentration of end-consumption activities.

The analysis also underscores the limitations of relying on individual indicators to assess circular economy progress. For example, metrics like domestic material consumption fail to account for hidden flows of raw materials embedded in imported goods, leading to an incomplete picture of regional environmental burdens. In this context, footprint metrics—such as material footprint or consumption footprint—offer more comprehensive insights. These indicators provide a clearer understanding of the broader material and environmental impacts of resource consumption, respectively. These metrics are particularly useful to single out specific differential behaviours in rural and urban regions. Urban areas, while often appearing efficient in direct resource use, show significantly higher environmental burdens when indirect material flows are considered.

4.2 Connecting rural and urban areas in a circular economy

Despite progress in urban and industrial contexts, the potential contributions of rural regions to the circular economy have yet to be fully realised. Nonetheless, the circular economy represents a key opportunity to integrate urban and rural areas into a cohesive framework of efficient resource management and environmental responsibility. Understanding the interdependencies between urban and rural areas is crucial for creating inclusive and equitable circular economy strategies that benefit all regions.

The analysis of material use, waste generation and consumption footprint indicators, highlight the distinct roles and challenges of urban and rural areas in the circular economy. Rural regions, driven by resource-intensive sectors such as agriculture, mining, and manufacturing, consume nearly 86% more materials per capita than urban areas. This reflects their role as primary suppliers of raw materials for downstream consumption in urban areas. Contrarywise, urban areas are more productive in their use of materials, producing €3.77 of economic output per kilogram of material used, compared to €1.50 in rural areas. But this material productivity is largely attributed to urban economies' reliance on service-oriented activities, which are less material-intensive than the extractive and industrial operations prevalent in rural regions.

The apparent efficiency of urban areas often hides the environmental impacts embedded in the supply chains that often originate in rural regions, both within and outside the European borders. In this context, the material footprint and consumption metrics provide a more comprehensive view by accounting for the upstream flows of materials associated with imports and exports. This broader perspective reveals that urban areas, despite lower direct material consumption, drive significant ecological burdens in rural regions through interregional supply chains. As a result, rural areas bear the concentrated environmental impacts of extraction and initial processing, even when the materials are consumed in urban markets. For rural regions focused on exporting raw materials, this creates an imbalance, where they shoulder environmental costs without equivalent economic benefits.

In terms of waste, urban areas, as centres of population density and end-consumption, produce significantly more municipal waste per capita than rural areas, reflecting the higher concentration of commercial activities and consumer goods in cities.

To ensure that everyone can benefit from a circular economy, it is essential to address the urban-rural dynamic through policies that promote interregional circular supply chains connecting producers with urban consumers in both directions. Rural and intermediate regions, as the primary source of raw materials, should not only supply resources to urban areas but could also benefit from urban byproducts, particularly organic and food residues, which can be reintegrated into agricultural processes as compost or biogas. Similarly, secondary raw materials from urban areas, such as recycling materials and urban mining, should be fed back into economy, reducing the demand for virgin resources. This reciprocal exchange between urban and rural economies ensures that both types of regions can contribute to and benefit from circular practices, thereby reducing environmental impacts and promoting a more equitable distribution of the economic and ecological costs of production and consumption. By creating policies that strengthen these interconnected supply chains, policymakers can facilitate a circular economy that is inclusive, sustainable, and mutually beneficial for urban and rural areas alike.

4.3 Circular economy as a key driver for climate-neutrality

Transitioning to a circular economy is a pivotal strategy for achieving climate neutrality, as it directly addresses the environmental impacts of material use and greenhouse gas (GHG) emissions. In a circular economy, resources are utilised more sustainably by designing products to last longer, promoting reuse, and prioritising recycling over disposal. This shift reduces the demand for new materials, thus lowering the need for resource extraction, production, and transportation—all of which contribute significantly to GHG emissions. By minimising the volume of materials entering and exiting the economy, a circular economy curbs emissions associated with these activities, directly supporting efforts to mitigate climate change.

This relationship between resource use and GHG emissions is exemplified by the strong correlation between material use (DMC) and GHG emissions across European region, which exceed 60%. Regions with high economic activity, such as urban centres and manufacturing hubs, tend to exhibit high material consumption alongside elevated GHG emissions. In contrast, areas with lower economic activity and material consumption generally show lower emissions, emphasising the critical link between resource use and environmental impact.

This dynamic is further supported by the decoupling patterns presented in Map 7and Map 8, where regions that have reduced material consumption also tend to show reductions in GHG emissions. This demonstrates that as regions transition to more resource-efficient practices, they can simultaneously reduce both material consumption and emissions—key goals for climate neutrality. However, transitioning to a circular economy is not only about reducing emissions and material consumption—it is also about fostering long-term economic resilience in a climate-neutral future. Encouraging patterns observed in regions such as Germany, France, and Greece show that it is indeed possible to achieve reductions in both emissions and material consumption while maintaining robust economic performance. However, it is important to note that these metrics do not account for upstream material consumption and emissions, which may occur outside the analysed regions.

While the exact mechanisms behind these positive trends need to be further explored, it is clear that circular economy-oriented strategies play a crucial role in achieving climate neutrality. Whether through innovative waste management systems, the development of cleaner technologies, or redesigning products for longevity and recyclability, these strategies are vital for reducing GHG emissions while ensuring that economic growth continues to thrive.

To fully unlock the potential of the circular economy as a driver for climate neutrality, circular economy principles should be integrated into climate strategies. These strategies should actively promote resource efficiency and waste reduction across industries and sectors. By embedding circular economy measures into policy agendas, regions can support their long-term economic well-being while advancing toward climate neutrality, ensuring that environmental progress is both resilient and economically sustainable.

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ESPON 2030

ESPON EGTC
11 Avenue John F. Kennedy
L-1855 Luxembourg
Grand Duchy of Luxembourg
Phone: +352 20 600 280
Email: info@espon.eu
www.espon.eu

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