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Indicators for Measuring the Circular Economy in Canada

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REPORT

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About the Collaborators

CIRAIG: Established in 2001, CIRAIG was created to meet the demands of industry and governments to develop leading edge academic expertise in sustainable development tools. CIRAIG is an internationally acclaimed centre of expertise in life cycle issues, and has developed a recognized expertise in life cycle tools including Life Cycle Assessment (LCA) and Social Life Cycle Assessment (SLCA). Completing this expertise, its research projects also cover material flow assessment (MFA), input-output (IO) modelling and other approaches such as circularity indicators.

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Table of Contents

List of Tables

List of Figures

Abbreviations and acronyms

CE	Circular Economy
DMC	Direct Material Consumption
DMO / DMI	Direct Material Output / Input
DPO / DPI	Domestic Processed Output / Input
EEIO	Environmentally Extended Input Output
EMC	Environmentally weighted Material Consumption
EW-MFA	Economy-Wide Material Flow Analysis
IO	Input Output tables
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MF	Material Footprint
MFA	Material Flow Analysis
MRIO	Multi-Regional Input Output
NAS	Net Addition to Stock
PSS	Product Service System
RMC	Raw Material Consumption
RME	Raw Material Equivalent
SLCA	Social Life Cycle Assessment

Executive Summary

While in recent years climate change and biodiversity loss have been Canada's environmental policy priorities, globally these issues are increasingly seen as symptoms of a broader problem of overuse of resources (e.g. fossil fuels, biomass, construction materials, water, land and energy) and lack of attention to the impacts on the environment, such as pollution, this causes. The "Circular Economy" (CE) is a conceptual model that has begun to emerge in business, policy, and civil society discussions as a response to these challenges. At its ideal, the vision for a CE is one where the needs of an increasingly populous and wealthy global society can be met within the safe boundaries of key ecological systems and processes. CE thought leaders, such as the Ellen MacArthur Foundation, offer three core principles to enact this vision: i) waste and pollution are designed out the economy; ii) products and materials are kept in use; iii) natural systems are regenerated and enhanced.

Global government and business leaders (including the G7, G20, European Union (EU), Organisation for Economic Cooperation and Development (OECD), United Nations (UN), World Business Council for Sustainable Development (WBCSD) and World Economic Forum (WEF)) have all endorsed the vision for a more circular economy. For example, the European Commission adopted its first CE Action Plan in 2015 (and upgraded it in 2020) – including initiatives along the entire lifecycle of products promoting CE processes, fostering sustainable consumption, and ensuring that resources are kept within the EU for as long as possible. China (2008) and Japan (2013) also have active CE strategies and legislation, and new collaborations, such as one between China and the EU (announced in 2018) suggest a more comprehensive global vision.

Without question, broad implementation of a CE will bring new and different challenges for Canada's economy. A CE will favour durable, reusable, recyclable and/or compostable materials, and correspondingly will likely increase demand for strategic raw materials that better accommodate product designs to meet these requirements. Identifying policies and strategies to increase innovations for improved recycling, recovery, quality-assurance, and traceability of material resources will be necessary to take advantage of the opportunity presented by an increasingly circular global economy. However, to do so we must also develop the indicators and modelling approaches needed to monitor and assess the advancement towards a CE in Canada.

As the development of adequate circularity indicators continues to gain relevance globally in order to further a CE transition (including, for example, the Ellen MacArthur Foundation's Circulytics initiative, the recent Circular Economy Indicators Coalition organized by the Platform for Accelerating the Circular Economy (PACE), or the Circular Economy Technical Committee formed by the ISO (ISO/TC 323)), this report aims to explore the relevant indicators and tools needed to monitor progress towards a CE at a national level for Canada, and what data and information is required to further modelling such indicators in the Canadian context. To better understand potential future pathways for a CE in Canada the report sought to provide insights and details about the indicators and tools that can be used to answer three major questions:

- How circular is the Canadian economy?
- How to improve the material circularity of Canada?
- To what extent a Canadian circular economy is a step toward a sustainable society?

In doing so, the report reviews experience with different indicators and how they align with these three guiding questions. In addition, a detailed appendix is provided, which lists key indicators reviewed in the development of this study and organizes them according to common characteristics, the types of questions each indicator is designed to address, and the CE strategies they embody. In doing so, this grouping and categorization is both novel and innovative, and the organizational framework provided to understand CE indicators is a key contribution of this report. Readers are particularly directed towards Table 1, which lays out this organizational framework.

A key take-away from this review is that measurements of material circularity cannot simply sum up kilograms of materials -- there are different dimensions to consider depending on the diversity of substances to account for, the diversity of economic sectors, and the consequences for society on different timeframes. Modelling approaches, objectives, and data requirements are not independent, and the required data collection and analysis frameworks need to be chosen accordingly.

The issue of how to effectively monitor progress towards CE is therefore an emerging and ongoing debate. As our findings illustrate, measuring the circularity of a system is challenging and there is no common agreement on how to capture the whole spectrum of CE strategies within one consistent assessment framework. However, in light of this review, we recommend considering the following aspects when measuring and tracking a Canadian CE transition:

1. Keeping track of global Canadian material flows;
2. Identifying the most strategic materials and sectors for the Canadian economy, and;
3. Designing circular scenarios to achieve optimal use of materials in Canada, along the entire supply chain from raw resource extraction to product end-of-life.

Introduction

Over the past decade, the Circular Economy (CE) has gained attention among policymakers, practitioners, and researchers. A CE aims to connect existing production-related strategies, such as eco-design, responsible production, and responsible procurement, to product and service optimization strategies, such as the sharing economy, maintenance and repair strategies, donating and reselling, performance (functionality) economy, reuse and redistribution, refurbishing, biochemical extraction, recycling and composting, and energy recovery (IEDDEC 2018). The growing interest in the CE is evidenced by the multiplication and diversity of definitions of a CE in academic disciplines and areas of implementation (Kirchherr et al., 2017).

The CE is an umbrella concept (Homrich et al., 2017) as it aims to encapsulate and connect separate areas of knowledge and experiences under a common denominator of resource efficiency and reduced environmental impacts. However, despite the lack of a unified definition and adequate assessment tools, it is largely agreed that its primary goal is to decouple economic activity from the degradation of natural capital, by using economic models that preserve resources and improve waste management. Rather than picking one of the numerous possible definitions in the literature, the authors of this paper refer to the CE framing and strategies outlined by IEDECC in Figure 1.

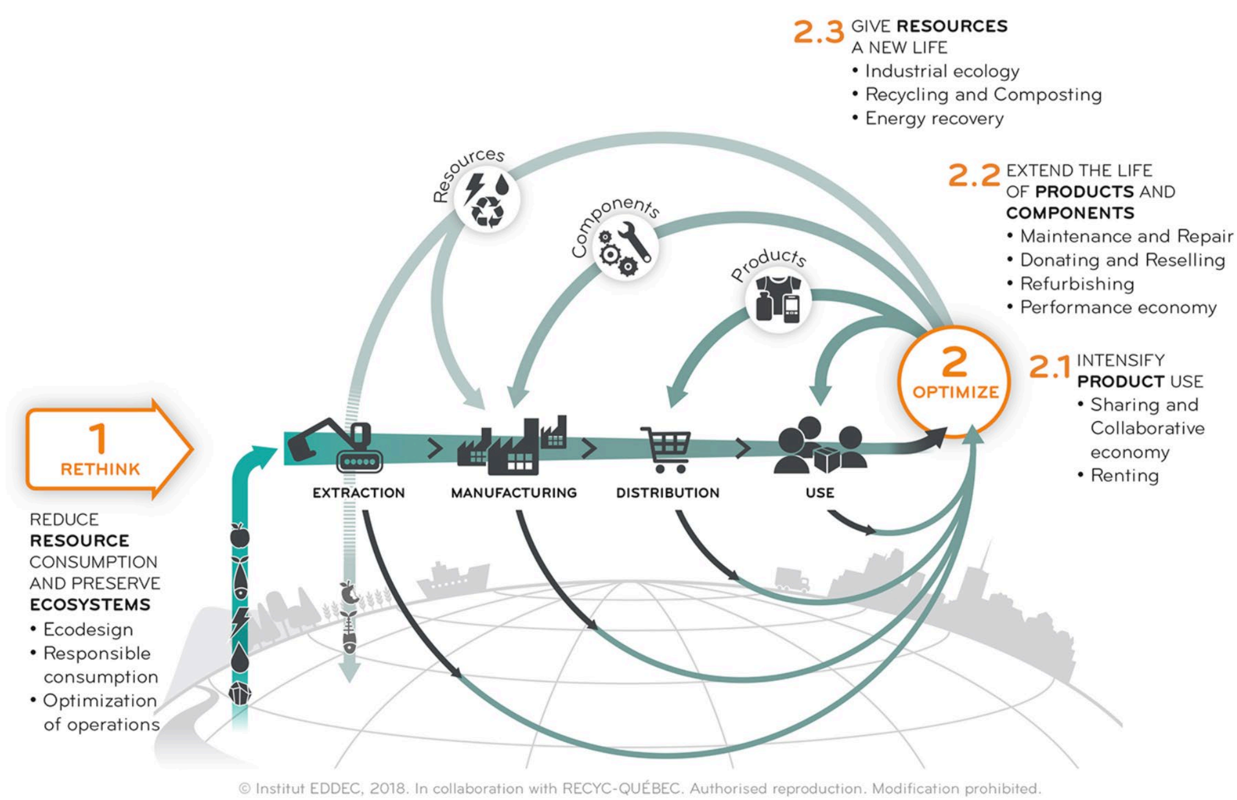


Figure 1: The circular economy concept and its strategies (IEDDEC 2018).

Both the EU and China are recognized for their legislative efforts towards implementing CE practices. However, they have differing contexts of implementation. In the case of China, rapid growth concurrent with issues related to pollution was the driver for the Chinese government to be among the very first to implement CE policies and concrete action plans for industries (McDowell et al. 2017). In the EU, the CE has been gaining traction since 2015 as demonstrated by various new policy measures as well as the adoption of a CE monitoring framework (EC 2015, 2020). However, monitoring progress towards a CE remains an ongoing debate. Most monitoring frameworks aim to measure material efficiency (through the degree of loop closing), and absolute reductions in resources extraction and consumption (through the overall inflows and outflows of societies' metabolism) (Mayer et al., 2019). In practice however, monitoring frameworks adopt different indicators, based on contextual factors. Thus, to achieve a national decoupling objective, relevant assessment metrics and methodologies need to be carefully understood and developed.

As the development of adequate circularity indicators continues to gain relevance to further the CE transition, this report aims to explore what are the relevant indicators and tools needed to monitor progress towards a CE at a national level and what data and information is required to further modelling such indicators in the Canadian context. To better understand potential future pathways for a CE in Canada the report sought to provide insights and details about the indicators and tools than can be used to answer three major questions:

- How circular is the Canadian economy?
- How to improve the material circularity of Canada?
- To what extent a Canadian circular economy is a step toward a sustainable society?

To achieve this objective, the authors reviewed indicators and tools noted in the scientific literature and grouped them based on common characteristics related to the type of question they answer. Figure 2 provides a high-level overview of the structure of the report based on the resulting indicator classifications, by question.

In the remainder of the report, Section 2 provides an overview of findings in this report, as they apply to informing the data and modelling approaches available to analyze a CE transition in Canada. Sections 3-5 then survey the types of indicators reviewed in this study, as they apply to each of our three guiding questions. Section 6 follows to explore evidence of priority industries for a CE in Canada, while Section 7 provides some final recommendations. In addition, a detailed appendix is included with the report, providing more background information on the data and indicators reviewed for this study, organized according to the following structure:

- Category: throughput indicators, material circularity indicators, normalized indicators, environmental impact indicators, socio-economic indicators and indicators measuring strategic characteristics of materials;
- Equation type of indicator, e.g. measure, ratio or index;
- Production, consumption or End-of-Life oriented indicators;
- Unit, e.g.: tons or dollars;
- Calculation method and type of data required;
- Examples of application and remarks.

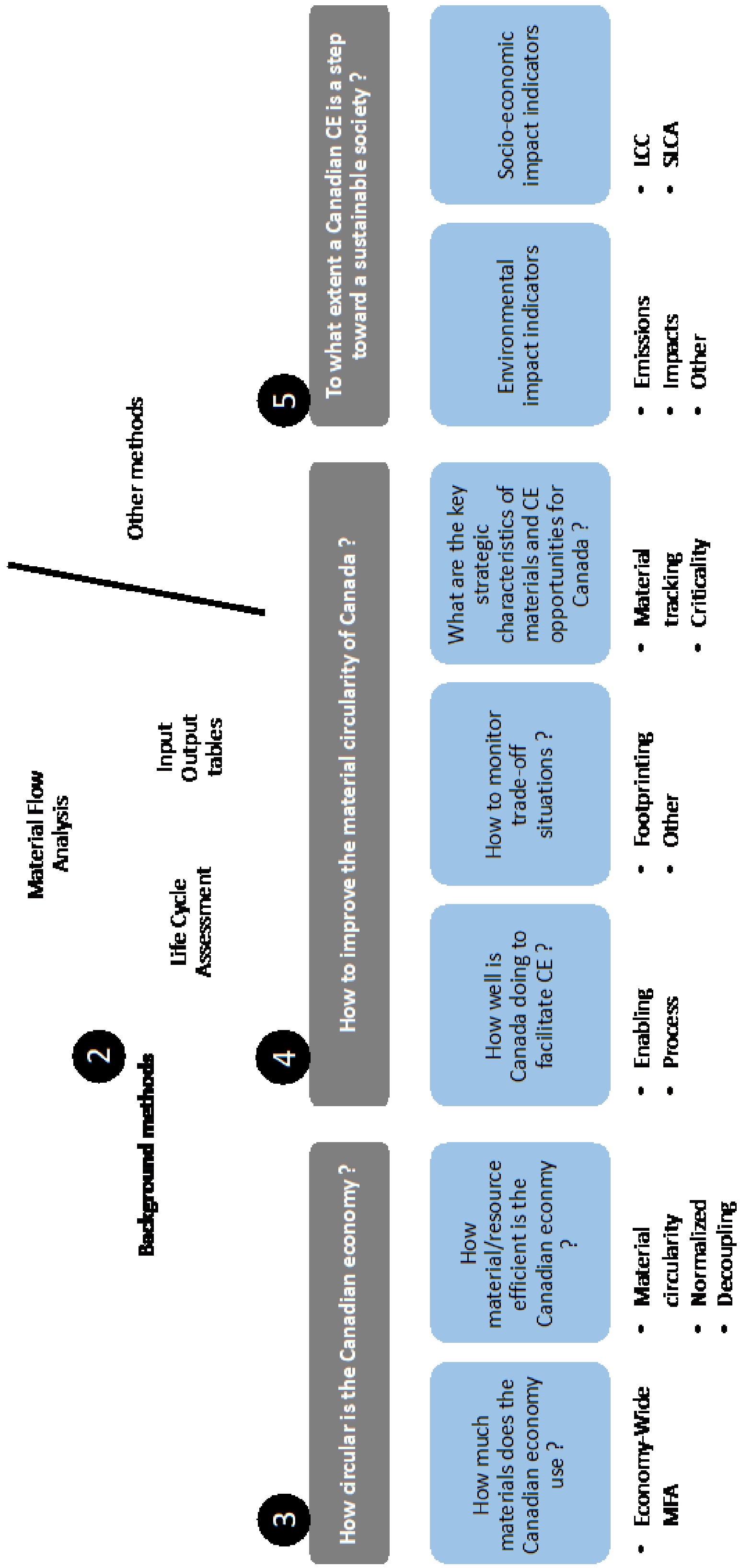


Figure 2: Organization of the report and indicators classification

Overview: Data & Modelling Tools to Support a Circular Economy Transition

A key implication emerging from this review is the need to improve data availability, measurement and tracking for CE transitions. Improved data availability, data sharing for improved material traceability, and the development of analytical and modelling tools to support scenario development for improved material circularity are highlighted as core requirements – with data gaps limiting our current understanding of a CE transition in Canada and elsewhere. However, the issue of how to effectively monitor progress towards a CE is an emerging and ongoing debate. Measuring the circularity of a system is challenging and there is neither a single approach to defining and measuring material circularity, nor is there common agreement on how to capture the whole spectrum of CE strategies within one consistent assessment framework.

A key take-away from this review is that measurements of material circularity cannot simply sum up kilograms of materials -- there are different dimensions to consider depending on the diversity of substances to account for, the diversity of economic sectors, and the consequences for society on different timeframes. Modelling approaches, objectives, and data requirements are not independent, and the required data collection and analysis frameworks need to be chosen accordingly.

To preview and supplement the discussion and findings in following sections on specific categories of CE indicators as they relate to the guiding questions for this report, Table 1 provides an overview of the different types of indicators that have been proposed in the literature to assess progress towards a CE. Table 1 is therefore, in many ways, a core outcome of this study, as it summarizes indicators and tools (mostly from the scientific literature) and groups them according to common characteristics, the types of questions each indicator is designed to address, and the CE strategies they embody. In doing so, this grouping and categorization is both novel and innovative, and the organizational framework provided to understand CE indicators is a key contribution of this report.

As highlighted in Table 1, understanding potential future pathways for a CE requires addressing our three major questions: (1) how circular is the economy or sector of interest?; (2) how can material circularity be improved?; and (3) to what extent are CE approaches compatible with movement towards a sustainable society?. In the remainder of this report, we review the types of indicators highlighted in Table 1 and address the questions they are most likely to help answer in order to provide insights on the data, indicators and tools that will be required to inform a CE transition in Canada.

How Circular is a Particular Economy or Sector of Interest?

To initiate a step towards a CE at any scale (product, company, city, country), knowing the current state of "circularity" – or, conversely, how much material is used -- is essential to have a basis of comparison. Material accounting is therefore necessary to answer fundamental questions about material flows and to help policymakers assess the given state of circularity. As the CE mainly focuses on material resources, material accounting methods place material management on the forefront.

Table 1: Summary of CE Indicators Proposed in the Literature, the Questions they are Designed to Address and the Circular Strategies they Embody.

	How linear is an economy?		What can be done to improve material circularity country-wide?			To what extent is a CE a step towards a sustainable society?		Other relevant questions	What are the circular strategies illustrated?			
	How many materials does an economy consume?	How material/ resource efficient is an economy?	How well is an economy doing to facilitate CE?	How to monitor trade-offs?	What are the key strategic characteristics of materials and CE opportunities?	What are the environmental implications of a CE	What are the socio-economic implications of a CE?	How to consistently aggregate kg of materials?	Reduce resource consumption and preserve ecosystems	Give resources a new life by linking value chains	Extend the life of products and components	Intensify products use
EW-MFA indicators	X								X	X		
Material circularity indicators		X							X	X		
Normalization options		X							X	X	X	X
Decoupling indicators		X							X	X		X
Enabling parameters			X						X	X	X	X
Process parameters			X						X	X	X	X
Footprint indicators	X	X		X	X	X			X	X		
Criticality indicators					X	X		X	X			
Environmental impact indicators				X		X		X	Scenario modelling in a life cycle approach			

Their goal is to indicate to what extent the system under assessment is material (and energy) consuming and how material (or energy) efficient it is.

However, accounting for material flows alone does not provide a complete indication of how circular an economic sector or system is. The CE encompasses much more than improved material efficiency, recycling, and recovery outcomes, including a broader range of both linear and non-linear material and energy flows, as well as environmental and social impacts. A number different approaches to measuring circularity have accordingly been developed in the literature and there is as yet no common agreement on a consistent or integrated set of indicators of circularity. We therefore summarize different approaches that have been adopted below, including Life Cycle Assessment, Input-Output Tables, Material Flow Analysis, and combinations thereof.

Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) requires identifying and quantifying matter and energy flows throughout a product's life cycle, which consists of technological processes from the cradle, i.e. raw materials extraction, to the grave, i.e. product's end of life processing. The first step of a LCA is to define a functional unit, which is a quantification of the product's or service's function under assessment, and determine the boundaries of the life cycle. This is followed by a Life Cycle Inventory (LCI) phase and a Life Cycle Impact Assessment (LCIA) phase, which translates resources, waste and emissions into the resulting environmental impacts (Hellweg & i Canals, 2014) building on scientifically-based cause-effect chains.

Life cycle methods have also been developed to evaluate the economic and social impacts of a life cycle, referred to as Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA), respectively (Fauzi et al., 2019). These along with the inclusion of temporal and geographical aspects, help answer sustainability-related questions arising from increasingly complex production and consumption systems.

Input-Output (IO) Tables

Input-Output (IO) tables are based on national statistics on industries' trading information and result from the combination of Supply and Use Tables (SUTs). The Supply Tables show the output value of the product groups that each industry sector produces. Use Tables on the other hand, show the purchases of products by industries (that use them in production) and final consumers (households and governments).

Similar to LCA, Environmentally Extended Input-Output analysis (EEIO) quantifies the emissions linked directly or indirectly to economic sectors (Agez et al., 2019). While LCA provides a detailed accounting of physical flows of every process involved in the life cycle, EEIOA groups national inventories to describe the interdependence between economic sectors (Miller & Blair, 2009). In EEIO, the environmental extension can account for industries emissions and resource use.

EEIO analysis has been used to a lesser extent than LCA to study the CE (Sassanelli et al., 2019). Wiebe et al., for instance, used the Multi-Regional IO (MRIO) database EXIOBASE in combination with a scenario from the International Energy Agency (IEA) to model a 2030 economy and study the impact of CE strategies (recycling, reducing, repair, and reuse) (Wiebe et al., 2019). They found that CE strategies could reduce raw material extraction by 10% while increasing employment by 2%.

Material Flow Analysis (MFA)

The goal of MFA is to map and quantify the flows and stock of resources into and from (or within) a particular entity of human society (Decker et al., 2000). For instance, MFA might be used to describe a system such as a city or a country in terms of its input and output flows of materials in space and time (Rincón et al., 2013). An MFA starts by defining a system's boundaries and then undertakes modelling of relevant processes and material flows within the system (Cencic & Rechberger 2008). Processes can be a transformation, transportation, or storage activity, and they are considered black boxes represented by inputs and outputs of the system (Cencic & Rechberger 2008). Processes are connected by material or energetic flows.

MFA can also be adapted to account for costs rather than physical flows in so-called material flow cost analysis (MFCA) (Merli et al., 2018). An advantage of MFA, as compared to LCA and EEIO, is that the method accounts for hidden flows of materials (Rincón et al., 2013). Those hidden flows constitute the materials that are necessary to obtain final goods, but which are not visible in economic accounts (e.g., wood harvesting losses) (Rincón et al., 2013). The methodology also enables keeping track of stocks, which is not possible in LCA or EEIO analysis (Lopes Silva et al., 2015).

MFA has been used to study CE at the country, region, or city scale. Some researchers, for instance, have applied MFA to develop circularity indicators (Sassanelli et al. 2019), while others have assessed the circularity of the global economy, the EU, or a specific city using an Economy-Wide MFA (EW-MFA) framework (Haas et al. 2015; Mayer et al. 2019; Voskamp et al. 2017). For example, a recent study assessing the circularity of European material flows (Mayer et al. 2019) has illustrated that the EU is still far away from achieving a CE -- with only a 9.6% recycling rate at the EU scale. MFA can also be adapted to account for costs rather than physical flows in so-called material flow cost analysis (MFCA) (Merli et al. 2018).

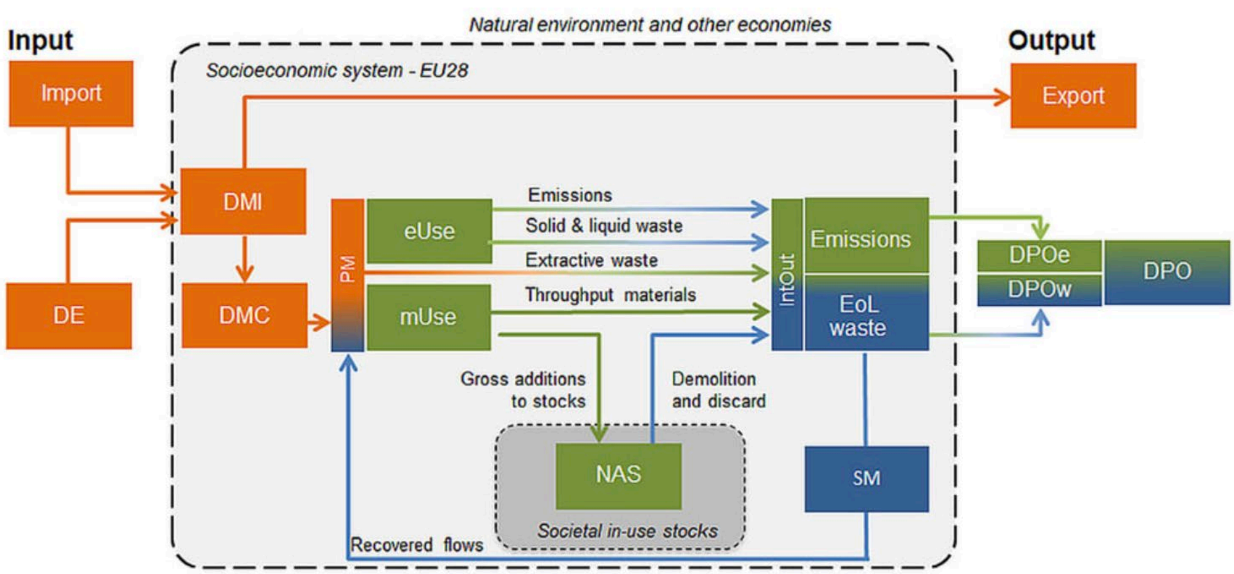
Scaling Indicators

Scaling indicators (also referred to as “throughput indicators”) measure the amount of material and energy flows throughout a system. These indicators, derived from the MFA methodology, help set governmental or regional targets on reducing raw material extraction and/or material waste: such as the total amount of industrial solid waste for final disposal, the total amount of wastewater discharge, or total material consumption to identify unrecovered waste. These “throughput indicators” scale material flows throughout a system defined in space and time, with the aggregation level defined according to national accounting preferences, data availability and policies.

Table 2 and Figure 3 summarize some of the main scaling indicators and their calculation method. These can also be found in Table A.1 in the Appendix, according to the classification method used throughout this report to highlight the different characteristics of the indicators surveyed. These indicators record material and energy flows from the environment to the economy, and vise-versa.

Table 1: Main EW-MFA indicators and their calculation method

Indicator	Calculation
DE (Domestic Extraction)	Known value
DPO (Domestic Processed Output)	Known value
IMPORT	Known value
EXPORT	Known value
DMC (Domestic Material Consumption)	DE + IMPORT - EXPORT
DMI (Direct Material Input)	DE + IMPORT
TMR (Total Material Requirement)	DE (used + unused) + IMPORT (direct + indirect)
PM (Processed Material)	DMC + SM
TMC (Total Material Consumption)	TMR - EXPORT
TDO (Total Domestic Output)	DPO (used + unused)
NAS (Net Addition to Stock)	PM - DPO - PM



DE = Domestic extraction; DMI = Direct material inputs; DMC = Domestic material consumption; PM = Processed material; eUse = Energetic use; mUse = Material use; NAS = Net additions to stocks; IntOut = Interim outputs; EoL waste = End-of-life waste; SM = Secondary materials; DPOe = Domestic processed output of emissions; DPOw = Domestic processed output of wastes; DPO = Domestic processed output

Figure 3: Framework and throughput indicators for an economy-wide CE assessment (Mayer et al., 2019)

For example, Domestic Extraction (DE) accounts for any “extraction or movement of natural materials on purpose and by humans or human-controlled means of technology” (Eurostat, 2018), while Domestic Processed Output (DPO) accounts for all material flows entering the environment as a result of production or consumption processes (Eurostat, 2018). Domestic Material Input (DMI), meanwhile, accounts for Domestic Extraction (DE) and imports, while Domestic Material Consumption (DMC) does the same but subtracts the exports. DMC is sometimes perceived as an overall proxy for (future) environmental pressure, hence covering all relevant environmental impacts. However, it is important to note that DMC accounts only for raw and finished materials, not for embodied materials in imported and exported goods (Material Footprint accounts for this as noted in subsequent sections).

Net Addition to Stock (NAS) measures the physical growth of the economy. NAS results from balancing MFA equations and is considered a "blind spot" in term of circularity assessment. Setting governmental targets on this indicator would require scaling down to the industry or product level in order to gauge circular practices (not identifiable as material flows in MFA) such as: extending product lifetimes, reusing and remanufacturing, or sharing. At the macro scale, these activities might only be accounted for qualitatively.

As MFA-derived indicators, the indicators in Table 2 aggregate kilograms of materials, generally disregarding whether they are semi-finished or finished products. To overcome this limitation, further key refinements can include expressing traded products in terms of domestic raw material extraction as the Raw Material Equivalent (RME). Indeed, when Domestic Material Consumption (DMC) is expressed in terms of RME, it is referred to as Raw Material Consumption (RMC).

Combining Methods

The different methods reviewed above can also be combined to alleviate each other’s weaknesses or to yield new indicators of overall circularity or material use. For instance, IO tables can complement MFA models, and the other way around, to track indirect material flows and calculate footprint indicators (reviewed in more detail in subsequent sections).

LCI and Life Cycle Impact Assessment (LCIA) can also complement both MFA and IO tables to characterize environmental impact indicators of material flows. For instance, the use of IO tables allows for extension of the boundaries of a system at the LCI stage. Thus, using both tools can help to overcome their respective weaknesses. In the case of LCA, defining system boundaries can often force the exclusion of background processes which, in turn, truncates parts of the real-world system. In the case of IO tables, individual firms and their specific technological processes are not represented, making it impossible to realize a study on a specific product or business model. Moreover, niche markets of the CE, such as second-hand products, are not represented in IO tables (they are instead aggregated in a broader economic sector such as "other manufactured goods).

Methods deriving from the field of Industrial Ecology can also be combined with methods deriving from complex systems science. For instance, agent-based modelling can help to deal with uncertainties deriving from behaviour-driven use, local variabilities, and emerging technologies when performing LCA (Micolier et al., 2019). Meanwhile, combining LCA with system dynamics and/or agent-based modelling can allow for the addition of temporal dynamics or for the consideration of mutual interactions among critical factors of business model, product design, and supply chain (see, for example, Peng et al. 2018, Asif et al. 2016). For instance, a recent study by Walzberg et al. (2019) combined LCA with agent-based modelling to explore energy consumption in smart buildings as an example of the advantages of combining methods to study CE strategies involving social changes.

Table 3: Summary of Methods from Industrial Ecology and their output indicators

Method	Indicators
Life cycle assessment	Raw Material Consumption (RMC), Environmental Interventions (LCI), Environmental Impact (LCIA)
Environmentally extended input-output analysis	Raw Material Consumption (RMC), Material Footprint (MF), Circularity gap index (CGI), Waste ratio, Environmental Interventions (LCI), Environmental Impact (LCIA)
Material flow analysis	Direct Material Input (DMI), Total Material Requirement (TMR), Total Domestic Output (TDO), Domestic Material Consumption (DMC), Processed Material (PM), Raw Material Consumption (RMC), Material Footprint (MF), Net Addition to Stock (NAS)

How Can Material Circularity be Improved?

Material accounting is an essential step to assess the circularity level of a system defined in space and time. However, more complex assessment methods are required to find ways to improve circularity. Circular strategies apply at different scales and can result in different practices for industries, governments, and civil society.

Thus, improving material circularity country-wide requires coordinating both top-down and bottom-up approaches. This raises two questions:

- How can individual initiatives (e.g., circular product designs or businesses) contribute to improving material circularity country-wide?
- How can governments foster and improve circular practices?

Even if the ultimate benefits of a CE are measured at a macro level, their success depends on initiatives at the micro scale. Since businesses and government have different purposes, they advocate for different CE operationalization pathways (based on different accounting of individual benefits vs collective consciousness).

Figure 4 illustrates the idea that improvements towards material circularity at micro scale do not necessarily correlate with a broader, market- or economy-wide material circularity. For example, maximizing the use of recycled PET in bottle production can increase the material circularity within bottles but may divert their use from other products where the recycling process is more efficient, thus decreasing material circularity of the PET market (Lonca et al., under review). This is also true the other way around: macro-level material circularity may require a partial increase in linearity. The

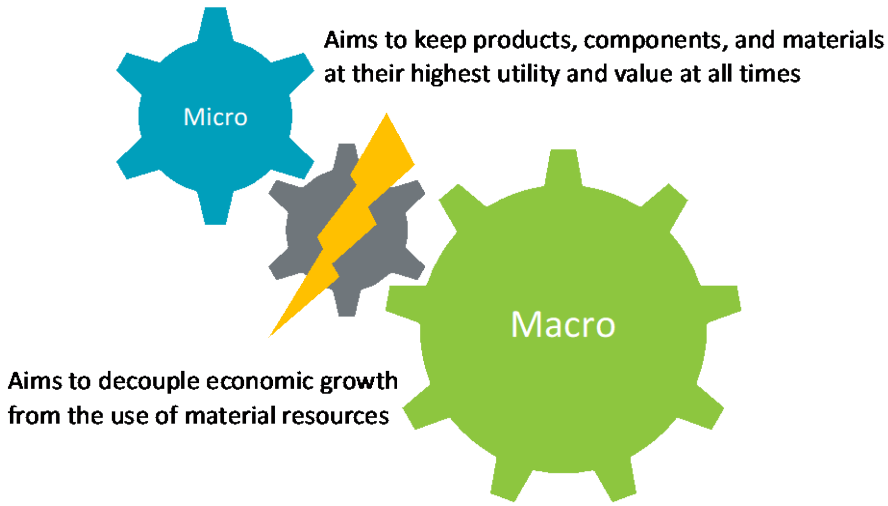


Figure 4: Coupling micro-level circular economy approaches with macro-scale targets.

micro-macro disconnection is especially true in a context favoring the emergence of synergies among industries and governments, where collaborations are essential.

How Material or Resource Efficient is the Economy?

Barring a reduction in consumption levels, total material use can conceivably only be reduced through an increase in the efficiency of material use in an economy (i.e. a decoupling of material extraction from production and consumption activities). This section presents indicators relevant to the question of material efficiency.

Material Circularity (or 'Gap') Indicators: Circularity indicators are usually represented in the form of ratios, capturing efficiency measures such as the share of recycled materials in production or the proportion of unrecoverable to total waste. Examples of material circularity indicators include the circularity gap indicators proposed by Aguilar-Hernandez et al. (2019), which compare non-recovered waste to waste generation and stock depletion. These types of indicators allow target-setting by tracking the share of recovered waste or by comparing non-recovered waste to domestic material consumption -- thus explicitly addressing the potential to reduce waste generation. Other approaches to circularity indicators focus on either input flows – capturing what is introduced into the economy, or output flows – capturing what is recovered at the end-of-life. These include Eurostat indicators on the recycling rate of municipal solid waste, the use of biomass (i.e. the ecological cycle), or fossil fuel use (reflecting non-circularity). Table B.2 in the Appendix summarizes and provides more detail regarding the material circularity indicators discussed here.

Normalized Indicators: Also identified as 'Intensive indicators', normalized indicators are designed to be independent of the size of the system under assessment. Normalized indicators often compare material flow indicators, either between each other or with other dimensions. A frequent application of normalized material accounts, for instance, is to compare obtained MFA values to another system of reference. In China, the National circular economy indicator system includes efficiency indicators such as energy consumption and water consumption *per unit product* in key industrial sectors. Other types of unidimensional indicators, such as the Eurostat indicator on self-sufficient of raw material use, indicate the dependence of the physical economy on domestic raw material supply by measuring the ratio of Domestic Material Consumption (DMC) to Domestic Extraction (DE), while still others illustrate trade intensity by measuring the import or export intensities of the physical economy (Krausmann et al. 2017). These indicators provide complementary information that help identify potential leakage, by measuring the displacement of raw material extraction abroad.

Other normalization options include dividing material quantities by population or gross domestic product (GDP) giving, respectively, a demographic and an economic context to circularity comparisons across countries or regions. China, for instance, tracks both energy consumption and water withdrawal per unit of GDP, as well as energy consumption and water withdrawal per added unit of industrial value. Japan, meanwhile, integrated a measure of GDP per DMI into their 2003 Fundamental Plan for a Sound Material-Cycle Society (FPSMCS). Table B.3 in the Appendix further summarizes and catalogues the normalization options discussed here.

Decoupling Indicators: In both academic and policy (grey) literature, the CE's ultimate objective is commonly described using the concept of decoupling, and definitions of the CE often reference a decoupling framework. For example, McCarthy et al. (2018, pg 16) define the CE as "any process that enables the decoupling of economic input from virgin resource extraction".

UNEP (2011) has distinguished two types of decoupling: resource decoupling and impact decoupling. While impact decoupling aims to minimize resource extraction's overall environmental impacts, the focus of resource decoupling is to use fewer primary resources per unit of economic growth, thus delinking (to the extent possible) economic growth and natural resource depletion by minimizing resource extraction (UNEP 2011). Traditional CE models have accordingly often encouraged resource decoupling – with a goal to minimize primary resource flows into the economy (Murray et al. 2015). Once raw material extraction has been minimized, impact decoupling principles are then applied further down the supply chain, to minimize waste, reduce pollution, and recover materials and value in manufacturing and consumer product markets. Figure 5, obtained from Eurostat, provides one example illustrating decoupling pathways over time. The red dashed lines in the figure demarcate the boundaries between 'no-decoupling', 'relative decoupling', and 'absolute decoupling' pathways.

Tracking GDP and material use such as DMC over time can accordingly serve to illustrate the decoupling process of a region. In a coupled pathway, the more the economy grows, the more it relies on raw material extraction. Decoupling implies a less material intensive economy, either by reducing material use or by introducing secondary materials back into the economy. Comparing material use or waste generation to population and tracking the evolution of population, GDP and material use (such as DMC) over time allows for measurement of the influence of specific explanatory variables on final material consumption and the possibility to calculate elasticities for these explanatory variables on material intensity.

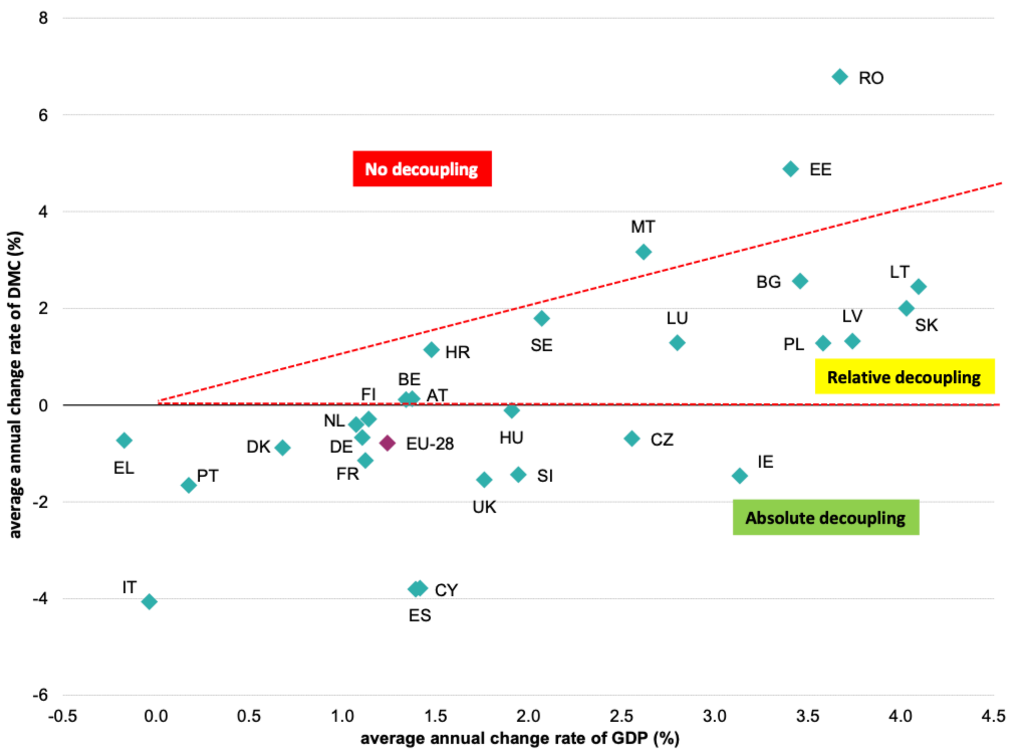


Figure 5: Decoupling pathways between 2000 and 2015 for EU countries (Eurostat, 2018).

Table B.3 in the Appendix summarizes decoupling indicators based on the normalization options discussed in the preceding section, while Table A.1 in Appendix A also lists recent decoupling studies, drawn from a summary published by Sanyé-Mengual et al (2019).

Enabling Parameters vs. Process Parameters

To gauge how well the CE mechanisms put in place in an economy or sector are performing, it is necessary also to distinguish between indicators and parameters based on whether the measured value represents a potential target to set governmental objectives in the transition towards a CE (indicator) or a contributor (parameter). For instance, recycling rates are considered one of the many parameters that contribute to decreasing the amount of primary material potentially introduced back into the economy (the indicator, quantifying an objective). There are two types of parameters: enabling and process parameters. Table A.4 in the Appendix further summarizes and lists additional detail regarding the indicators and parameters discussed here.

Enabling Parameters: Unlike the material circularity, normalized, and decoupling indicators discussed above, enabling parameters do not quantify how well a particular region, country, or municipality is performing with regards to circularity. Instead, enabling parameters indicate how well a particular region or jurisdiction is doing to *facilitate* a CE through public policies or programs. For instance, Eurostat proposes to quantify gross investment in the recycling, repair and reuse sectors, as well as the number of patents related to recycling and secondary raw materials (see Table 4 for a more complete classification of EU CE Monitoring Indicators, drawn from Eurostat). Other potential enabling parameters include the number of circular businesses supported, investment in CE demonstration projects, legislative and normative incentives created, enterprises receiving financial support in connection with the CE, or the amount of financial aid granted to companies in connection with the CE.

Table 4: Classification of the EU CE Monitoring Framework Indicators

Classification	Focus	Indicators
Production & Consumption	EU Self-Sufficiency for Raw Materials	• Net Import Reliance (%)
	Green Public Procurement	• Share of public procurement measures above EU thresholds which include environmental elements
	Waste Generation	• Generation of municipal waste per capita (Kg per capita) • Generation of waste excluding major mineral waste per GDP unit (Kg per 1000 Euro) • Generation of waste excluding major mineral wastes per domestic material consumption (%)
	Food Waste	• Waste generated in the production, distribution, and consumption of food (million tonne)
Waste Management	Recycling Rates	▪ Recycling rate of municipal waste (%) ▪ Recycling rate of all waste excluding major mineral waste (%)
	Recycling/Recovery for Specific Waste Streams	▪ Recycling rate of (i) overall packaging, (ii) plastic packaging, (iii) wooden packaging, and (iv) e-waste (%) ▪ Recycling of biowaste (kg per capita) ▪ Recovery rate of construction and demolition waste (%)
Secondary Raw Materials	Contribution of Recycled Materials to Raw Materials Demand	▪ End-of-life recycling input rates (%) ▪ Circular material use rate (%)
	Trade in Recyclable Raw Materials	▪ Imports from non-EU countries (tonne) ▪ Exports to non-EU countries (tonne) ▪ Intra EU trade (tonne)
Competitiveness and Innovation	Private Investment, Jobs and Gross Value Added Related to Circular Economy Sectors	▪ Gross investment in tangible goods (% of GDP) ▪ Persons employed (% of total employment) ▪ Value added at factor cost (% of GDP)
	Number of Patents	▪ Number of patents related to recycling and secondary raw materials

Source: Adapted from Eurostat: Circular Economy Indicators (https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework)

Process Parameters: Process parameters attempt to make explicit what traditional MFA-derived indicators indirectly capture. Due to their black-box structure, MFA-derived indicators for macro-scale systems (i.e. EW-MFA indicators) do not allow a sufficient level of detail to identify the contributions of alternative CE practices, and may allow for different interpretations of circularity outcomes. Process parameters, alternatively, attempt to track the implementation of specific CE strategies which ultimately may lead to reduced resource consumption.

A typical illustration of process parameters deriving from the implementation of CE strategies was explored by Material Economics, in a recent report quantifying the potential for CE opportunities to reduce GHG emissions from heavy industry by 2050 in the EU (Material Economics 2018). For each material studied (steel, plastics, aluminum and cement) they identified circularity measures that reduce the need for primary materials, such as increased recycling, reduced waste in production, increased reuse of components, new business models (e.g. car sharing) or circular materials handling (e.g. increased reuse of building components). With this approach, Material Economics found that material recirculation strategies, product material efficiency improvement and circular business models could reduce 178 Mt CO_2 per year, 56 Mt CO_2 per year and 62 Mt CO_2 per year, respectively, making emissions fall from 530 Mt CO_2 per year to 234 Mt CO_2 per year by 2050 in the EU (Lonca et al., 2019). See Figure 6.

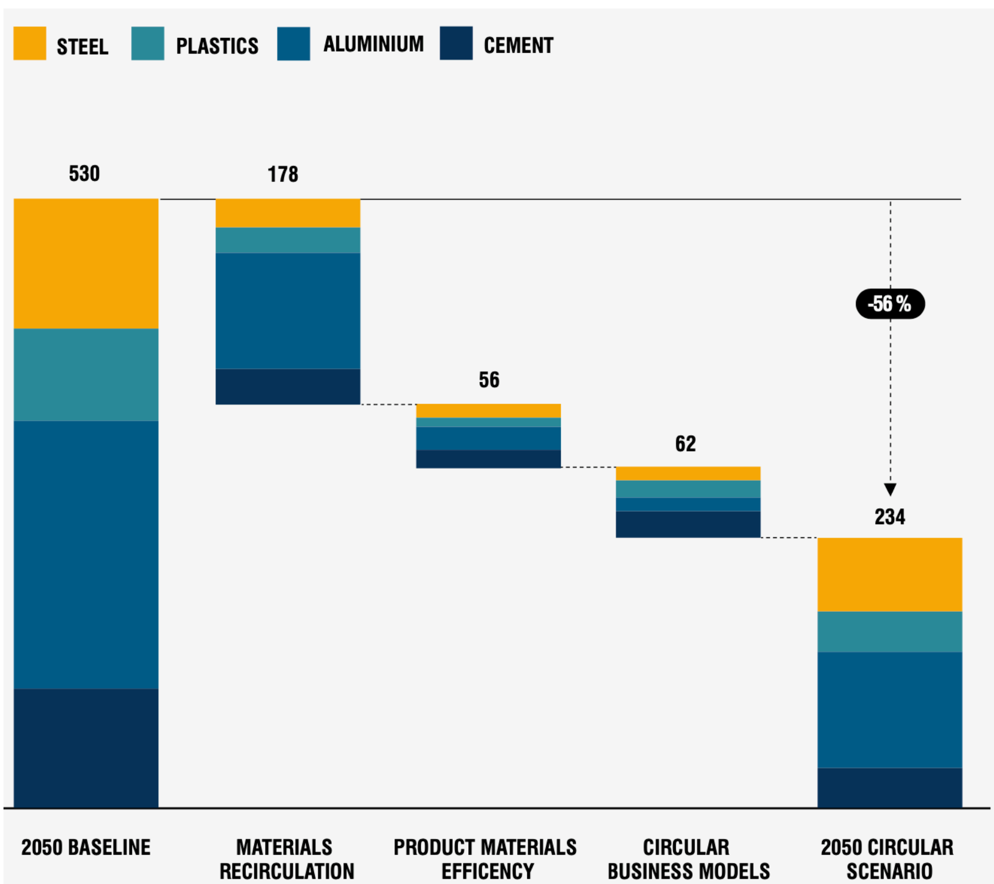


Figure 4: EU emissions reductions potential from a more circular economy, 2050 (in Million tons of CO_2 per year) from Material Economics (2018)

The underlying idea with process parameters is therefore to explore the potential of specific CE strategies which may ultimately lead to reduced resource consumption via relative or absolute decoupling. As a general example, if we restrict our measurement of material circularity to macro-level indicators, such as DMC per GDP, this treats the underlying drivers of CE improvements as a black box, allowing for various interpretations of circularity outcomes. Process indicators rather refer to specific CE strategies, as illustrated in the decomposition below. If we define DMC with the following identity:

$$DMC = GDP \times \frac{DMC}{GDP} \tag{1}$$

Splitting the second term to illustrate CE process drivers could take the following form:

$$DMC = \sum \frac{Virgin\ material}{Product} \times \frac{Product}{service} \times \frac{Service}{capita} \times \frac{capita}{GDP} \times GDP \tag{2}$$

Here the first term (*Virgin material* / Product) could either illustrate the amount of recycled materials introduced back into the economy, thus illustrating how well secondary materials are used, or how less material intensive a product is due to the application of eco-design principles. The second term (Product / Service) could illustrate the degree of adoption of Product-System Services (PSS), which favour the service content of value production and thus potentially support the dematerialization of the economy or the extension of product lifetimes. Finally, the third term (*Service/Capita*) embodies sharing activities, and when associated with the second term, illustrates the degree of adoption of a collaborative economy, thus fostering the sharing of material assets to improve the intensity of product use. This is an example of what the indicator of DMC per GDP could hide in a context where CE practices are intended to be implemented. In turn, each term could be further split into several process parameters.

Thus, rather than a single indicator, approaches with process parameters illustrate CE as a combination of factors working together towards a reduction of material or energy use.

Micro-scale Indicators for CE

There is an extensive body of literature attempting to design CE assessment indicators dedicated to micro-scale systems, such as for process and products. Some of these are explored below to highlight the similarities and distinctions in capturing CE attributes with micro- versus macro-scale indicators.

The Material Circularity Indicator (MCI) developed by Ellen MacArthur Foundation and Granta Design (2015) measures for a specific product "the extent to which linear flow has been minimized and restorative flow maximized for its component materials, and how long and intensively it is used compared to a similar industry-average product". The MCI is based on four (4) circularity principles/components: the fraction of recycled/reuse content in a product, the fraction of a product recycled/reused at the end-of-life, product lifetime and product use frequency.

While the MCI is often considered to represent the best attempt in taking product longevity into account, it is not the only indicator to do so. Based on the idea that a CE focuses on creating value through material retention, Franklin-Johnson et al. (2016) proposed a longevity indicator to measure the duration of resource components throughout successive product cycles. The result is expressed in time units and accounts for the fraction of recovered materials and the duration of their successive use.

Other indicators focus more specifically on micro-level recycling rates or overall product recyclability. For example, Linder et al. (2017) propose a product-level circularity metric using value chain costs as an estimator to compute the ratio of recirculated economic value to total product value. The Material Recycling Index (Material-RI) by van Schaik and Reuter (2016) is a tool created to visualize the recycling rate of a product, by expressing the recycling rate of the individual elements from the flowsheet of a specific process. Alternatively, the CEI (Circular Economy Index) proposed by Di Maio and Rem (2015) focusses on market value of recycling activity, estimating the ratio of the material value produced by a recycler to the material value entering the recycling facility.

Similar to measuring simple recycling rates, Park and Chertow (2014) propose an approach that instead focusses on technical recycling potential -- the Resource Potential Indicator (RPI). RPI is the ratio of the mass of economically recoverable material, according to the available technology, to the total mass of material waste. Similarly, Vanegas et al. (2017) propose a single indicator called the EDiM (Ease of Disassembly Metric) based on a calculation of product disassembly time. These types of indicators illustrate more the "circularity potential" rather than the actual circularity degree of a product. The word "potential" refers to the ideal maximum capacity for reusing a material, primarily from a technological perspective.

Finally, based on the idea of connecting micro-level behavior to macro-level outcomes, Figge et al. (2017) proposed measuring the eco-efficiency of virgin resources (EEVR). Acknowledging that improving understanding of eco-efficiency at the micro-level helps in decision-making for individual actors, the EEVR combines the material efficiency of a product along multiple and successive steps, from resource extraction to ultimate end-of-life.

To What Extent are CE Approaches Compatible with a Sustainable Society?

While the concept of CE is often directly linked to strategies for reducing waste and saving material resources, it should also make explicit the connections of circular strategies to broader issues of sustainable development. For instance, recycling processes are sometimes energy intensive, so that connecting CE to other sustainability indicators is necessary to highlight potential trade-offs for CE strategies. This section therefore considers indicators directly connecting other sustainable development dimensions with material use. In addition, it will explore questions concerning the quantification of different resource flows – since material values often differ depending on material type, characteristics, as well as endowed environmental load (or impact). Most of the indicators cited in this section should accordingly be considered as quantification methods dedicated to aggregating resources based on their environmental, waste, and economic characteristics.

Environmental Impact & Footprint Indicators

While material flows are often viewed as a proxy for environmental damage in CE studies, linkages between material flows and specific environmental impacts should be further elaborated (Moriguchi 2007). Life Cycle Assessment (LCA) – discussed in Section 3 above – is one of the most widely applied methodologies to assess the environmental performance of CE strategies (Sassanelli et al. 2019). For example, Lonca et al. (2018) used it to identify potential environmental trade-offs between material versus environmental efficiency of circular strategies, while Laso et al. (2018) used LCC to evaluate both the environmental and economic benefits of certain CE strategies. Outcomes from such LCA studies suggest that circularity indicators based on MFA may in some cases be at odds with environmental indicators (Lonca et al. 2018; Walker et al. 2018).

Similarly, material footprint indicators capture specific quantities of key input factors or impacts (e.g. environmental impacts, material or energy consumption) which are required across the supply chain to service final demand. Footprint indicators recognize that not all material inputs into the manufacturing process necessarily become part of the product. A country can, for instance, have a very high Domestic Material Consumption (DMC) because it has a large primary production sector for export or a very low DMC because it has outsourced most of the material intensive industrial process to other countries. Thus, a material footprint is an extension of standard material flow accounts that captures the amount of extracted material needed to produce a certain (set of) product(s), throughout the entire production chain, irrespective of whether material extraction took place domestically or in the rest of the world (Eurostat 2018). For example, Wiedmann et al. (2015) use footprint indicators to track countries' use of non-domestic resources throughout international supply chains.

Ecological footprint calculations aggregate up various material footprint indicators to allow comparison to carrying capacity, documenting the extent to which human activities compromise the biosphere's ability to regenerate. Usually expressed in number of 'Earths' consumed, ecological footprint gives a clear idea on how unsustainable an economy is, however it also hides detailed information about the components and drivers of unsustainability and so can be of limited use for policymakers.

Table B.4 in the Appendix further summarizes these environmental impact indicators.

Socio-economic impact indicators

In the pursuit of developing an integrated Life Cycle Sustainability Assessment (LCSA) tool, the social pillar of sustainable development is an indispensable dimension that needs to be adequately assessed. In this regard, Social Life Cycle Assessment (SLCA) provides a list of indicators to address social issues along product lifecycles. However, research in SLCA is fragmented, and many social indicators lack standardization (Kühnen and Hahn, 2017).

The CE also lacks sufficient evidence regarding the impact of circularity on inequality. Among the recurring outcomes of adopting a CE in industry is the creation of qualified jobs due to new business opportunities, new ways of recovering residual materials, or the adoption of professional reintegration programs (e.g., Insertech in Montréal). For instance, research has shown that container deposit programs have enabled many homeless people to make money (Andersen, 2007). On the other hand, the implementation of CE strategies may have negative employment effects in primary resource extraction sectors such as mining (Meyer et al. 2016). It is therefore difficult to conclude the net benefits linked to job creation and greater attention to integrating socio-economic indicators may be beneficial in the context of a Canadian transition to a CE.

Table B.5. in the Appendix summaries available socio-economic indicators.

Application: Priority Industries & Strategic Indicators for a CE in Canada

Priority Industries for a Circular Economy in Canada

As mentioned throughout the report, measuring the circularity of a system is not straightforward. It is challenging to find a consistent assessment framework to capture the full spectrum of CE strategies. Measuring CE progress goes beyond simply measuring material efficiency and absolute reductions in resource extraction and consumption throughout societal flows. It is illustrated through a multitude of different indicators adapted to contextual factors where CE measures are implemented.

Similarly, CE cannot be achieved using a one size fits all approach. Policy options driving circularity will differ significantly by sector as they each face unique barriers and opportunities. Thus, the development of a national CE strategy or CE indicators should be preceded by identifying which industries and sectors of the Canadian economy would reap the greatest benefits of becoming circular.

Currently, there is no set methodology to assess priority industries for a CE transition, and different jurisdictions and academics have developed unique quantitative and qualitative methodologies based on their contextual circumstances and requirements. However, a recent report adapted by The Smart Prosperity Institute (Patel & Donin, 2020) aimed to overcome this challenge. The report builds on the quantitative methodology initially developed by Yves Richelle for L'Institut EDDEC and presents a preliminary economic analysis to identify high potential industries in Canada, its territories, and provinces based on popular ongoing circular economy initiatives worldwide.

It is important to note that the recommendations of the report are not to be seen as definitive recommendations on which industries and sectors to prioritize for CE policies in Canada, but rather as a steppingstone for further deliberations with essential stakeholders and sectoral experts as different methodologies may yield different conclusions. Figure 7 illustrates the methodology used by SPI to conduct the analysis.

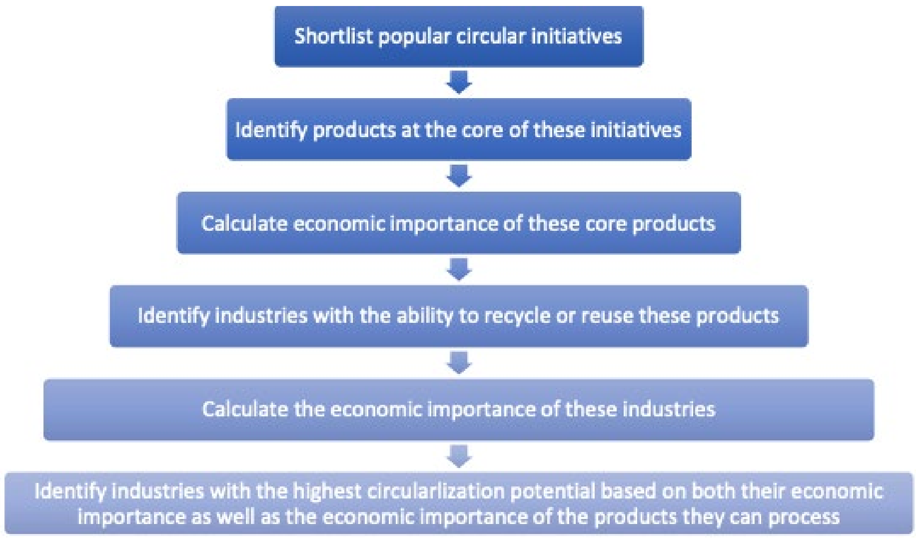


Figure7. Methodology to identify industries of priority for a CE

As outlined in Figure 7, the first step towards identifying high potential industries for a CE in Canada was to shortlist popular ongoing circularity initiatives worldwide. This was followed by identifying the core products used in these initiatives and finding their NAPCS classification. Next, the circularization potential of industries related to these initiatives in Canada was determined by calculating their economic importance and the economic importance of the products at the core of these initiatives. The economic importance of core products was estimated by calculating the total value of the product acquired by industries, households, and the public sector in a year. The output of this calculation was used as a proxy to indicate the economic importance of the core product in a jurisdiction. Finally, the economic importance of industries that can process the core products was determined. The economic importance was assessed by extracting the gross domestic product (GDP) of the industries for each jurisdiction from the Statistic Canada's – 2016 Supply and Use tables.

To determine which industries and sectors have the highest potential to benefit from circularization, the economic importance of both products and industries was observed concurrently. Figure 8 illustrates the findings:

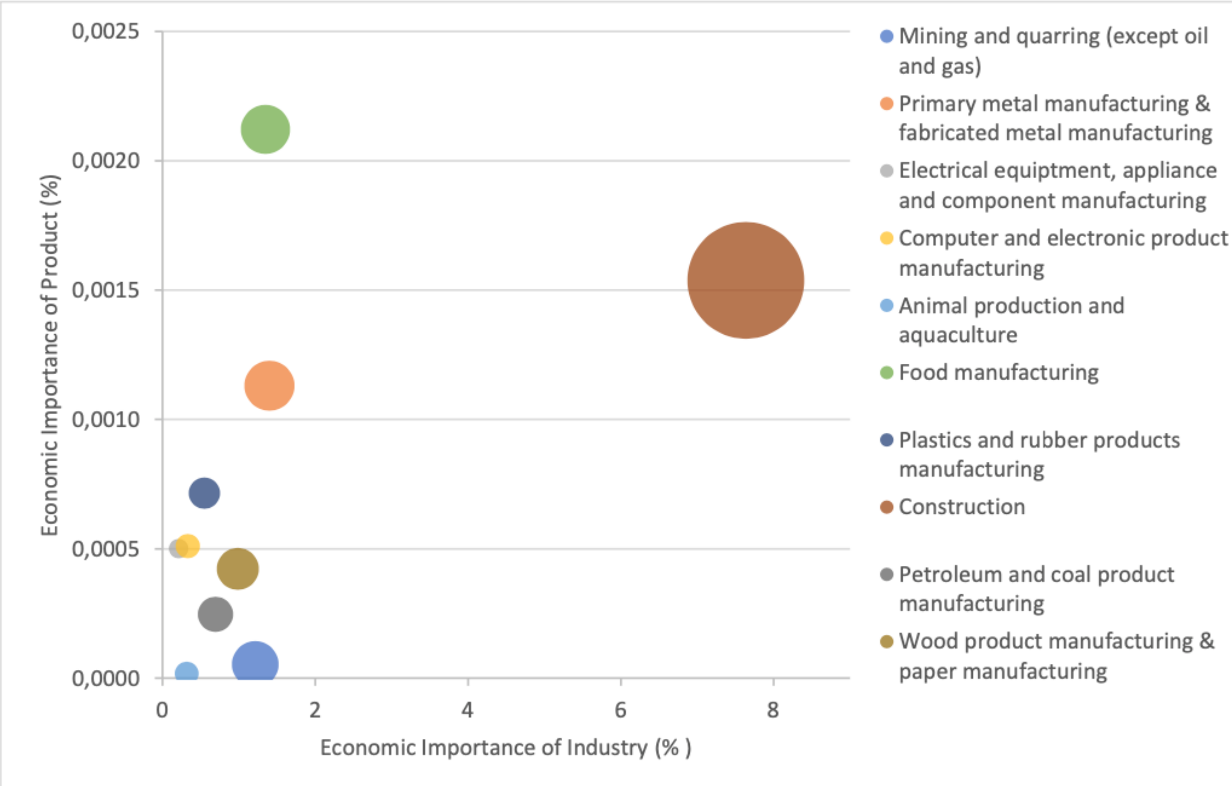


Figure 8. Prioritization of Industries for a CE in Canada

As figure 8 demonstrates, the industries which emerged with the highest CE potential were found to be construction, food manufacturing, and primary metal manufacturing, and fabricated metal manufacturing (taken together).

The analysis was replicated to determine the industries with the highest potential in the Provinces and Territories. Figure 9 illustrates the results of that analysis.

Similar to the findings at the national level, construction and food manufacturing emerged as the industries with the highest potential to benefit from circularization. It is important to note that the industries identified in Figure 9 are not ranked and are presented in no hierarchical order.

It is important to reiterate that the findings from this analysis are meant to act as a steppingstone for future deliberations amongst key stakeholders and sectoral experts. The findings should not be interpreted as definitive recommendations on sectors and industries for prioritization for CE policy in Canada, as alternative methodologies may yield different conclusions. A more in-depth evaluation which considers a full range of products that can potentially become a part of the circular economy, more circularization processes, and the industries capable of undertaking these processes is required to determine which sectors and industries have the highest potential to reap the benefits of a circular economy at both the federal and provincial level.

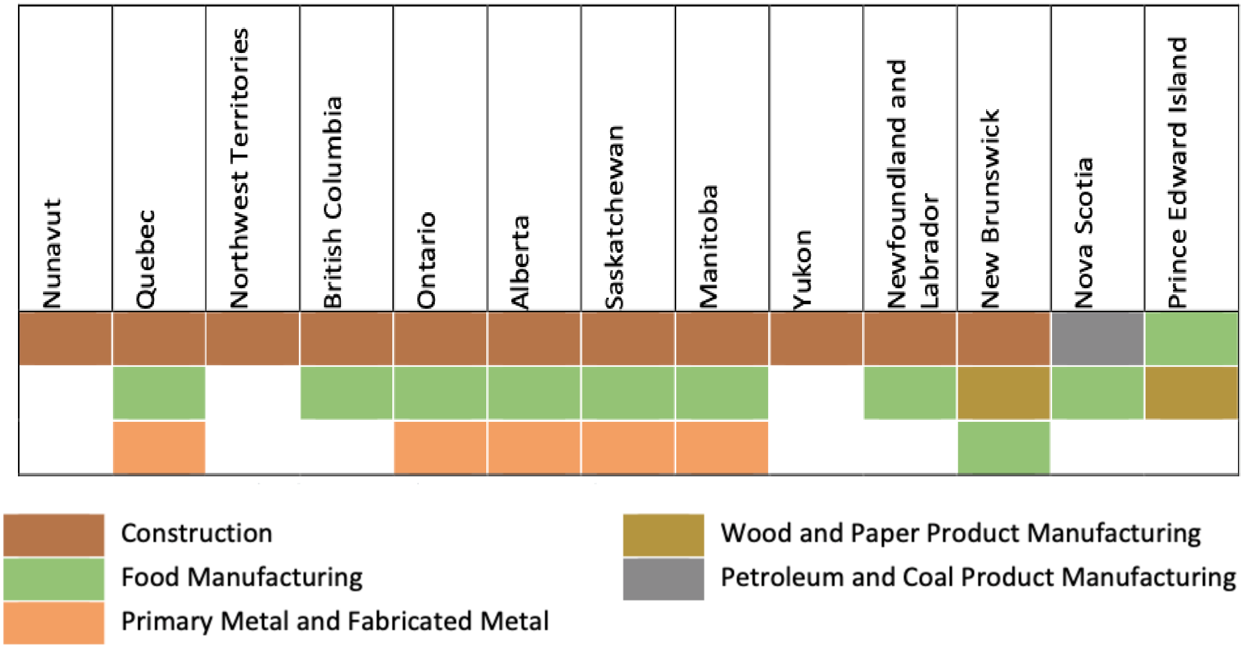


Figure 9. Prioritization of Industries for a CE in Canadian Provinces and Territories

Strategic characteristics of materials and CE opportunities for Canada

Further to the assessment of priority sectors for a CE in Canada, which may inform indicator prioritization and selection, it is also important to understand how CE indicators may used to measure strategic characteristics of material flows for Canada. These strategic characteristics refer to cross-dimensional material-related issues across key sectors, inducing strategic decisions for governments and industries. This group of indicators accounts for the multi-actor context induced by the globalization of material flows. Table B.6 in the Appendix summarizes the indicators used to measure strategic characteristics of material flows as we discuss here.

Material Tracking: Scholars have developed methodologies to trace the fate of material throughout a specific application based on the combined use of IO and MFA (Løvik et al., 2014; Nakamura et al., 2014). This combined approach traces the destination of material by-products and losses over time following initial production, thereby accounting for the number of times a unit of a material goes through end-of-life and its technological lifetime depending on its application. This type of analysis gives additional information on the application of CE strategies at product, process and industry levels and can help to improve the durability of specific material in product use.

Figure 10 provides an example based on the use of steel as a key component of car manufacturing from Nakamura et al/ (2014).

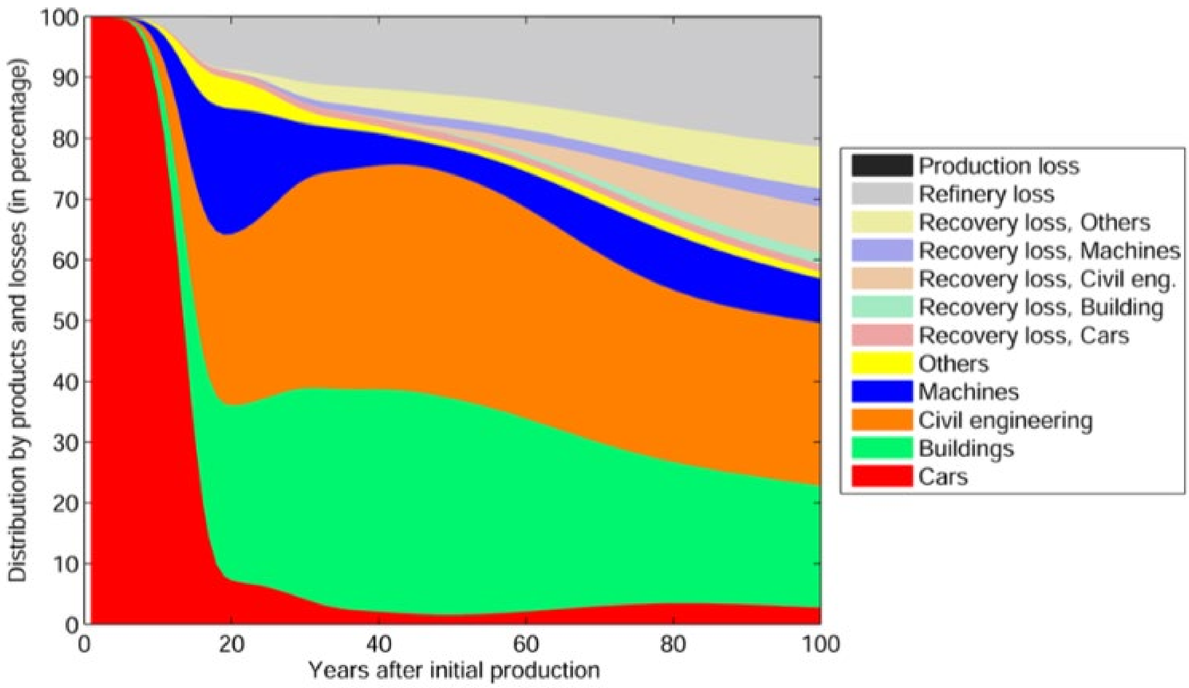


Figure 10: Destination of car steel used in Japan from Nakamura et al. (2014)

Criticality Indicators: Criticality indicators refer to the geopolitical and strategic context of material use, usually capturing three primary dimensions of criticality: high geopolitical concentration of primary production, lack of available substitutes, and political instability in the extraction region (Graedel et al. 2015). Criticality indicators are highly relevant to make strategic decisions on the use of material in industrial supply chains – as they identify the vulnerability for industrial sustainability to various material-related supply constraints. For instance, Graedel et al. (2015) find that the criticality of metal supply tends to be particularly acute for those metals available largely or entirely as byproducts, used in small quantities for highly specialized applications, and possessing no effective substitutes.

Even in cases where concern over material waste, resource efficiency, or embodied energy are already captured by other CE indicators or measures, criticality assessments add another factor to the choice over material supply. Individual indicators (disaggregated along the lines suggested by Graedel et al (2015): see Figure 11) must then be used to study the situation locally. Considering how critical a kg of a certain material is, and thus it's relation to broader notions of economic sustainability, adds other relevant dimensions to the issue of material and energetic resources management. Therefore, for certain decisions, it is important to distinguish between material sustainability characteristics in different dimensions, and not aggregate their characteristics in a global "total mass" indicator as in Section 3.

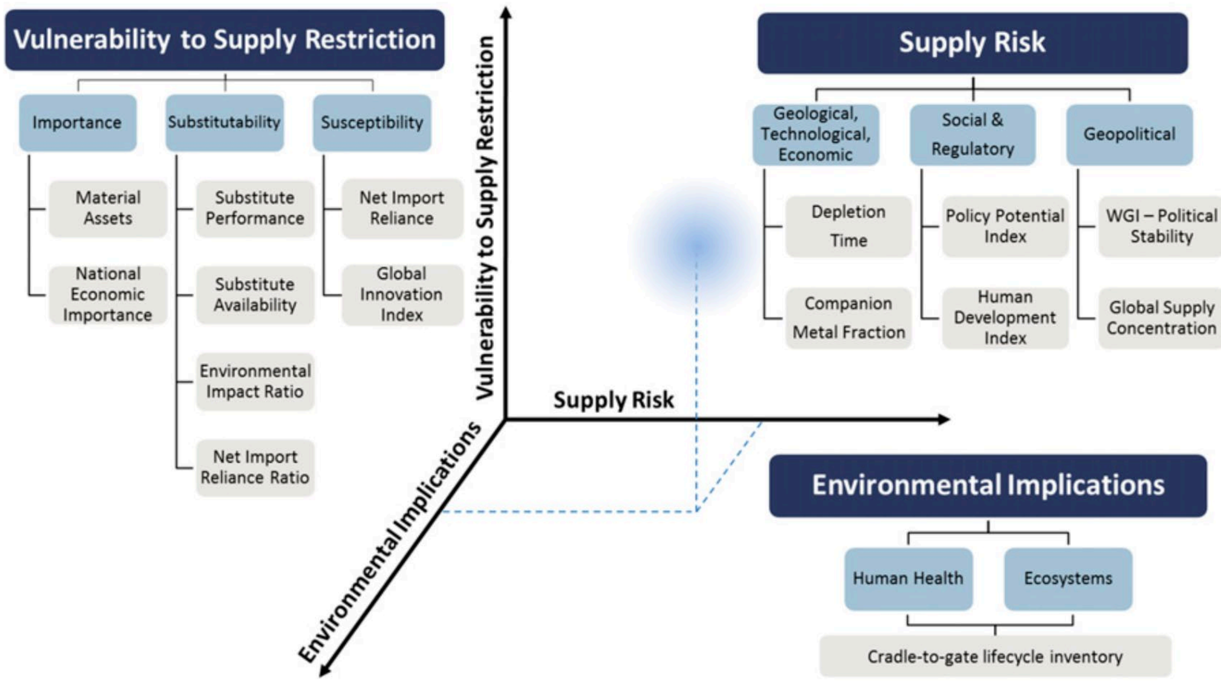


Figure 11: The methodology for criticality at the nation level from Graedel et al. (2015)

Conclusion: Summary & Recommendations

As this report illustrates, measuring the circularity of a system is challenging and there is no agreement on how to capture the whole spectrum of CE strategies with one consistent assessment framework. Nor is there one way to define and measure material circularity. The choice of modelling approach, tool selection and data collection are not independent, and the chosen framework(s) should be selected and developed accordingly.

Measuring Canadian material circularity cannot be performed by only summing up kilograms of materials. There are different dimensions to consider according to the diversity of substances to account for, the diversity of economic sectors and the consequences for society on different timeframes.

This report accordingly recommends considering the following aspects when measuring a CE:

1. *Keeping track of global Canadian material flows*

As discussed in Section 3, some European countries keep track of overall material flows to assess their decoupling levels. Using top-down indicators on overall circular performance, with throughput indicators derived from EW-MFA, improves the analysis of global circularity, and helps make comparisons with other countries. However, adding up kilograms of different types of materials is not sufficient to give a clear idea of how to improve circularity levels. The level of disaggregation of the flows should depend on the relative importance of each material and/or sector for the Canadian economy – following the kind of analysis illustrated in Section 6 above. The modelling framework should also ensure that the data collected are serving a policy purpose and open the door to more detailed data collection/analysis for specific cases/policy analyses.

2. *Identifying the most strategic materials and sectors for the Canadian economy*

Material flows should be detailed according to two aspects: the types of materials and the economic sectors using these materials. This approach will enable building a consistent framework that could then be used to map current/future flows and design adequate circular policies. In this regard, a Substance Flow Analysis could be done if needed for a specific material. This type of analysis is a disaggregated form of an EW-MFA and can be developed from existing Canadian IO tables.[1]

To facilitate the building of such a framework, it is recommended to start with the key materials and sectors of the Canadian economy. Criticality indicators could be used to define these key elements, to understand how the economy works regarding the use of a specific substance and their critical stakes such as the geopolitical context or their related environmental and social impacts. These key materials and sectors should be represented with a high resolution and confidence level – and should be prioritized for improved data collection where current data availability is found insufficient. Non-critical materials or sectors do not need such disaggregated and precise modelling, even if they could represent important materials in an EW-MFA.

Also, acknowledging the environmental and social implications of material uses is relevant at this stage. Identifying materials that have the greatest impact on Canadian sustainable development should be part of any circularity assessment. CE should not be considered a single-objective strategy. Even though the CE concept sheds light on resource preservation, it is not the sole objective to achieving sustainable development. Complementary indicators to monitor trade-offs with other environmental and across socio-economic issues need to be considered, to avoid making resource preservation a priority at the expense of other sustainability issues. While the Canadian IO tables and the derived material footprint indicators are relevant tools to consider in this regard, LCA is a relevant tool to consider at this stage since it reflects specific sustainability issues for a given material in each application (sector).

3. *Designing circular scenarios to achieve an optimal use of materials in Canada*

By developing circular scenarios and models at a high-resolution level, we should be able to develop a better understanding of the relevant materials and key economic sectors for Canada in a transition from a (mostly) linear to a (more) circular economy. At this stage, it is recommended to design prospective scenarios based on circular strategies that could be replicated at different levels (micro vs. macro), and including process and enabling parameters, alongside material use and sector-based outcomes, to better inform on the optimal use of materials.

[1] See, for example, Open IO-Canada, which distinguishes 246 commodities and 112 industries.

In this respect, Table 1, included earlier in this report, is meant to support the design of a set of indicators according to the questions they might answer in such a scenario-development process. Indicators to support policy decisions in relationship to the circular economy, at a regional, sub-national, or national level, should include indicators covering each of the following questions:

- How circular is the [Canadian] economy?
- How to improve the material circularity of the jurisdiction [Canada] in question?
- To what extent is a [Canadian] circular economy a step toward a sustainable society?

The final selection of indicators usually derives from political choices. There is no common framework to perform a targeted analysis of Canada's industrial sectors with the aim of identifying relevant CE strategies and monitoring their implementation over time. Considering the three questions and the key aspects and characteristics of available indicators summarized here (and further detailed in the appendices) when collecting data will help prioritize actions that allow the Canadian economy to quickly improve its circularity level in a sustainable way.

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Appendix A [Reference List of Decoupling Studies]

Table A.1: Details of collected decoupling studies by decoupling type (resource – R, environmental – E) and approach (production – P, consumption – C, geographical area, timeframe, resource/environment (R/E) accounting and indicator, and economic indicator, from Sanyé-Mengual et al., (2019)

Table 1
Details of collected decoupling studies by decoupling type (resource – R, environmental – E) and approach (production – P, consumption – C), geographical area, timeframe, resources/environment (R/E) accounting and indicator, and economic indicator.

Decoupling Type	Approach	Geography	Timeframe	R/E accounting	R/E indicator	Economic indicator	Study
R	P,C	United States	1870 –2005	Economy-wide MFA	Domestic Material Consumption (DMC) Total Primary Energy Supply (TPES)	GDP Income (GDP per capita)	[1]
R	C	Worldwide	1980 –2009	Economy-wide MFA	DMC Material productivity	GDP	[2]
R	C	Worldwide World regions Countries	1900 –2009	Economy-wide MFA	DMC	GDP Income (GDP per capita)	[3]
R	C	Worldwide	1900 –2009	Economy-wide MFA	Energy use	GDP Income (GDP per capita)	[4]
E	C	Beijing – Tianjin – Hebei, China	1996 –2010	National accounting	Energy consumption CO_2 emissions (IPCC)	GDP	[5]
E	C	Jiangsu, China	1995 –2009	Energy accounting (EFA)	Energy-related CO_2 emissions (IPCC)	GDP	[6]
E	C	Brazil	2004 –2009	National energy balance (EFA)	Energy-related CO_2 emissions (IPCC)	GDP	[7]
E	C	European Union (EU25)	1995 –2005	National accounting	Municipal Solid waste (MSW)	Final consumption expenditure	[8]
E	C	Taiwan; Japan; Germany; South Korea	1990 –2002	National accounting (OECD)	Highway transport-related CO_2 emissions (IPCC)	GDP	[9]
E	C	Gulf countries	1980 –2010	National accounting	Energy consumption Energy-related CO_2 emissions (IPCC)	Income (GDP per capita)	[10]
E	C	China (textile industry)	2001 –2014	National statistics	Water footprint	Gross annual industrial output	[11]
E	P,C	EU countries	1993 –2010	National accounting	Carbon footprint	GDP	[12]
E	C	EU manufacturing sector	1990 –2003	Energy accounting	Energy-related CO_2 emissions (IPCC)	Total added value	[13]
E	C	Italy (energy sector)	1998 –2006	National accounting (MFA)	Energy consumption CO_2 emissions (IPCC)	GDP	[14]
R, E	P, C	World	2010 –2050	Economy-wide MFA	Material intensity Energy intensity Carbon emissions	Income (GDP per capita)	[15]
R,E	C	China	1978 –2010	Economy-wide MFA	Domestic extraction used (DEU) Total energy consumption CO_2 emissions SO_2 emissions Soot emissions Wastewater emissions COD emissions NH_3 emissions	GDP	[16]
R, E	C	Macao, China	2000 –2013	Greenhouse gas protocol	Total energy consumption (TEC) Total embodied GHG emissions (TEGE)	GDP	[17]
R, E	C	World 1995–2011	1995 –2011	Multi-regional input-output	GHG emissions Energy use Material use Blue water consumption Land use	GDP	[18]
R,E	C	Scandinavia (industry)	1993 –2001	Energy accounting	Energy consumption Energy-related CO_2 emissions	Gross added value	[19]

[1](Gierlinger and Krausmann, 2012); [2](Giljum et al., 2014); [3](Bithas and Kalimeris, 2018); [4](Bithas and Kalimeris, 2018); [5](Wang and Yang, 2015); [6](Zhang and Wang, 2013); [7](de Freitas and Kaneko, 2011); [8](Mazzanti and Zoboli, 2008); [9](Lu et al., 2007); [10](Salahuddin and Gow, 2014); [11](Li et al., 2017); [12](Liobikiene and Dagiliute, 2016)[13](Diakoulaki and Mandaraka, 2007); [14](Andreoni and Galmarini, 2012); [15](Schandl et al., 2016); [16](Yu et al., 2013); [17](Chen et al., 2017); [18](Wood et al., 2018); [19](Enevoldsen et al., 2007).

Appendix B [Summary Tables of Indicators Reviewed for this Study]

Table B.1: Scaling indicators

Indicator name	Equation type of indicator	Production / consumption / EoL oriented	Unit	Supporting methodology	Calculation method and type of data required	Examples and remarks	Reference	What are they used for ?
Direct Material Input (DMI) and Total Material Requirement (TMR)	Measure	Production	t	EW-MFA	Input: biomass (3), metal ores (2), non-metallic ores (8), fossil fuel (2), other, imported waste (1) Imports/exports **DMI** = used domestic extraction (excavated raw material, harvested biomass) + imports **TMR** = domestic extraction (used + unused) + imports + import indirect flows		Krausmann et al. (2018), Eurostat (2018)	Set governmental targets on reducing raw material extraction
Domestic Processed Output (DPO) and Total Domestic Output (TDO)	Measure	EoL	t	EW-MFA	Output: emissions to air (1), waste to landfill (2), water (5), dissipative uses (8), dissipative losses (1). **DPO** = emissions to air + landfilled wastes from industrial processes and households + the material load in wastewater + dissipative uses + losses of products **TDO** = DPO + unused domestic extractions	**National circular economy indicator system in China - Waste disposal and pollutant emissions**: Total amount of industrial solid waste for final disposal, Total amount of wastewater discharge, Total amount of SO_2 emission, Total amount of COD discharge	Krausmann et al. (2018), Eurostat (2018), Geng et al. (2012)	Set governmental targets on reducing material waste
Domestic Material Consumption (DMC), Processed Material (PM) and Total Material Consumption (TMC)	Measure	Consumption	t	EW-MFA	Input: biomass (3), metal ores (2), non-metallic ores (8), fossil fuel (2), other, imported waste (1) Imports/exports **DMC** = extraction + imports - exports **PM** = DMC + secondary materials **TMC** = TMR - exports	DMC does not account for the fate of materials, but the DPO does "perceived by some as an overall proxy for (future) environmental pressure hence covering all relevant environmental impacts"	Krausmann et al. (2018), Eurostat (2018), Geng et al. (2012)	Set governmental targets on reducing material consumption
Raw Material Consumption (RMC), Material Footprint (MF) and Ecological Rucksack	Measure	Consumption	t	EW-MFA (and global multiregion IO model)	Input: biomass (3), metal ores (2), non-metallic ores (8), fossil fuel (2), other, imported waste (1) Imports/exports MF = **RMC** (IO tables) **MF** = Raw Material Extraction of imports (RMEi) + Domestic Extraction (DE) - Raw Material Extraction of exports (RMEe)	extraction of materials needed to produce the final products used by households, governments or non-profit institutions serving households, or used for gross capital formation" **MF**: "In contrast to indicators of standard economy-wide material flow accounting, which are based on apparent physical consumption, the MF does not record the actual physical movement of materials within and among countries but, instead,	Eurostat (2018), Mayer et al. (2019)	Set governmental targets on reducing raw material consumption (RMC) and finding a way to reduce its dependace on raw material imports?
Net Addition to Stock (NAS)	Measure	Consumption	t	EW-MFA	Input data, Output data, Imports/exports	NAS "measures the physical growth rate of the economy. Each year new materials are added to economic stocks, such as new buildings and durable goods, whilst old materials are removed from this	Krausmann et al. (2018), Eurostat (2018)	Allows to measure the "physical growth of the economy". NAS results from balancing equation and is definitely a "blind spot". Setting governmental targets on this
Circularity gap (CG) and waste generation indicators	Measure	EoL	t	IO-MFA	**Waste generation** **CG** = waste supply + stock depletion - waste recovery	Eurostat indicators - Production and consumption : Food waste	Aguilar-Hernandez et al. (2019)	Identify unrecovered waste that can potentially be introduced back into the economy as materials or products

Table B.2: Material Circularity indicators

Indicator name	Equation type of indicator	Production / consumption / EoL oriented	Unit	Supporting methodology	Calculation method and type of data required	Examples and remarks	Reference	What are they used for ?
Recycling rate and Input socioeconomic cycling rate (ISCr)	Ratio	Production	%	EW-MFA	EW-MFA data **ISCr** = SM / PM = SM / (DMC + SM)	ISCr is the share of Secondary Material (SM) in Processed Material (PM) **Eurostat indicators - Secondary raw material** : EoL recycling input rates (excluding manufacturing scrap), circular material use rate (Circular use material / Domestic Material Consumption (DMC)), imports & exports and intra-EU trade of recyclable raw materials	Mayer et al. (2019)	Set governmental targets on increasing the recycling capacity or on reducing the total amount of unrecovered materials = increasing the share of recycled materials; i.e. the share of recycled content
Input ecological cycling rate potential (IECrp)	Ratio	Production	%	EW-MFA	EW-MFA data **IECp** = DMC (biomass) / PM = DMC (biomass) / (DMC + SM)	IECp is the share of Domestic Material Consumption (DMC) of biomass in Processed Material (PM) National circular economy indicator system in China - **Integrated resource utilization rate** : Industrial water reuse ratio, Recycling rate of reclaimed municipal wastewater	Mayer et al. (2019)	Set governmental targets on the share of biomass among the set of processed materials, i.e. the share of renewable materials
Input non-circularity rate (INCr)	Ratio	Production	%	EW-MFA	EW-MFA data **INCr** = DMC (energetic use of fossil energy carriers) / PM	INCr is the share of energetic use of fossil energy carriers in Processed Material (PM)	Mayer et al. (2019)	Set governmental strategies on reducing the share of fossil fuel among the set of processed materials, i.e. the share of energetic non-renewable input
Output socioeconomic cycling rate (OSCr)	Ratio	EoL	%	EW-MFA	EW-MFA data **OSCr** = SM / (DPO - SM)	OSCr is the share of Secondary Material (SM) in IntOut (EoL waste and Domestic Processed Output emissions(DPO)) **National circular economy indicator system in China - Integrated resource utilization rate** : Recycling rate of industrial solid waste, Safe treatment rate of domestic solid wastes, Recycling rate of iron scrap, Recycling rate of non-ferrous metal, Recycling rate of waste paper, Recycling rate of plastic, Recycling rate of rubber **Eurostat indicators - Waste management** : Recycling rate of municipal solid waste, all waste excluding major mineral wastes, overall packaging, plastic packaging, wooden packaging, e-waste, construction and demolition waste	Mayer et al. (2019)	Set governmental targets on increasing the recycling capacity or on reducing the total amount of unrecoverable waste = increasing the share of recycled materials; i.e. the share of EoL recycling
Output ecological cycling rate potential (OECrp)	Ratio	EoL	%	EW-MFA	EW-MFA data **OECrp** = DPO (biomass) / SM = DPO (biomass) / (DPO - SM)	OECrp is the share of Domestic Processed Output biomass (DPO) in IntOut (EoL waste and DPO emissions)	Mayer et al. (2019)	Set governmental targets on the share of biomass among the set of outpu, i.e. the share of biomass recovered (composted?)
Output noncircularity rate (ONCr)	Ratio	EoL	%	EW-MFA	EW-MFA data **ONCr** = DPO (energetic use of fossil energy carriers) / SM = DPO (energetic use of fossil energy carriers) / (DPO - SM)	ONCr is the share of energetic use of fossil energy carriers in IntOut (EoL waste and Domestic Processed Output emissions(DPO))	Mayer et al. (2019)	Set governmental strategies on reducing the share of fossil fuel among the set of output emissions?
Circularity gap index (CGI)	Ratio	EoL	%	IO-MFA	**CGI** = (waste supply + stock depletion - waste recovery) / (waste supply + stock depletion)	The circularity gap is the difference between input flows to waste treatment activities and recycled output	Aguilar-Hernandez et al. (2019)	These type of indicators might relate to targets related to waste prevention.
Waste ratio	Ratio	EoL	%	IO-MFA	Waste / Domestic Material Consumption (DMC)	**Eurostat indicators - Production and consumption** : Generation of waste (excluding major mineral wastes) per domestic material consumption	Eurostat	These type of indicators might relate to targets related to waste prevention.

Table B.3: Normalization options

Indicator name	Equation type of indicator	Production / consumption / EoL oriented	Unit	Supporting methodology	Calculation method and type of data required	Examples and remarks	Reference
Resource productivity	Rate	EoL	$/t	EW-MFA	Resource productivity = GDP/ Domestic Material Consumption (DMC) or GDP / Material Footprint (MF), and other	**National circular economy indicator system in China - Resource Output rate** : Output of main mineral resource, output of energy in strandard coal equivalent **Fundamental Plan for a Sound Material-Cycle Society in Japan (2003)**: GDP per DMI	Eurostat (2018) Geng et al. (2012)
Resource productivity per capita	Graph	EoL	$/cap and t/cap	EW-MFA	Graphical representation: GDP/cap and DMC/cap	Population density plays an important role in the results	Eurostat (2018)
Material or resource intensity	Rate	Consumption	t/$	EW-MFA	Material intensity = Domestic Material Consumption (DMC) / GDP, and other tsce/$, tsce/$, m3/$, m3/$) tsce (strandard coal equivalent)	**National circular economy indicator system in China - Resource Consumption Rate** : Energy consumption per unit of GDP, Energy consumption per added industrial value, Water withdrawal per unit of GDP, Water withdrawal per added industrial value,	Geng et al. (2012)
Waste and recycling per capita	Rate	EoL	t/cap			**Eurostat indicators - Production and consumption** : Generation of waste (including AND excluding major mineral wastes) per capita - **Waste management** : Recycling rate of biowaste per capita	
Elasticities of explanatory variables	Index	All	[0,1]	EW-MFA, multivariate regression analysis		Elasticities represent the relative change in per-capita resource use corresponding to a relative change in the explanatory variables: GDP/pop, DE/pop, pop/area...	Wiedmann et al. (2012)
Decoupling DMC and GDP	Graph	Consumption	(%;%)	EW-MFA	Time series, DMC and GDP	Average annual change rate of DMC (%) and average annual change rate of GDP (%): y>x then coupling, 0<y<x than relative decoupling, y<0 than absolute decoupling	Eurostat (2018) Kovanda and Hak (2007)
Decoupling factor	Ratio	All	%	EW-MFA	Time series **DF** = 1 - (Env pressure/Driv force)end-of-period/(Env pressure/Driv force)start-of-period		OECD (2002)
Efficiency indicators	Rate / ratio / coefficient	All		EW-MFA	tsce/t, m3/t, nd	**National circular economy indicator system in China - Resource Consumption rate (other)** : Energy consumption of per unit product in key industrial sectors, Water consumption of per unit product in key industrial sectors, Coefficient of irrigation water utilization	Geng et al. (2012)
Domestic resource dependency, trade intensity	Ratio	All	%		DE/DMC Import_or_Export/DMI	Domestic resource dependency: The ratio of domestic extraction to domestic material consumption indicates the dependence of the physical economy on domestic raw material supply. **Eurostat indicators - Production and consumption** : Self-sufficiency for raw materials Trade intensity: Indicate the import or export intensities of the physical economies	Krausmann et al. (2018)

Table B.4: Environmental impact indicators

Indicator name	Equation type of Indicator	Production / consumption / EoL oriented	Unit	Supporting methodology	Calculation method and type of data required	Examples and remarks	Reference
Environmental interventions (LCI)	Measure	Production / EoL	various environmental dimensions	Environmentally-weighted MFA OR Environmentally-extended IO	EW-MFA data + Ecoinvent data IO data + Ecoinvent data	IO Canada distinguishes 246 commodities and 112 industries Life Cycle Inventory, impacts categories depend on the choice of impact methodology	European Commission: Van der Voet et al. (2005) Van der Voet et al. (2004): Dematerialization: not just a matter of weight
Environmental impacts categories	Measure	Production / EoL	environmental dimensions according to LCIA methodology	Environmentally-weighted MFA OR Environmentally-extended IO	EW-MFA data + Ecoinvent data IO data + Ecoinvent data		European Commission: Van der Voet et al. (2005) Van der Voet et al. (2004): Dematerialization: not just a matter of weight
Human Appropriation of Net Primary Production (HANPP)	Ratio	Production	%		Geographic Information System (GIS)	It measures which percentage of the net primary production of biomass (or energy or carbon embodied in it) in nature is used by humans, by land conversion and biomass harvest [...]	Repertoried in Van der Voet et al. (2009)
Ecological Footprint	Measure / Index	Production	ha or #earth		EW-MFA: metal ores, fossil fuels, construction minerals and biomass	Allows comparison to carying capacity: "document to what extent human activities compromise the biosphere's ability to regenerate", measuring "the amount of the regenerative capacity of the biosphere occupied by human activities" "measures how much biologically productive land and water area a population uses to produce the resources it consumes and the waste it generates, taken the prevailing technology and resource management into account"	Repertoried in Van der Voet et al. (2009)

Table B.5: Socio-economic impact indicators

Indicator name	Equation type of Indicator	Production / consumption / EoL oriented	Unit	Supporting methodology	Calculation method and type of data required	Examples and remarks	Reference
Direct jobs in CE and indirect jobs					Percentage of persons employed in the recycling sector and repair and reuse sector	Direct includes the firm, e.g. "working proprietors, partners working regularly in the unit and unpaid family workers" Indirect includes "persons who work outside the unit who belong to it and are paid by it", e.g. : "sales representatives, delivery personnel, repair and maintenance teams"	Eurostat and City of Brussel (2019)
Gross investment in tangible goods					Investment in the recycling sector and repair and reuse sector	"Included are new and existing tangible capital goods, whether bought from third parties or produced for own use (i.e. capitalised production of tangible capital goods), having a useful life of more than one year including non-produced tangible goods such as land."	Eurostat
Value added at factor cost					"The sum of turnover, capitalized production, other operating income, increases minus decreases of stocks, and deducting the following items: purchases of goods and services, other taxes on products which are linked to turnover but not deductible, duties and taxes linked to production"	"Gross income from operating activities after adjusting for operating subsidies and indirect taxes"	Eurostat
Number of patents					Number of patents related to recycling and secondary raw materials		Eurostat
Indicators developed for "circular cities"					CE procurements, Number of business supported, Number of demonstration projects, Number of Ph.Ds/university courses/patents in CE, Number of legislative and normative incentives created, Amount of financial aid granted to companies in connection with the CE, Number of enterprises receiving financial support in connection with the CE, Number of companies involved in industrial symbiosis.		City of Brussel (2019)

Table B.6: Strategic characteristics of material flows

Category	Indicator name	Equation type of indicator	Production / consumption / EoL oriented	Unit	Examples and remarks	Reference
Tracing the fate of a material	Destination of a material	Graph	EoL	(%;yr) or (t;yr)	Trace the fate of a material throughout a specific application and yields the destination of the material by products and losses through years after initial production	Nakamura et al. (2014)
	Number of time a material is used	Measure	EoL	#	Trace the destination of a material throughout its successive applications before being lost and calculates how many times a material comes through and EoL before being lost	Duchin and Levine (2010)
	Technologic lifetime of a material	Measure	EoL	yr	Trace the destination of a material throughout its successive applications before being lost and calculates its average technological lifetime	Eckelman et al. (2012)
Criticality	Vulnerability to supply restriction	Measure	Consumptio n	#	**Importance:** Material assets, National economic importance **Substitutability:** Substitute performance, Substitute availability, Environmental impact ratio, Net import reliance **Susceptibility:** Net import reliance, Global inno vation index	Graedel et al. (2015)
	Supply risk	Measure	Consumption	#	**Geological, technological and economic:** Depletion time, Companion material fraction **Social and regulatory:** Policy potential index, Human development index **Geopolitical:** WGI (Worldwide Governance Indicator) – political stability, Global supply concentration	Graedel et al. (2015)
	Environmental implications	Measure	Consump tion	#	**Human health** (based on a cradle-to-gate lifecycle inventory) **Ecosystems** (based on a cradle-to-gate lifecycle inventory)	Graedel et al. (2015)

Appendix C [Supplementary Material from February 2020 Workshop]

C.1 Circular Economy Data & Modelling Workshop Agenda & Participants List

Circular Economy Data & Modelling Workshop

Hosted in Partnership with

Environment & Climate Change Canada (ECCC)

26th February 2020
Faculty of Social Sciences Building, Room 4004
University of Ottawa

AGENDA

Objectives

The Circular Economy (CE) has emerged as one of the potential opportunities to address major efficiency gaps in current economic production and consumption models. There is accordingly a growing demand for information to understand potential future pathways for circular economy (CE) in Canada. However, a major challenge involves finding methodologically sound ways to measure the circular economy, and particularly determining the kind of data required to produce meaningful conclusions for policy-makers. Developing preliminary CE models that can be used to provide targeted sectoral analysis of Canada's industries and forecast potential implications of adopting CE practices is therefore of considerable interest.

The objective of this workshop is accordingly to review experience with CE data and modelling approaches, and to begin to identify the data sources, tools, and indicators required to effectively track and model the CE in Canada, ideally at the sectoral level. Though the presentations and discussions scheduled below, we will accordingly endeavour to:

1. Review leading methods, approaches, and indicators used to track and model circularity, and explore their application in Canada (two background reports, from Midsummer Analytics/Stratos and CIRAIG/SPI -- to be presented during the workshop -- begin to explore this).
2. Help identify and explore options for the collection of key data sources, tools, and indicators for modelling the circular economy in Canada, based on the approaches identified in (1) above.
3. To the extent possible, review/ explore data sources that are available to focus on sectoral material flow, I/O modelling, or sector-specific LCA, otherwise to track circularity in Canada, and avenues to pursue further data development.

Following the workshop, all lessons learned will be synthesized and documented in a final project document, updating the preliminary report from CIRAIG (Polytechnique Montréal) and SPI (University of Ottawa).

To share additional documents or background materials to inform these efforts, please contact Hossein Hosseini at the Smart Prosperity Institute (hossein@smartprosperity.ca).

Agenda

11.00am – 12.00pm: Arrival & Networking [Early Lunch Served]

12.00-12.15pm: Introductions & Opening Comments

- Geoff McCarney (uOttawa / Smart Prosperity Institute)
- Derek Hermanutz (Director General, Economic Analysis Directorate, ECCC)

12.15-12.45pm: Background – Current Modelling Efforts at ECCC

- 12.15-12.35: Nick Macaluso (Economic Analysis Directorate, ECCC) – Link to Presentation.
- 12.35-12.45pm: Questions/Discussion

12.45-1.15pm: Eurostat – Overview: European Material Flows & Related Modelling for the CE

- 12.45-1.05: Arturo de la Fuente (Deputy Head of Unit, Eurostat – remote) – Link to Presentation.
- 1.05-1.15: Questions/Discussion

1.15-1.45pm: OECD – Overview of Modelling for *Global Material Resources Outlook to 2060*.

- 1.15-1.35: Ruben Bibas (Environment and Economy Integration Division, OECD - remote) – Link to Presentation.
- 1.35-1.45: Questions/Discussion

1.45 – 2.00pm: DISCUSSION BREAK

2.00-2.40pm: Report -- Approaches to Measurement of the Circular Economy in Canada

- 2.00-2.20: Rob Smith (Midsummer Analytics) & Emma Bedlington (Stratos) – Link to Presentation.
- 2.20-2.40: Questions/Discussion

2.40-3.20pm: Report – Data & Modelling Needs for a Circular Economy in Canada

- 2.40-3.00: Guillaume Majeau-Bettez & Geoffrey Lonca (CIRAIG, Polytechnique Montréal) – Link to Presentation.
- 3.00-3.20: Questions/Discussion

3.20-3.30: DISCUSSION BREAK

3.30-4.15: Overview of other Federal Government Data Collection Efforts

- 3.30-3.40: Farid Bensebaa (National Research Council of Canada) – Link to Presentation
- 3.40-3.50: Catherine Peters (ISED, Canada) – Link to Presentation
- 3.50-4.05: Jeff Fritzsche (Statistics Canada) – Link to Presentation
- 4.05-4.15: Questions/Discussion

4.15-5.00: Panel – Specific Needs/Challenges for CE Data & Modelling in Resource Sectors

- Alan Young (Circular Economy Leadership Coalition)
- Paul Ekins (University College London & UNEP International Resource Panel)
- Raimund Bleischwitz (University College London Institute for Sustainable Resources)
- Moderator: Stephanie Cairns (Smart Prosperity Institute)

5.00-5.30: Open Discussion

Participants List

Name	Organisation
Stéphane Arabackyj	Natural Resources Canada
Emma Bedlington	Stratos
Farid Bensebaa	National Research Council (NRC)
Ruben Bibas (remote)	OECD
Raimund Bleischwitz	University College London
Emilie Brown	Environment & Climate Change Canada
Emily Caddell	Stratos
Stephanie Cairns	Smart Prosperity Institute
Damian Crawley	Natural Resources Canada
Arturo de la Fuente (remote)	Eurostat
Genevieve Donin	Institute of the Environment, University of Ottawa
Madison Downe	Canadian Council of Academies
Paul Ekins	University College London
Abdel Felfel	Natural Resources Canada
Jeff Fritzsche	Statistics Canada
Warren Goodlet	Environment & Climate Change Canada
Geoff Guest	National Research Council (NRC)
Derek Hermanutz	Environment & Climate Change Canada
Hossein Hosseini	Smart Prosperity Institute
David Hughes	The Natural Step / Circular Economy Leadership Coalition
Matthew Ivanowich	Canadian Council of Academies
Jason Jabbour (remote)	United Nations Environment Programme (UNEP)
Jack Jensen	Natural Resources Canada
Andrew Linton	Institute of the Environment, University of Ottawa
Geoffrey Lonca	CIRAIG, Polytechnique Montréal
James Lu	Environment & Climate Change Canada
Nick Macaluso	Environment & Climate Change Canada
Guillaume Majeau-Bettez	CIRAIG, Polytechnique Montréal
Jonathan Martin	National Research Council (NRC)
Jerome Marty	Canadian Council of Academies
Geoff McCarney	University of Ottawa / Smart Prosperity Institute
Somayyeh Montazer-Hojat	Environment & Climate Change Canada
Steve Morrissey	Cement Association of Canada
Sonia Patel	Smart Prosperity Institute
Catherine Peters	Innovation, Science and Economic Development, Canada
Janice Pillon	Innovation, Science and Economic Development, Canada
Greg Rampley	Canadian Forest Service
Jacob Rattray	Environment & Climate Change Canada
Emmanuel Raufflet	Institut EDDEC, HEC Montréal
Beth Rohr	Clean Growth Hub, Natural Resources Canada
Paul Sandage	Environment & Climate Change Canada
Dave Sawyer	EnviroEconomics
Carolina Seward	Environment & Climate Change Canada
Sandra Scott	Environment & Climate Change Canada
Rob Smith	Midsummer Analytics
Jo-Anne St. Godard	Recycling Council of Ontario
Barbara Swartzentruber	Guelph Smart Cities Office
Alan Young	Circular Economy Leadership Coalition (CELC)

Circular Economy Data & Modelling Workshop

Summary Notes

February 26th, 2020

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1. State of Existing Research and Discussion Context

This workshop's objective was to review experience with circular economy data and modelling approaches, and to begin identifying the data sources, tools, and indicators required to effectively track and model circular economy in Canada (ideally at the sectoral level).

<u>Key themes discussed in the workshop include:</u>

- Canadian Circular Economy Models:
  - There is a suite of circular economy models that are available, including EC Pro (for carbon pricing), EC MSRR (which is like the OECD model), and the Infometrica Model. People are looking into how these models can be modified and how to link the circular economy block so that it becomes more ambitious in climate change targets.
  - One challenge: How to build in supply constraints, particularly waste.
  - Circular Economy data needs the following: material flows; data on input requirements, costs, and supply constraints; estimates on substitutability; recycling and waste data; future recycling rates; and land-use data.

- European Circular Economy Models:
  - Eurostat (a Directorate-General of the European Commission) does not develop waste accounts, but rather integrates them into the material flow accounts, and they use material flows instead of stocks.
  - Eurostat has been producing Material Flow Accounts on an annual basis for more than a decade. These accounts are mainly used for resource efficiency and circular economy purposes.
  - The modelling produced by Eurostat is used to convert material flow into raw material equivalents.
  - They recently launched an interactive Sankey.
  - The models – which are published each year – are used to generate material footprints, enhanced flow details, and regional information.

- Global Materials:
    - The use of global materials is expected to nearly double in 2060 from the 2011 levels, however the growth rate will be slow due to structural and technological changes that imply only relative decoupling.
    - The growth in global materials varies by material (sand and gravel are seeing the largest growth) and by country (largest growth seen in Brazil, Russian, India, China, and South Africa).
    - The environmental impacts from resource extraction and processing are expected to more than double by 2060.
    - Primary materials will cause far more damage than secondary materials, meaning that policies are therefore needed to encourage more secondary material use. While recycling is expected to become more competitive, it is not enough (on its own) to help the shift from primary to secondary materials.
    - The current work on global materials is focused on policies to promote a circular economy. Future work will be looking at the transformation of plastics.

- Measuring Circular Economy in Canada:
    - Since the circular economy lens is new in Canada there is little evidence to inform decisions. There are two broad groups of circular economy definition: one is focused on materials, while the other is broader and is often too idealistic and not achievable.
    - *Proposed Circular Economy Definition:* To minimize demands on the environment as a source of raw materials and energy, and as a sink for waste materials and energy through:
        - Smarter design, production, distribution, and use of goods and services;
        - Extensions of lifespans for existing goods;
        - The replacement of goods with services; and
        - Transformation of waste into inputs.
    - There are four approaches to modeling the circular economy:
        1) A broad economy-wide material flow analysis (e.g. Eurostat's work).
        2) Narrow (sector) material flow analysis (e.g. agricultural water use, GDP).
        3) Extended Input-Output analysis (e.g. energy demand needed to satisfy household demand).
        4) Lifecycle analysis – which is often heard of but does not apply at the national level statistically.

- Data and Modelling Needs for a Circular Economy in Canada:
    - There is a difference between a Material Flow Analysis indicator and a footprint indicator. As we move towards outcome-level indicators, the number of indicators is reduced, but so does the information to make decisions.
    - Indicators can help measure:
        - How efficiently we are using materials (e.g. scale indicators, material circularity ratios).

        - The effects of material use (e.g. environmental impact indicators, socio-economic indicators).
        - Strategic characteristics of materials (e.g. tracing the fate of materials, criticality).
    - There are two main frameworks that are currently used: the Chinese and European frameworks.

- Canadian Federal Government Data Collection:
    - Canadian federal government circular economy programs include work on bioenergy and materials for clean fuel.
    - Lessons learned from the Clean Tech Data Strategy include:
        - Achieve consensus on your objective.
        - Establish a clear definition and taxonomy.
        - Coordinate among partners.
    - The federal government's current work ties into the zero plastic waste and ocean's plastic charter strategies.

- Circular Economy and the Resource Sectors:
    - Any vision for circular economy in Canada will be different from other countries to the varying extractive sectors. E.g. Mining companies are looking at where they can invest so they can capture more embedded value.
    - It is critical to know what the circular economy is trying to achieve, as people are losing sight of its purpose to reduce the impact of extraction and use.
    - The biggest perception of circular economy is waste management – a lot of the drive comes from there.
    - The idea that there are "no losers" in a circular economy is false; the "losers" exist and will need to be properly managed.
    - There is a lot of work needed for sectoral analysis. E.g. the EU is pushing for product passports, since information on what is in each product is scarce.
    - In the future there will be greater focus on waste prevention, which is difficult to measure. (How does one measure something that was prevented?)

2. Research Questions Identified

- Circular Economy modelling is focused on recycling and not material flow. What plans exist to measure reuse rather than recycling through stocks?

- Are producers surveyed to see how they have changed their approach to design products?

- Are large companies working on matters such as Artificial Intelligence?

- What is Canada's track record when it comes to working with material stocks?

- What is being done to create more regional estimates?
- What is the genesis of the willingness to invest in circular economy data?
- Is it possible to measure the mix/bleeding of materials? E.g. micro-plastics when washing.
- What do the projections of planned global stocks and of current stocks show? When will we surpass available stocks?
- To what extent does clean innovation overlap with circular innovation?
- How can we include plastic imports into the circular economy?
- To what extent do we investigate the cleantech data on how much better technology is from the baseline?