Data-driven Policymaking and Monitoring for the Circular Economy: Conceptualization of Data Sources and Information

Michiel Pauwels[1,2,*], Jolien Ubacht[3], René Reich[1,4], Boriana Rukanova[3], Jelmer Lennartz[5], Luc Alaerts [1,4], Elmer Rietveld[5], Yao-Hua Tan[3], Karel Van Acker[1,4]

[1] *KU Leuven, Leuven, Belgium*
[2] *VITO, Mol, Belgium*
[3] *Delft University of Technology, Delft, the Netherlands*
[4] *Flanders Make Vzw, VCCM Corelab, Leuven, Belgium*
[5] *TNO, The Hague, the Netherlands*

Abstract

The EU Green Deal and the ensuing policies and regulations to stimulate the transition toward a circular economy pose challenges to policymakers and authorities. Taking planetary boundaries into account is a nascent topic on all regulatory levels, and data-driven policymaking and its implementation require the collection and access to new types of data in all policy-making phases, from agenda-setting to policy formulation, implementation, and evaluation. Extant studies into data-driven policymaking have not yet addressed which information types are needed and how policymakers and enforcement agencies can gain access to data sources, whereas the urgency to prepare for this is high. We use the lens of the policy cycles to assess the required data. In three typical cases, we explore the data sources at different policy levels of monitoring to develop a conceptual framework of data attributes to inform policymakers. We position that the extant data used in the policy phases for the transition to the circular economy are different from the familiar data that public administrations use in their respective domains. Our conceptual framework provides an initial overview of new types of data and potential shared use among the policy phases to support policymakers and enforcement agencies to timely prepare for access to the relevant data and data sources. We recommend the creation of data ecosystems for public administrations, the adoption of new capabilities for CE literacy, exploring the added value of Digital Product Passports, and AI-based tools and mechanisms to handle large volumes of data to structure messy data.

Keywords

Circular Economy, Monitoring, Policy Framework, Data sources, Digital Product Passport

1. Introduction

Under the EU regulatory framework to implement the vision of the Green Deal [1], governments in the EU Member States are introducing policies and regulations to stimulate the transition towards a circular economy (CE). Digital data is needed to support policymakers in their tasks to steer this CE transition, but they are confronted with uncertainties as new types of data and relevant data sources need to be explored to this end. The urgency to prepare for their CE monitoring tasks is high. This highlights the need for greater transparency and an overview of relevant data sources, tailored to

Proceedings EGOV-CeDEM-ePart conference, August 31-September 4, 2025, University for Continuing Education, Krems, Austria. ∗ Corresponding author. EMAIL: michiel.pauwels@kuleuven.be (A.1); j.ubacht@tudelft.nl (A.2); rene.reich@kuleuven.be (A.3); b.d.rukanova@tudelft.nl (A.4); jelmer.lennartz@tno.nl (A.5); luc.alaerts@kuleuven.be (A.6); elmer.rietveld@tno.nl (A.7); y.tan@tudelft.nl (A.8); karel.vanacker@kuleuven.be (A.9) ORCID: 0009-0009-5605-6226 (A.1); 0000-0002-1269-7189 (A.2); 0000-0002-9670-3434 (A.3); 0000-0003-0254-5787 (A.4); 0009-0001-1663-7386 (A.5); 0000-0002-6640-6287 (A.6); 0000-0003-2890-1567 (A.7); 0000-0002-5930-5138 (A.8); 0000-0002-5320-8839 (A.9)

both the policy phase and the administrative level at which the policymakers operates. To bring conceptual clarity, we develop a conceptual framework that can capture the required new types of data and their sources for the CE policy phases of agenda-setting, policy formulation, policy implementation, and policy evaluation. This framework is meant to inform and support policymakers to timely prepare for their CE monitoring tasks. In section 2, we address the political goal of the CE and our theoretical perspective on the policy phases. Next, we address the research context and our approach of using three illustrative cases to develop the conceptual framework, in section 3. In section 4, the three cases are presented, followed by the case findings and discussion in section 5. We present our conclusion and future research topics in section 6.

2. Theoretical background

2.1. The policy goal of the circular economy

Nowadays, the CE is often seen as a means for achieving sustainability by preserving and maintaining natural resources while mitigating the negative environmental impacts of existing 'linear' economic models and enhancing territorial resilience by reducing dependence on virgin materials [2]. As a result, an increasing number of governmental authorities have set the transition towards a CE as a political goal [3]. This transition is particularly prominent in Europe, where policymakers have actively developed legislative frameworks over the past decade to accelerate the shift toward circularity. In 2015, the EU introduced the Circular Economy Action Plan (CEAP) [4], which was later updated in 2020 as a core component of the European Green Deal, outlining strategies for Europe's sustainable growth. This plan has resulted in a comprehensive policy mix, introducing new regulations across the entire product life cycle. Its primary objective is to make sustainable products the norm within the EU while empowering both consumers and businesses to make environmentally responsible choices, ultimately reducing ecological impact and creating socio-economic opportunities.

The EU's emphasis on circularity has also trickled down to its Member States. For instance, the Netherlands has committed to establishing a fully circular economy by 2050, with an interim goal of reducing raw abiotic material use by 50% by 2030 [5]. France introduced a national action plan: Anti-Waste Law for a Circular Economy, to promote circular production and minimize waste [6]. Additionally, regions such as Flanders in Belgium [7] and Catalonia in Spain [8] have launched regional initiatives that foster collaboration between governmental and non-governmental actors to implement and accelerate the transition towards a circular society across key sectors.

More recently, the CE has also gained traction as a strategic framework for urban development. Recognizing the central role of cities in this transition, the EU's CEAP [9] positions cities at the forefront of CE implementation, emphasizing their potential to drive systemic change and foster sustainable urban transformation. The development of the Circular Cities and Regions initiative [10] and the Circular Cities Declaration [11] reflects this momentum. Despite increasing engagement across multiple levels of governance, CE policymaking remains in its early stages and lacks coherence both across and within different governmental levels [12, 13]. While the EU provides a strategic action plan, disparities in national regulatory frameworks, divergent policy priorities, and limited local expertise often result in inconsistencies that hinder a smooth transition to circularity. Addressing these challenges requires access to accurate data on material flows, product composition and quality, life cycles, and the impacts and effects of CE initiatives and circular business models. Such data is essential for designing effective policies, monitoring progress, and identifying areas for intervention. As a result, public authorities at various governmental levels are increasingly seeking reliable data and analytical tools to support evidence-based policymaking for CE across their jurisdictions.

2.2. Data-driven policymaking for the circular economy

Data-driven policymaking builds on the concept of evidence-based policymaking, where data is instrumental to ground political judgments in scientific and empirical findings [14]. In this context, the notion of data aligns with Buckland's concept of information-as-thing, where data is used attributively for a type of tangible information that is instrumental in informing users (information-as-process) and serves as a basis for imparting knowledge (information-as-knowledge) [15]. Data can thus be informative for the CE transition in the policy-making process. However, the effective use of data is inherently contextual and relational, influenced by how the information is transmitted and interpreted by the user. Importantly, data is the only type of information that can be directly processed by information technologies (IT), making it a fundamental component for evidence-based policymaking in digital governance. In this study, we understand information as processed data through analysis or aggregation to support policymaking. Data, on the other hand, are digital quantities, characteristics, and symbols generated by the digitization of analogue (real-world) facts. Building on this, advancements in IT have opened a new era of governmental policymaking, enabling more efficient collection and processing of vast amounts of data [16]. These tools enhance governments' ability to address societal and environmental challenges with greater responsiveness.

In the context of CE, Medaglia et al. found that digital government plays a key role in driving the CE transition by establishing policies, regulations, and requirements for monitoring and control [17]. However, effective CE policymaking requires more than regulatory oversight. It also depends on mechanisms that ensure data accessibility, interoperability, and integration across value chains and stakeholders to enhance the circularity of material flows [18]. A key challenge in this regard is the unequal distribution of value within ecosystems, where the costs of generating data typically fall on a different organization than the one that benefits from using the data [19]. This misalignment creates barriers for policymakers in collecting and utilizing data for the CE transition, highlighting the need for more transparency to reduce uncertainties in CE monitoring tasks. Compounding this challenge is the fact that existing data sources are often fragmented, and it is not clear which data is needed to prepare policymakers for the CE transition.

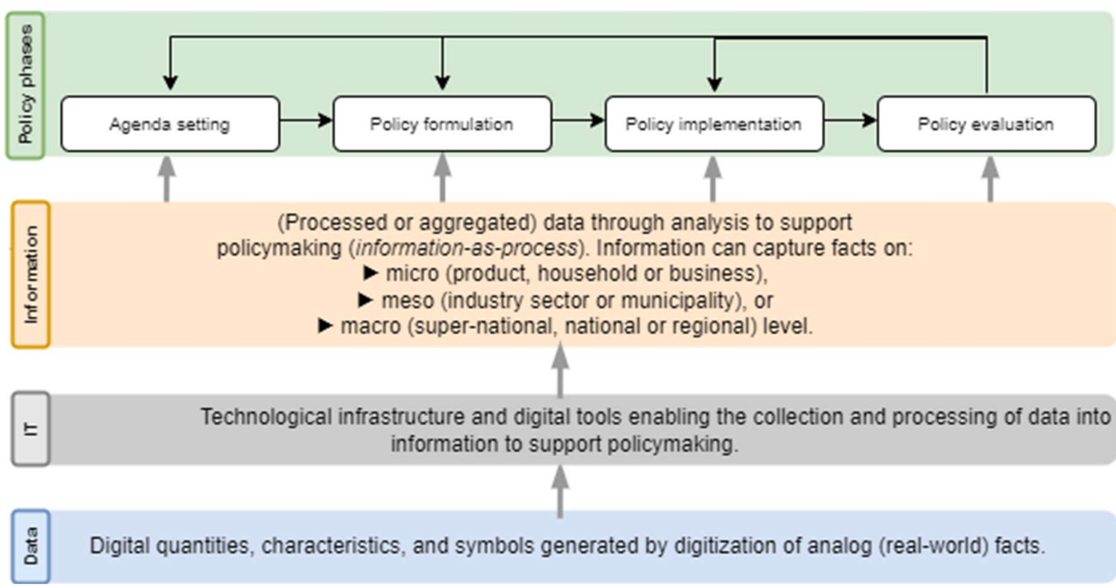

Figure 1: Conceptual overview of the paper. The policy cycle relies on IT tools to obtain information that is generated from common data generated by stakeholders in the economy.

2.3. The policy cycle

A well-established framework to conceptualize the policymaking process is the policy cycle, first introduced by Harold Lasswell in 1956. This framework provides a structured approach to understanding the sequential and interdependent stages of public policy development. Lasswell [20] identified five key stages in the policy cycle: agenda-setting, policy formulation, decision-making, implementation, and evaluation. Each stage supports a rationale for data-driven policymaking and serves as a structured framework to guide government officials through the complexities of public policy processes [21, 22].

The cycle begins with agenda-setting, where data is essential for raising awareness about societal issues. In the policy formulation stage, data is used to ground potential solutions in empirical evidence. During decision-making, policies are selected based on a set of measurable criteria, ensuring that the most effective options are chosen. In the implementation phase, one can distinguish two aspects with respect to the use of data. One is that enforcement agencies can use data to monitor the compliance of businesses or citizens with existing regulations. Second, data can also be used to track whether the policy is being implemented as planned. As policymaking is not an exact science, data is needed after an initiative has been implemented to evaluate whether the intervention is successful or needs to be refined.

In the context of the CE, data-driven policymaking necessitates the availability and use of relevant data throughout each stage of the policy cycle. However, current research offers limited insight into the specific data requirements at different stages of CE-related policymaking, as well as how these data can be coordinated and aligned across stages. This article seeks to explore and conceptualize the types of data currently utilized by policymakers and enforcement authorities across the various phases of the policy cycle. We limit ourselves to four policy phases; further research can focus on adding the decision-making phase as well.

3. Research context and approach

To develop the conceptual framework, we draw on the author's expertise and insights from ongoing and finalized research projects, and related project reports, other publications, and artefacts. The policy phases of agenda-setting and policy formulation are examined through two research projects focused on developing governmental CE monitoring systems in Flanders. Project A involves the creation of a regional CE monitor, developed collaboratively by researchers and policymakers to provide more direct feedback on the CE transition [23]. The development of this online monitor spanned five years, beginning in 2017, with its initial publication in 2021 and an update in 2024. The publicly accessible platform (https://cemonitor.be/) provides a comprehensive assessment of circularity through approximately 100 indicators. These indicators, sourced from statistical bodies and new research findings [24] follow a layered approach, measuring the CE transition at three levels: micro (product categories), meso (need satisfier systems such as food, mobility, and housing), and macro (overall circularity and its broader effects) [25]. Project B is a monitoring framework developed together with the public administration of a city government to measure and monitor the progress towards circularity in the city. In this case, indicators are linked to the action possibilities of different stakeholders in the urban ecosystem, emphasizing the city government's role in steering the transition. A central focus of the monitoring system is to track and assess circular initiatives taking place in the city. The phases of policy implementation and evaluation were prominent in the finalized project C (DATAPIPE project), in which the goal was to explore how data available in (business) digital infrastructures and in future Digital Product Passports (DPPs) can be used for CE monitoring tasks. In this project, the concept of CE monitoring was explored with a team of experts with, on the one hand, a background in international trade and the use of data for border control (for the policy implementation phase) and, on the other hand, experts from policy and environmental analysis (for the policy evaluation phase). For each phase, we selected an illustrative case to show the different requirements for data-driven policymaking in the execution of monitoring tasks by policymakers and enforcement agencies.

In the following section, we elaborate on the four phases of CE monitoring to arrive at a conceptual framework with an information and data typology for CE monitoring. This framework shows the diversity of data requirements and the relevant data sources to support CE monitoring tasks on the micro, meso, and macro levels in four phases of the policy cycle. This framework is meant to inform and support policymakers to timely prepare for their CE monitoring tasks.

4. Results

4.1. Agenda-setting phase

The agenda-setting phase often relies on aggregated data from statistical bodies, presented as indicators within a monitoring system. This macro level information helps conceptualize the CE, providing policymakers with a structured framework to enhance their understanding and raise awareness of the focal areas of the CE transition to intervene. In this regard, these indicators enable policymakers to identify and focus on high-priority issues in discussions and debates.

For instance, the indicator mass of new cars on the market in the CE monitor remained stable until 2018 but exhibited a sharp upward trend from 2019 onward, with an average annual increase of approximately 60 kg between 2019 and 2023. This shift is likely attributable to the growing adoption of electric vehicles, which tend to be heavier than their conventional counterparts. As a result, the visualisation of this trend may spark debates among policymakers on the rebound effects of the electric transition, particularly regarding the need for additional materials. A similar trend in the mobility sector was the sudden rise of electric bicycles in the data, which serves as evidence for the modal shift. Setting the CE agenda at the municipal level requires city-specific data. Macro-level information, such as the average regional material footprint, offers limited insights into the specific contextual factors of individual cities. While in reality, such indicators are sometimes used as proxy indicators to quantify the broader landscape of the CE, they fail to address the heterogeneity for evidence-based policymaking at the city level. Capturing the diversity of demographic, spatial, and socio-economic features that characterize a city requires more granular data. Meso-level information that is available at the city level, such as waste collection rates, is sometimes used as a proxy to determine the resource efficiency in cities. This allows local governments to pinpoint areas where additional awareness campaigns or infrastructure improvements may be necessary to improve the collection rates, ensuring that policy discussions are tailored to the specific needs of each municipality. At the micro level, data on household characteristics and consumption patterns offer insights into the demographic and socio-economic factors driving (un)sustainable consumption behaviors. For example, data on household expenditure behavior on reuse activities reveal that younger people are more likely to repair their goods [26]. As a result, this type of micro-level information can raise awareness among policymakers to target other demographic groups, encouraging broader adoption of the reuse movement. So, in the agenda-setting phase data is mainly used as a conversation starter to ground and steer the policy debate by evidence.

4.2. Policy formulation phase

In the policy formulation stage, access to relevant data is essential for policymakers aiming to make evidence-based decisions for the CE transition. There are no formally established CE policies at the Flanders Region or city level. However, in recent years, policy discourse has increasingly focused on setting macro-level targets to operationalize the CE transition in Flanders [27]. Data is needed to ground these targets in scientific evidence. For instance, the Flemish government has set the target to reduce the material footprint by 30% by 2030. To operationalize this target, they rely on material flow accounts (MFA) analysis, using environmental regional input-output databases, to quantify resource consumption and flows in the economy [26]. Another example of how data informs the formulation of policy targets is seen in the 2024 update of the monitor, where material productivity indicators were given a more prominent role. This change was the result of dedicated research on CE targets in dialogue with stakeholders from the Flemish transition landscape As a result, the policy document from the Department of Economy, supporting the 2024 government agreement of the newly formed Flemish government, designated material productivity as a key performance indicator (KPI) for the Flemish economy [28]. Current efforts are therefore directed toward a more nuanced understanding and interpretation of material productivity metrics, with the aim of informing future discussions on setting concrete targets for this KPI.

At the city level, meso-level information supports alignment with regional goals and justifies interventions. For instance, the Flemish government set a target to reduce residual waste to a maximum of 100kg per capita per municipality [29]. Local authorities use waste volume data to monitor progress, compare performance across cities, and design targeted measures such as increasing the cost of residual waste treatment to encourage better sorting and reduction.

In the context of higher-value material retention, the city is exploring innovative ways to recover waste streams and reintegrate them into the urban ecosystem. One key initiative is the Material Bank, which aims to recover over 1,000 tons of building materials annually by creating a secondhand market for building materials. It is considered a strategic project to help achieve the city's climate and circular economy goals. Achieving this target requires micro-level data on both supply (e.g., demolition project locations) and demand (e.g., quality of recovered materials). This information is essential to refine policy targets and scaling up urban circular procurement initiatives. Overall, in both case studies, data in the policy formulation phase is primarily used to operationalize CE targets and ensure their scientific and practical foundation.

4.3. Policy implementation phase

CE monitoring in the policy implementation phase is mainly driven by the challenge to control and manage business compliance with the legislation. The implementation phase includes both businesses implementing the legislation to be compliant with the new requirements, as well as enforcement agencies checking the compliance. In the context of the transition toward a CE, new legislations such as Ecodesign for Sustainable Products regulation [30] and the Battery Regulation put CE requirements on products that are put on the EU market (e.g. EV batteries) [31]. These products are often produced abroad and imported into the EU. Related developments are the Critical Raw Materials (CRM) Act aimed at keeping CRMs in the EU [32] and waste-related legislation like the Waste Shipment Regulation [33]. In the context of these legislations, an important monitoring task for EU governmental executive institutions such as border authorities is to monitor the import and export of products and materials. The question is which business data for CE monitoring can be used in this policy implementation phase.

For border authorities, business data such as invoices containing information about goods and the value of the goods is potentially valuable for cross-validating import declarations for fiscal aspects. This is to check whether the declared value of the goods in the import declarations corresponds to the value of the goods as reported in business documents [34]. This is an example of business data that authorities use for their current operations. However, with CE-related legislation, other data elements may be needed to monitor for circularity and sustainability concerns.

From the point of view of the information scope (macro, meso, and micro), in the implementation phase, authorities are focused on controlling specific good flows (e.g. border authorities monitoring import and export of cars, waste, etc., and risk assessing individual shipments; or market surveillance authorities monitoring cars put on the market whether they comply with the legislative requirements). Due to the nature of these tasks, micro-level data about the individual products is most relevant. For instance, very specific data elements about the battery used in electric cars can be used for controlling individual cars as well as the EV batteries in those cars.

But, in the implementation phase, macro and meso level data can also be relevant to serve as a trigger for increased attention for monitoring specific areas. For example, a steep increase in export numbers of electric vehicles from Europe or a steep increase in the export of scrap from one year to another at the macro level can be a trigger for the border authorities to conduct more checks on individual cars (micro level) to identify what is going on and to ensure that regulations are properly enforced. Also, meso-level data (for example, data about drastic shifts of export flows of cars or scrap from one region- e.g., the Port of Rotterdam to another, e.g., the Port of Antwerp) can be insightful for authorities and trigger extra checks to identify irregularities. However, while the macro and the meso-level data may act as triggers to direct attention towards specific streams of goods, for the daily monitoring and risk assessment of the goods, the micro-level data (or additional data about the specific transaction or products) is more important. To illustrate, we zoom in on a specific example related to EV battery data.

In the DATAPIPE project, we focused on how authorities may potentially benefit in the future from accessing business data that resides in business digital infrastructures and DPPs to enhance their compliance monitoring tasks for the CE. The Ecodesign for Sustainable Products Regulation (ESPR) [32] stipulates that products from specific product groups that are placed on the European market will need a DPP. The first DPPs for batteries that fall under the Battery Regulation are mandatory from 2027, with the expectation that other product groups will be gradually introduced under the ESPR and other legislations to include textiles, electronics, tires, toys, etc. These DPP developments are in an early phase: the allocation of roles and responsibilities of the authorities for enforcing these legislations are still being shaped. Hence, we used a potential imaginary scenario, building on insights from the Battery Regulation to assess the potential benefits of using DPP data for compliance monitoring. Next to the Battery Regulation, we took as inspiration the EU policies on limiting the export of waste to non-EU countries and on the enhancement of resource resilience by keeping CRMs in the EU. Our perspective was based on these (forthcoming) regulations and the potential monitoring role of EU border authorities, and we focused on the export of Electric Vehicles (EVs) that contain EV batteries. This example was further inspired by the cases where authorities make use of micro-level business data (as the example about the fiscal risk assessment given before) for their risk assessment processes. EV batteries contain CRMs which the EU wants to keep within their own borders when they become waste, to become less dependent on the import (of virgin CRMs) from non-EU countries. Current macro data indicates that second-hand vehicles that approach their end-of-life are exported to Africa. This raises issues with dispatching some of the responsibilities for (sustainable) end-of-life treatment to countries outside of the EU. This displacement may also have environmental consequences in the destination country.

In this scenario, we explored the potential role of data in Battery Passports for CE compliance monitoring tasks. In particular, the dynamic data related to the battery's state of health can be of interest to the border authorities as one of the indicators of whether a car that is declared for export approaches its end-of-life. When available, this data element can be valuable for customs to decide whether a car is approaching end-of-life. If so, they can be considered as waste and banned from export and the car would need to be dismantled following EU regulations. This will also allow the CRMs to be retained for reuse in the EU. In this example, similarly to the invoice example for fiscal risk assessment, transaction level (micro-level) DPP data is potentially valuable to border authorities as additional data for their risk assessment for future monitoring of the CE and for sustainability concerns.

4.4. Policy evaluation phase

As the EU aims to achieve climate neutrality, establish a CE, and ensure strategic autonomy, monitoring the state of play regarding material flows, stocks, and (embodied) environmental impacts on a macro-level (national and/or EU level) is vital. In the policy evaluation phase, this allows for the evaluation of the progress towards meeting the sector, national or continental commitments and obligations set in various regulations. The European Green Deal lays down targets for the emission reduction of greenhouse gases [35], and the Critical Raw Materials (CRM) Act [33] sets targets on the mining, processing, and recycling capacity of CRMs within the EU. To keep track of the intended policy pathway and ensure transparency and accountability, regular monitoring of the state of play is required. Particularly, as the transition is intended to happen within a determined time frame, there is a high pace of change in the economy, and monitoring of sector, national, or continental commitments should be on top of the progress. This requires macro-level data.

The need extends beyond monitoring the progress towards the commitments: authorities need to be able to steer and enforce as well. The EU implemented a series of regulations for the transition towards a sustainable economy. Monitoring might identify undesired effects, such as carbon leakage or shifts in material use. Monitoring the state of play allows us to identify whether the legislation effectively contributes to the transitions and whether it is sufficient to meet the targets. If legislation proves inadequate, public decision-makers need to provide evidence of undesired effects to justify the possibility of adapting legislation throughout the transition. Some sustainability regulations, such as the Ecodesign regulation [30] and the Battery Waste regulation [36], lay down sustainability requirements based on the realistic technical and scientific situation. To make sure that the requirements are feasible and challenging at the same time, continuous refinement is required to align with the market situation.

Different monitoring practices have already been put into place by the EU and its Member States to keep track of material flows, stocks, and related environmental impacts. Most implemented practices apply a top-down assessment approach, which is based on collected statistical transaction data and makes use of supplementary information regarding composition and/or input-output flows. Supplementary information is applied when the collected data does not suffice for the desired information. The representativeness of the supplementary information used is a key challenge for the monitoring's accuracy following a top-down approach. The analysis' accuracy is particularly affected when there is a large uncertainty or variability in the supplementary information. Furthermore, the information is often not up to date as it is based on historical situations [37].

The deployment of data in business digital infrastructures for gathering micro-level data from economic operators can enhance macro-level monitoring. Collecting more detailed sustainability-related information concerning products, processes, facilities, or transport of economic operators allows the retrieval of previously inaccessible information, reducing the need for supplementary information and increasing the credibility of public interventions. Adding business data to macro-level monitoring can help overcome challenges related to data representativeness and timeliness.

5. Discussion: an information and data typology for CE monitoring

This study demonstrates that effective CE monitoring within public administration requires a multi-level information approach, integrating diverse data types and aligning them with different phases of the policy cycle. As shown in Figure 2, each phase has distinct information needs and objectives, which determine how information is computed at the macro, meso, and micro levels. Figure 2 places these policy phases horizontally and vertically distinguish the three information levels: macro (super-national, national, regional), meso (industry sector, municipalities), and micro (business, product, households). At the macro level, authorities receive aggregated statistics and proxies that capture broad trends in resource consumption, employment in circular sectors, and material footprints. These data points support high-level agenda setting and help policymakers evaluate whether overarching policy goals, such as reducing total material use, are being met. However, macro-level data can mask local variations and requires complementary insights from the meso and micro levels.

At the meso level, municipal and city-specific data refines broad aggregated metrics. Indicators like waste collection rates, building demolition numbers, and localized product trends enable policymakers to design interventions that reflect the needs of distinct urban or sectorial contexts. By highlighting local conditions, this approach bridges the gap between strategic policy objectives and practical implementation. Meso-level data is used in policy formulation to identify specific areas requiring attention and in policy implementation to support ongoing monitoring of local performance.

At the micro level, attention shifts to granular information, often based on transactional and process data that businesses record in their digital infrastructures, including DPPs. These systems offer detailed insights into product characteristics, materials used, and manufacturing or operational processes, all of which are essential for real-time risk analysis and compliance checks. For instance, product-level data can help border authorities determine if a vehicle's battery is near end-of-life, an issue with potential ramifications for illegal exports or improper waste handling. This level of detail allows for immediate corrective actions when legislative requirements are not met.

Figure 2 also categorizes data by characteristics, amount or volume, process, exchange, monetary, and location data, such as material origin or the presence of substances of concern, illustrating how each type can be aggregated or analyzed in different policy phases. The data can serve as direct input for policymaking in the format of micro-level information or form the basis for the analytics that generate meso and macro information. Ownership and control of data sources is a key factor in the design of effective CE monitoring systems. At the micro level, private businesses frequently hold data, which means that authorities often need (legal) incentives and consent mechanisms to gain access. Certificates and assurances that verify regulatory compliance may be shared through direct digital transmission or via intermediaries such as certification agencies. In contrast, data stored in government systems, such as centralized DPP registries, is under public control and can be accessed by authorities with the proper permissions. This dual ownership model requires transparent and secure data-sharing arrangements to maintain trust between businesses and public administrations.

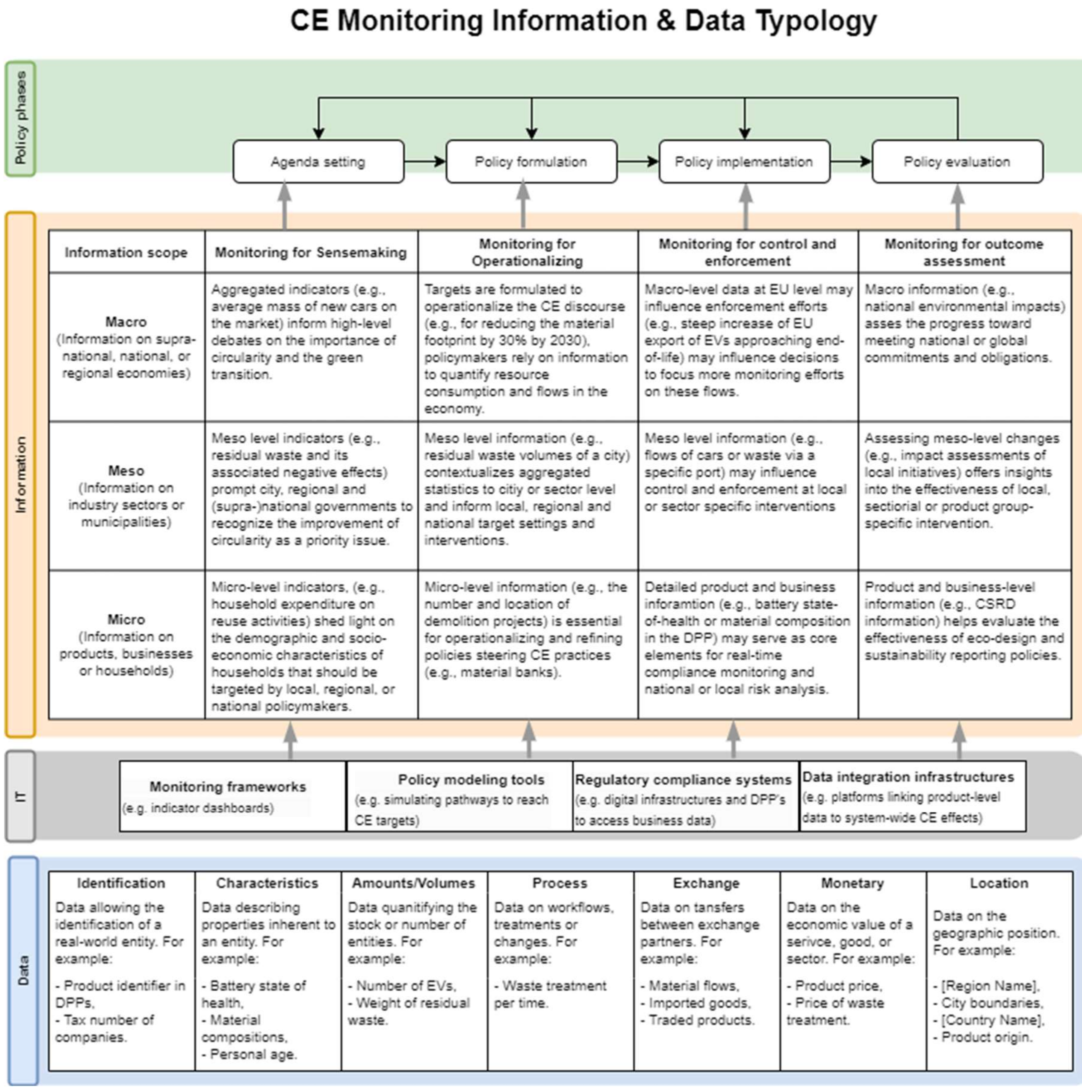

Figure 2: Information and data typology for CE monitoring.

There are several limitations to our research that merit discussion. First, our focus on existing digital infrastructures and data typologies may not fully capture the rapid technological changes that influence how data is generated, stored, and analyzed. As new tools and platforms emerge, the data categories we have identified could shift or expand, indicating a need for ongoing refinement of the typology. Second, we used the policy cycles as a framework to simplify reality by distinguishing different stages. However, in practice, these stages often overlap and interact. This was illustrated in the city monitoring case: data to inform the policy formulation on waste treatment was later used to report waste fractions and to evaluate the effectiveness of the intervention. By combining information at the macro, meso, and micro levels, policymakers can develop an adaptive, evidence-based approach to guiding the transition to a circular economy. Aggregated statistics and proxies at the macro level inform national targets and long-term strategies, more granular data at the meso level shapes localized interventions, and detailed exchange data at the micro level facilitates real-time compliance checks. Although our framework provides a solid foundation for data-driven multi-level CE monitoring, the evolving nature of digital infrastructures and the potential for AI-based technologies to enhance data analysis and predictive capabilities suggest that further refinement is necessary. Future research is needed to investigate innovative technological solutions, including AI-based analytics, to strengthen public administrations' ability to monitor and enforce CE initiatives in an increasingly dynamic digital landscape. Third, our study is predominantly grounded in a European context and may not translate seamlessly to regions with different regulatory frameworks or technological capabilities. Further research is needed to ensure that the proposed monitoring framework remains relevant and adaptable to diverse contexts.

6. Conclusion

Policymakers and public authorities have an important role in steering the CE transition. Whereas governments rely on specific data sources for their tasks (e.g., policymakers on macro-economic statistical data and border authorities on customs and other declaration data), new CE monitoring tasks require them to look beyond these familiar data sources. This creates uncertainties on how to get access to relevant data and requires preparations with a sense of urgency in view of the timelines of the EU regulatory framework for the transition to a CE. For their (potential) CE monitoring tasks, data is essential through all stages of the policy process: agenda setting, policy formation, implementation, and evaluation, on all levels. By zooming in on the different needs and roles governments have during these stages of the policy cycle, we identified a variety of information types and data sources that governments (can) deploy. By analyzing three typical cases of CE monitoring in each policy phase, we created a conceptual framework to inform and support policymakers and public authorities on different levels of policymaking and enforcement to prepare for gaining access to relevant data.

In the early policy phases, combining data sources can enhance CE monitoring by improving data quality and granularity. Currently, macro-indicators such as material footprints or material flows are derived from top-down regional input-output models, which provide a general idea of resource consumption in Flanders. However, these indicators overlook sectoral and municipal differences, which limits their usefulness for targeted policy interventions. The integration of micro- and meso-level data, such as LCA data or household budget surveys, can identify key drivers (e.g. specific product categories, household characteristics or sectoral impacts) and highlight hotspots for agenda setting and provide more actionable insights for policy formulation

With the advancement of digital infrastructures on the business side (either due to business drivers or because of policy interventions, as is the case with DPPs), increasingly more data will become available. This data can be used for different purposes. For example, in the policy implementation phase, micro-level business data from DPPs can be used to cross-validate legally required transactional data for the purpose of compliance control by customs authorities. And in the policy evaluation phase, aggregated micro level data can yield additional input to the macro-economic data that is used for policy insights. Hence, data quality and availability can be enhanced for CE monitoring tasks.

Beyond showing the information and data typology in our conceptual framework, we offer two ways forward for policymakers and enforcement agencies. First, the preparations for gaining access to the relevant data require investments in IT capabilities and technical skills. If public organizations have similar interests, they can collaborate to share their capabilities and jointly create incentives for businesses to voluntarily share data beyond the mandatory data. Second, even if the same data (source) is of interest to several public organizations, a tailored approach is required as their roles in CE monitoring are either on different levels or in different policy phases. Therefore, we recommend future research into the creation of data ecosystems for public administrations to exchange knowledge and capabilities for CE literacy, to explore the added value of DPPs, and of AI-based tools and mechanisms to handle large volumes of data to structure messy data.

Acknowledgements

This paper has been partially funded by the DATAPIPE project, which has received funding from the European Union's Technical Support Instrument (TSI) programme under grant agreement No 101094495. Ideas and opinions expressed by the authors do not necessarily represent those of all partners. L. Alaerts acknowledge the financial support received from the Flemish administration via CE Center (Steunpunt Circulaire Economie). R. H. Reich is grateful for the internal C2-funding of KU Leuven (Grant No: 3E210013). M. Pauwels is grateful for KU Leuven's funding provided by VITO (Grant No: 3E230665). This publication contains the opinions of the authors, not those of the Flemish administration. The Flemish administration will not carry any liability with respect to the use that can be made of the produced data or conclusions.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

References

[1] European Commission: The European Green Deal. COM(2019) 640 final. European Commission, Brussel (2019)
[2] Schroeder, P., Anggraeni, K., Weber, U.: The relevance of circular economy practices to the sustainable development goals. Journal of Industrial Ecology. 23, 77–95 (2019)
[3] Morseletto, P.: Targets for a circular economy. Resources, conservation and recycling. 153, 104553 (2020)
[4] European Commission: Closing the loop—An EU action plan for the circular economy, (2015)
[5] Ministerie van Infrastructuur en Milieu: A Circular Economy in the Netherlands by 2050, (2016)
[6] French Government: A French act of law against waste and for a circular economy, (2020)
[7] Vlaamse Regering: Mededeling aan de Vlaamse regering: Een transversale werking voor de circulaire economie van Vlaanderen, (2020)
[8] Generalitat de Calunya: Roadmap for the Circular Economy in Catalonia 2030, (2024)
[9] European Commission: A new Circular Economy Action Plan, (2020)
[10] European Commission: Circular Cites and Regions Initiative: Supporting Europe's circular economy at local and regional level, (2020)
[11] ICLEI: Circular Cities Declaration Report 2024 Insights on implementation, measurement, and nature, (2024)
[12] Milios, L.: Advancing to a Circular Economy: three essential ingredients for a comprehensive policy mix. Sustainability Science. 13, 861–878 (2018). https://doi.org/10.1007/s11625-017-0502-9
[13] Hartley, K., Schülzchen, S., Bakker, C.A., Kirchherr, J.: A policy framework for the circular economy: Lessons from the EU. Journal of Cleaner Production. 412, 137176 (2023)
[14] Cairney, P.: The politics of evidence-based policy making. Springer (2016)
[15] Buckland, M.K.: Information as thing. Journal of the American Society for information science. 42, 351–360 (1991)
[16] Esty, D., Rushing, R.: The promise of data-driven policymaking. Issues in Science and Technology. 23, 67–72 (2007)
[17] Medaglia, R., Rukanova, B., Zhang, Z.: Digital government and the circular economy transition: An analytical framework and a research agenda. Government Information Quarterly. 41, 101904 (2024). https://doi.org/10.1016/j.giq.2023.101904
[18] Zeiss, R., Ixmeier, A., Recker, J., Kranz, J.: Mobilising information systems scholarship for a circular economy: Review, synthesis, and directions for future research. Information Systems

Journal. 31, 148–183 (2021). https://doi.org/10.1111/isj.12305
[19] Reich, R.H., Arteaga Prieto, E., Pauwels, M., Alaerts, L., Van Acker, K.: Discovering the circular economy as a problem space for information systems research. (2025)
[20] Lasswell, H.D.: The decision process: Seven categories of functional analysis. University of Maryland Press (1956)
[21] De Marchi, G., Lucertini, G., Tsoukiàs, A.: From evidence-based policy making to policy analytics. Annals of operations research. 236, 15–38 (2016)
[22] Jann, W., Wegrich, K.: Theories of the policy cycle. In: Handbook of Public Policy Analysis. pp. 69–88. Routledge (2017)
[23] Alaerts, L., Van Acker, K., Rousseau, S., De Jaeger, S., Moraga, G., Dewulf, J., De Meester, S., Van Passel, S., Compernolle, T., Bachus, K., Vrancken, K., Eyckmans, J.: Towards a more direct policy feedback in circular economy monitoring via a societal needs perspective. Resources, Conservation and Recycling. 149, 363–371 (2019). https://doi.org/10.1016/j.resconrec.2019.06.004
[24] Van Acker, A., Borms, L., Pals, E., Dams, Y.: Repair indicators. CE monitor background document. (2024)
[25] Reich, R.H., Vermeyen, V., Alaerts, L., Van Acker, K.: How to measure a circular economy: A holistic method compiling policy monitors. Resources, Conservation and Recycling. 188, 106707 (2023)
[26] Flanders, S.: Materialenvoetafdruk, (2024)
[27] Férauge, S., Alaerts, L., Thomassen, G., Christis, M., Vercalsteren, A., Van Acker, K.: Overview of Existing Targets for the Circular Economy in Flanders. (2024)
[28] Vlaamse Regering: Beleidsnota 2024-2029: Economie, Wetenschap, Innovatie en Industrie, (2024)
[29] OVAM: Lokaal Materialenplan 2023 - 2030. (2023)
[30] European Parliament, Council of the European Union: Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repeal, (2024)
[31] European Parliament and the Council of the European Union: Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, (2023)
[32] European Parliament and the Council of the European Union: Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/17, (2024)
[33] European Commission: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Our Waste, our responsibility: Waste shipments in a clean and more circular economy COM(2021) 708 final, (2021)
[34] Segers, L., Ubacht, J., Tan, Y.-H., Rukanova, B.: The use of a blockchain-based smart import declaration to reduce the need for manual cross-validation by customs authorities. In: Proceedings of the 20th Annual International Conference on Digital Government Research. pp. 196–203. ACM, New York, NY, USA (2019)
[35] European Commission: Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. COM(2019) 640 final, (2019)
[36] European Commission: Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020. COM(2020) 789 final, (2020)
[37] Lennartz, J., Jansen, K., Rietveld, E.: Digital products passport data to improve the material flow and stock monitoring and forecasting at EU-level: the case of EV-batteries. In: 32nd CIRP Conference on Life Cycle Engineering (LCE2025). , Manchester, United Kingdom, April