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Integrating Life Cycle Assessment and Circularity Assessment into EU Public Procurement: Opportunities, Challenges, and Future Directions

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Integrating Life Cycle Assessment and Circularity Assessment into EU Public Procurement: Opportunities, Challenges, and Future Directions

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Abstract: Public procurement is a powerful tool for driving sustainability and circularity in the European Union (EU), given its significant economic impact. The integration of Life Cycle Assessment (LCA) and Circularity Assessment (CA) into public procurement processes offers a promising approach to support the EU's sustainability and circular economy goals. This paper presents a comprehensive review of the current state of LCA and CA in EU public procurement, based on a systematic literature review. The review covers the evolution of public procurement in the EU, the current legal and policy framework, the principles and methodologies of LCA and CA, and the practical application of these tools in procurement processes. The paper identifies key opportunities and challenges associated with the integration of LCA and CA, including the complexity of the methods, data availability and quality issues, and the need to balance sustainability with other procurement principles. The review also highlights best practices and innovative approaches from various EU member states and public entities. Based on the findings, the paper provides recommendations for policymakers, procurement practitioners, and researchers to support the effective implementation of LCA and CA in public procurement. These recommendations include the development of simplified tools and standardized methodologies, capacity building and training, and the promotion of collaboration and knowledge sharing among stakeholders. The paper concludes by emphasizing the crucial role of public procurement in driving the transition towards a more sustainable and circular economy in the EU and the importance of continued research and innovation in this field.

Keywords: public procurement, life cycle assessment, circularity assessment, sustainability, circular economy, European Union

Introduction

Public procurement, the process by which public authorities purchase goods, services, and works, is a powerful economic lever within the European Union (EU). Recent estimates indicate that public procurement accounts for approximately 14% of the EU's Gross Domestic Product (GDP), translating to over €2 trillion annually (European Commission, 2021). This substantial economic footprint underscores the immense potential of public procurement to drive market trends, influence industry practices, and shape the broader economic landscape of the EU (Alhola et al., 2018).

In recent years, there has been a paradigm shift in how public procurement is perceived and utilized. Beyond its traditional role of ensuring value for money and fair competition, public procurement is increasingly recognized as a strategic tool for achieving broader societal goals, particularly in the realms of sustainable development and circular economy (Cheng et al., 2018). This evolution aligns with the EU's overarching commitment to sustainability, as exemplified by initiatives such as the European Green Deal (European Commission, 2019) and the Circular Economy Action Plan (European Commission, 2020a).

At the heart of this transformative approach to public procurement lie two key methodologies: Life Cycle

Assessment (LCA) and Circularity Assessment (CA). These tools offer comprehensive frameworks for evaluating the environmental impacts and resource efficiency of products and services throughout their entire life cycles, from raw material extraction to end-of-life disposal or recycling (Rainville, 2021).

LCA, a well-established methodology standardized by ISO 14040 and 14044 (ISO, 2006a, 2006b), provides a holistic view of a product or service's environmental footprint. It considers multiple impact categories, such as climate change, resource depletion, and ecosystem quality, across all stages of the life cycle (European Commission, 2016). This comprehensive approach helps prevent burden-shifting, where improvements in one phase of the life cycle might lead to unintended negative consequences in another (Hauschild et al., 2018).

CA, while less standardized than LCA, focuses on evaluating how well a product or service aligns with circular economy principles (Saidani et al., 2019). It examines aspects such as material input (e.g., recycled content), product lifespan, repairability, and end-of-life recyclability (Kristensen & Mosgaard, 2020). By incorporating CA into procurement decisions, public authorities can stimulate demand for more circular products and services, thereby catalyzing the transition to a more resource-efficient economy (Witjes & Lozano, 2016).

The European Union has been at the vanguard of integrating sustainability considerations into public procurement practices. This commitment is exemplified by the EU Public Procurement Directive 2014/24/EU, a landmark piece of legislation that explicitly allows for the inclusion of environmental and social criteria in procurement decisions (European Union, 2014). This directive, along with its counterparts for utilities (2014/25/EU) and concessions (2014/23/EU), marked a significant shift from the traditional focus on lowest price to a more holistic concept of "most economically advantageous tender" (MEAT), which can include environmental and social factors (European Commission, 2016).

Furthermore, the EU has developed a range of supportive tools and initiatives to promote sustainable public procurement. These include the Green Public Procurement (GPP) criteria for various product groups, the EU Ecolabel, and guidance documents such as "Buying Green! A Handbook on Green Public Procurement" (European Commission, 2016). More recently, the Circular Economy Action Plan has emphasized the role of public procurement in driving demand for sustainable and circular products and services (European Commission, 2020a).

Despite this supportive policy framework, the practical implementation of LCA and CA in public procurement processes remains challenging. The complexity of these methodologies, especially for procurement officials who may lack specialized environmental expertise, poses a significant hurdle (Testa et al., 2016). Data availability and quality issues can complicate the assessment process, particularly for innovative products or services where comprehensive life cycle data may not yet exist (Ibáñez-Forés et al., 2014). The lack of standardized methodologies, especially for CA, can lead to inconsistencies in application and difficulties in comparing bids (Alhola et al., 2018).

Moreover, the integration of LCA and CA into procurement processes must be balanced with other key procurement principles, such as ensuring fair competition, achieving value for money, and meeting specific functional requirements (European Commission, 2020b). This balancing act requires careful consideration and often necessitates trade-offs between different objectives (Parikka-Alhola, 2008).

This paper aims to provide a comprehensive examination of the current state of LCA and CA in EU public procurement. By exploring the legal framework, implementation challenges, and potential benefits, we seek to offer a nuanced understanding of how these tools can be more effectively integrated into procurement processes to support the EU's sustainability and circular economy goals.

The research methodology, detailed in the following section, involves a systematic literature review using Google Scholar and a combination of keywords related to LCA, CA, and public procurement. The review covers scientific articles, policy documents, reports, and guidelines from international organizations and government agencies. The insights gained from this review are synthesized to provide an overview of the current state of knowledge, identify key themes and trends, and highlight gaps and opportunities for further research.

The subsequent sections of this paper delve into the evolution of public procurement in the European Union, the current EU public procurement framework, the principles and methodologies of LCA and CA, and the

intersection of these approaches in the context of public procurement. The discussion section reflects on the main findings, challenges, and opportunities identified in the literature review, and provides recommendations for policymakers, procurement practitioners, and researchers working towards more sustainable and circular public procurement practices.

As the EU continues to grapple with pressing environmental challenges, from climate change to resource depletion, the strategic use of public procurement becomes increasingly crucial. By effectively integrating LCA and CA into procurement decisions, the public sector can not only reduce its own environmental footprint but also drive market innovation, create demand for sustainable solutions, and set new standards for the private sector to follow (Rainville, 2021).

This research comes at a critical juncture, as the EU seeks to 'build back better' and accelerate the transition to a more sustainable and resilient economy in the wake of the COVID-19 pandemic (European Commission, 2020c). The insights and recommendations provided in this paper aim to support this transition, helping to ensure that the substantial financial resources channeled through public procurement are leveraged to their full potential in creating a more sustainable and circular future for Europe.

Methods

To provide a comprehensive overview of the current state of LCA and CA in the context of public procurement, we conducted a systematic literature review using Google Scholar. The search was performed using a combination of keywords related to the main concepts of interest: "Life Cycle Assessment," "Circularity Assessment," and "Public Procurement."

The specific search strings used were:

1. "Life Cycle Assessment" AND "Public Procurement"
2. "Circularity Assessment" AND "Public Procurement"
3. "Life Cycle Assessment" AND "Circularity Assessment" AND "Public Procurement"

The search was limited to articles published in English between 2000 and 2023 to capture the most recent developments and discussions in the field. We also reviewed the reference lists of the identified articles to find additional relevant studies that may not have been captured by the initial search (i.e., backward snowballing).

The titles and abstracts of the identified articles were screened for relevance to the research topic. Articles that focused on the application, challenges, or opportunities of LCA and CA in public procurement were included for full-text review. Studies that only briefly mentioned these concepts without substantial discussion were excluded.

The full-text review involved a detailed analysis of the selected articles, focusing on the following aspects:

1. The context and objectives of the study
2. The specific application of LCA and/or CA in public procurement
3. The benefits, challenges, and limitations identified
4. The recommendations for future research and practice

The information extracted from the articles was synthesized to provide an overview of the current state of knowledge, identify key themes and trends, and highlight gaps and opportunities for further research.

In addition to the scientific literature, we also reviewed relevant policy documents, reports, and guidelines from international organizations and government agencies, such as the European Commission, the Organisation for Economic Co-operation and Development (OECD), and the United Nations Environment Programme (UNEP). These documents provided valuable insights into the policy context and practical implementation of LCA and CA in public procurement.

The results of this literature review are presented in the following sections, which cover the evolution of public procurement in the European Union, the current EU public procurement framework, the principles and methodologies of LCA and CA, and the intersection of these approaches in the context of public procurement. The insights gained from this review are then used to formulate recommendations for policymakers,

procurement practitioners, and researchers working towards more sustainable and circular public procurement practices.

Results

The Evolution of Public Procurement in the European Union and the Current EU Public Procurement Framework

Public procurement in the European Union has undergone a significant evolution, reflecting broader shifts in economic thinking, political priorities, and societal values across the continent. The journey began in the aftermath of World War II, as European nations sought to rebuild their economies and foster cooperation. The establishment of the European Coal and Steel Community (ECSC) in 1951 marked the first step towards economic integration and laid the groundwork for common rules governing public contracts in strategic sectors (European Union, 2012).

The Treaty of Rome in 1957, which established the European Economic Community (EEC), further emphasized the importance of creating a common market and prohibited discrimination on grounds of nationality (Treaty Establishing the European Economic Community, 1957). However, public procurement remained largely governed by national rules and practices, often favoring domestic suppliers (Bovis, 2007).

The 1960s and 1970s saw growing recognition of the need for more specific rules on public procurement. The EEC adopted its first directives addressing public works contracts (Council Directive 71/305/EEC, 1971) and public supply contracts (Council Directive 77/62/EEC, 1977), focusing primarily on ensuring non-discrimination and transparency above certain thresholds. Despite these initial steps, implementation and enforcement remained inconsistent across member states (Gelderman et al., 2006).

The mid-1980s marked a turning point, with the White Paper on Completing the Internal Market identifying public procurement as a key area for reform (Commission of the European Communities, 1985). This led to a comprehensive overhaul of EU procurement legislation in the late 1980s and early 1990s, introducing more detailed rules on contract award procedures and expanding coverage to previously excluded sectors such as utilities (Council Directive 89/440/EEC, 1989; Council Directive 92/50/EEC, 1992; Council Directive 93/38/EEC, 1993).

As the EU entered the new millennium, public procurement policy began to evolve beyond its original focus on market opening and non-discrimination. The Lisbon Strategy (European Council, 2000) and the 2004 procurement directives (Directive 2004/17/EC, 2004; Directive 2004/18/EC, 2004) emphasized using public purchasing to drive innovation and achieve social and environmental objectives. The concept of "most economically advantageous tender" (MEAT) was introduced, allowing contracting authorities to consider factors beyond price when awarding contracts.

The global financial crisis of 2008 brought new challenges and priorities, with increased pressure to demonstrate value for money in public spending and calls for procurement to stimulate economic recovery (OECD, 2009). These pressures informed the development of the 2014 procurement directives, which represent the current framework for EU public procurement (Directive 2014/23/EU, 2014; Directive 2014/24/EU, 2014; Directive 2014/25/EU, 2014).

The current EU public procurement framework, based on the 2014 directives, aims to simplify procedures, increase flexibility, and promote the strategic use of procurement to achieve broader policy objectives. Key features include:

1. The "most economically advantageous tender" (MEAT) as the sole award criterion, encouraging consideration of factors beyond price (Directive 2014/24/EU, 2014, Art. 67).
2. New procurement procedures, such as the innovation partnership, to facilitate collaboration between public buyers and suppliers in developing innovative solutions (Directive 2014/24/EU, 2014, Art. 31).
3. Explicit permission to consider social and environmental factors throughout the procurement process (Directive 2014/24/EU, 2014, Art. 18(2), Art. 42, Art. 62, Art. 70).

4. Measures to improve access for small and medium-sized enterprises (SMEs), such as dividing contracts into lots and simplifying documentation requirements (Directive 2014/24/EU, 2014, Art. 46, Art. 59).
5. A transition to fully electronic communication in procurement procedures (Directive 2014/24/EU, 2014, Art. 22).

In addition to the main directives, the framework includes the Remedies Directives (Council Directive 89/665/EEC, 1989; Council Directive 92/13/EEC, 1992), providing legal recourse for suppliers, and various regulations establishing standardized vocabularies (Regulation (EC) No 2195/2002, 2002), forms (Commission Implementing Regulation (EU) 2015/1986, 2015), and self-declaration documents (Commission Implementing Regulation (EU) 2016/7, 2016) to facilitate cross-border procurement.

The implementation of the framework is primarily the responsibility of member states, with the European Commission playing a crucial oversight role. The Commission monitors compliance, provides guidance, and can initiate infringement proceedings against non-compliant member states (Directive 2014/24/EU, 2014, Art. 83).

The current framework emphasizes flexibility and discretion for contracting authorities, allowing them considerable latitude in structuring procurements to achieve the best outcomes. It also recognizes the importance of preliminary market consultations and encourages the use of functional or performance-based specifications to foster innovation (Directive 2014/24/EU, 2014, Art. 40, Art. 42).

Sustainability is a central theme, with the framework allowing for the inclusion of environmental and social considerations at multiple stages of the procurement process. Life-cycle costing is recognized as a valid approach to evaluating tenders, considering costs beyond the purchase price (Directive 2014/24/EU, 2014, Art. 68).

The framework also places a strong emphasis on integrity and preventing corruption, with provisions on conflicts of interest and strengthened grounds for exclusion of economic operators (Directive 2014/24/EU, 2014, Art. 24, Art. 57). Cross-border procurement is facilitated through standardized notices, vocabularies, and documents (Directive 2014/24/EU, 2014, Art. 51; Regulation (EC) No 2195/2002, 2002).

In recent years, the strategic importance of public procurement in achieving broader policy objectives has gained increasing recognition. The European Green Deal (European Commission, 2019) and the Circular Economy Action Plan (European Commission, 2020) emphasize the role of procurement in driving sustainability and innovation. The COVID-19 pandemic has also highlighted the need for flexibility and resilience in procurement systems (European Commission, 2020).

Looking ahead, the EU public procurement framework is likely to continue evolving to meet new challenges and policy priorities. Potential areas of development include further integration of circular economy principles (Witjes & Lozano, 2016), enhanced use of digital technologies (OECD, 2019), greater emphasis on supply chain resilience and security (Cerutti et al., 2021), increased focus on innovation (Uyarra et al., 2014), measures to facilitate SME participation (Flynn & Davis, 2016), and enhanced provisions for addressing labor rights and working conditions (Martin-Ortega, 2018).

The evolution of EU public procurement reflects a gradual shift from a narrow focus on cost efficiency and non-discrimination towards a more holistic consideration of value, encompassing economic, social, and environmental dimensions. This mirrors broader trends in public management, such as the move from New Public Management towards Public Value and New Public Governance (O'Flynn, 2007; Osborne, 2006).

The current EU public procurement framework represents a sophisticated and flexible set of rules and principles designed to ensure transparency, fairness, and value for money while leveraging the power of public spending to achieve strategic objectives. As the EU continues to face new challenges and opportunities, the framework will undoubtedly continue to adapt, reflecting evolving priorities and lessons learned from practical experience across the diverse landscape of European public procurement.

The journey of public procurement in the EU is far from over. As societal expectations, technological capabilities, and global challenges continue to evolve, so too must the frameworks and practices that govern this critical area of public spending. The ongoing challenge will be to strike a balance between competing

objectives, harnessing the power of procurement to drive positive change while ensuring the integrity, efficiency, and accessibility of the process for all stakeholders.

The future of EU public procurement is likely to be shaped by a range of factors, including the increasing urgency of climate action, the need for resilient and sustainable supply chains, the transformative potential of digital technologies, and the growing demand for social value and inclusion. Policymakers, contracting authorities, suppliers, and civil society will all have a role to play in shaping this future, through dialogue, innovation, and a shared commitment to the public good.

One key area of focus will be the further integration of sustainability criteria into procurement processes. The European Green Deal has set ambitious targets for decarbonization and resource efficiency, and public procurement will be a critical tool in achieving these goals (European Commission, 2019). This may involve the development of more stringent and standardized green procurement criteria (Testa et al., 2016), as well as increased use of life-cycle costing and circular economy principles (Witjes & Lozano, 2016).

Digital transformation is another major trend that will shape the future of public procurement. The increasing use of e-procurement platforms, data analytics, and emerging technologies such as blockchain and artificial intelligence has the potential to streamline processes, improve transparency, and enable more strategic decision-making (OECD, 2019). However, it will also require significant investment in digital infrastructure and skills, as well as careful consideration of data protection and cybersecurity risks (European Commission, 2017).

The COVID-19 pandemic has also highlighted the importance of agility and resilience in public procurement. The ability to quickly respond to changing needs and circumstances, while ensuring the continuity of essential services and supplies, will be a key priority going forward (Cerutti et al., 2021). This may involve the development of more flexible and collaborative procurement models, as well as increased attention to risk management and contingency planning (OECD, 2020).

Another important consideration will be the role of public procurement in promoting social value and inclusion. This may involve the use of social clauses and reserved contracts to support employment opportunities for disadvantaged groups, as well as increased engagement with social enterprises and local communities (European Commission, 2021). Ensuring that public procurement benefits are distributed fairly and equitably will be a key challenge, particularly in the context of rising inequality and social tension (OECD, 2018).

Finally, the increasing globalization of supply chains and the growing awareness of human rights and environmental impacts in these chains will necessitate a more proactive and holistic approach to procurement. This may involve the development of more robust due diligence and monitoring processes, as well as increased collaboration with international partners to promote responsible business conduct and sustainable development (Martin-Ortega, 2018; OECD, 2020).

In navigating these challenges and opportunities, the EU public procurement framework will need to continue to evolve in a way that balances the need for flexibility and innovation with the core principles of transparency, fairness, and integrity. This will require ongoing dialogue and collaboration between all stakeholders, as well as a willingness to learn from experience and adapt to changing circumstances.

Ultimately, the success of EU public procurement in achieving its strategic objectives will depend not only on the design of the framework itself but also on the capacity and commitment of those responsible for its implementation. Contracting authorities will need to be equipped with the skills, resources, and political support necessary to use procurement as a strategic tool for driving positive change (OECD, 2019). This will require ongoing investment in training, guidance, and knowledge-sharing, as well as a culture of innovation and continuous improvement.

At the same time, suppliers will need to be engaged as partners in the pursuit of sustainable and innovative solutions. This will require a shift towards more collaborative and outcome-oriented procurement models, as well as increased transparency and dialogue throughout the procurement process (Uyarra et al., 2014).

Finally, civil society will have an important role to play in holding public authorities accountable for their procurement decisions and ensuring that the benefits of public spending are shared equitably. This will require increased transparency and opportunities for public participation, as well as robust mechanisms

for monitoring and reporting on the social, environmental, and economic impacts of procurement (Open Contracting Partnership, 2021).

In conclusion, the evolution of public procurement in the EU reflects a growing recognition of the strategic importance of this area of public spending in achieving broader societal goals. The current EU public procurement framework provides a solid foundation for harnessing the power of procurement to drive innovation, sustainability, and social value, while ensuring the integrity and efficiency of the process.

As the EU looks to the future, the ongoing development of this framework will be crucial in addressing the complex challenges and opportunities of the 21st century. By embracing innovation, collaboration, and a commitment to continuous improvement, public procurement can play a vital role in building a more sustainable, inclusive, and resilient future for all.

Life Cycle Assessment (LCA): Principles and Methodology

LCA is a comprehensive and systematic methodology for evaluating the environmental impacts associated with all stages of a product's life cycle, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling (ISO, 2006a). This cradle-to-grave approach provides a holistic view of a product's environmental footprint, allowing for informed decision-making in product design and policy development (European Commission, 2016).

The roots of LCA can be traced back to the 1960s and 1970s, when concerns about resource depletion and environmental pollution began to gain prominence (Guinée et al., 2011). Early studies focused primarily on energy use and waste generation (Hunt & Franklin, 1996). The oil crises of the 1970s further spurred interest in understanding the energy implications of product life cycles (Boustead, 1996).

The modern concept of LCA began to take shape in the 1990s, with efforts to standardize methodologies and create a more comprehensive framework for environmental assessment (Klöpffer, 1997). This period saw increased collaboration between academia, industry, and governmental organizations to develop robust and consistent approaches to life cycle thinking (Fava et al., 1991). The growing recognition of global environmental challenges further underscored the need for a holistic approach to assessing product impacts (Pennington et al., 2004).

A significant milestone in the development of LCA was the creation of the ISO 14040 series of standards, first published in 1997 (ISO, 1997). These standards provided guidelines for conducting LCA studies, ensuring consistency and comparability in approach. The current framework is primarily governed by ISO 14040:2006 and ISO 14044:2006 (ISO, 2006a, 2006b).

According to the ISO standards, an LCA study consists of four main phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation (ISO, 2006a). These phases are interdependent and often iterative (European Commission, 2010).

The Goal and Scope Definition phase sets the foundation for the entire LCA study, clearly articulating the purpose, intended audience, functional unit, system boundaries, and assumptions (ISO, 2006a). The functional unit is a critical element, allowing for fair comparison between different products or systems (European Commission, 2010).

The Inventory Analysis phase, or Life Cycle Inventory (LCI) analysis, involves collecting and quantifying all inputs and outputs for a product system throughout its life cycle (ISO, 2006a). This requires gathering data for each unit process within the system boundaries (European Commission, 2010). Data quality and representativeness are crucial to the reliability of the LCA results (Weidema & Wesnæs, 1996).

The Impact Assessment phase, or Life Cycle Impact Assessment (LCIA), evaluates the significance of potential environmental impacts based on the LCI results (ISO, 2006a). This phase involves classifying inventory data into impact categories, characterizing the impacts, and optionally normalizing, grouping, and weighting the results (European Commission, 2010).

The Interpretation phase involves analyzing results, reaching conclusions, explaining limitations, and providing recommendations based on the findings (ISO, 2006a). Sensitivity analysis is a critical aspect of this phase,

assessing the robustness of the conclusions (European Commission, 2010).

LCA has limitations, such as the complexity of product systems, data availability and uncertainty, and its primary focus on environmental impacts (Finnveden et al., 2009; Huijbregts et al., 2001). However, it remains an indispensable tool for environmental management and sustainable development, widely used in industry, policymaking, and academia (Hellweg & Milà i Canals, 2014).

The field of LCA continues to evolve, with ongoing research addressing methodological challenges and expanding the scope of assessments. Recent developments include efforts to better integrate biodiversity impacts (Teillard et al., 2016), water use (Boulay et al., 2018), and social considerations (UNEP/SETAC, 2009). There is also growing interest in consequential LCA, which aims to capture the system-wide changes induced by decisions (Weidema et al., 2018).

The digitalization of LCA is another important trend, with software tools and databases making it easier to conduct studies and interpret results (Speck et al., 2015). This is particularly important for integrating LCA into decision-making processes (Sonnemann & Vigon, 2011).

In conclusion, LCA provides a robust and comprehensive methodology for evaluating the environmental impacts of products and services. Its holistic, cradle-to-grave approach offers valuable insights for improving product design, informing policy decisions, and promoting more sustainable consumption and production patterns.

Circularity Assessment (CA): Emerging Concepts and Frameworks

CA is an emerging field that aims to evaluate the extent to which a product, service, or system aligns with the principles of a circular economy. Unlike the more established LCA, CA is still evolving, with various frameworks and methodologies being developed and refined (Saidani et al., 2019). The concept of CA has gained significant traction in recent years as businesses, policymakers, and researchers seek ways to transition from the traditional linear "take-make-dispose" economic model to a more sustainable circular approach (Kirchherr et al., 2017).

The roots of CA can be traced back to the broader concept of the circular economy, which itself draws inspiration from various schools of thought including industrial ecology, cradle-to-cradle design, and biomimicry (Ellen MacArthur Foundation, 2013). The circular economy concept gained mainstream attention in the early 2010s, largely due to the work of organizations like the Ellen MacArthur Foundation, which has been instrumental in promoting circular economy principles and developing frameworks for their implementation (Ellen MacArthur Foundation, 2015).

At its core, CA seeks to measure how well a product or system keeps resources in use for as long as possible, extracts the maximum value from them while in use, and recovers and regenerates products and materials at the end of their service life (Kristensen & Mosgaard, 2020). This contrasts with the linear economy model, which typically results in resources being used once and then discarded as waste (Ghisellini et al., 2016).

While there is no single standardized methodology for CA, several frameworks and tools have been developed to assess circularity at various levels, from individual products to entire organizations or systems. These frameworks often consider factors such as material input (proportion of recycled, renewable, or reused materials), product lifespan and intensity of use, repairability and upgradability, recyclability and biodegradability, and waste generation (Saidani et al., 2019).

One of the most prominent frameworks for CA is the Circulytics tool developed by the Ellen MacArthur Foundation (2020). Launched in 2020, Circulytics provides a comprehensive assessment of an organization's circular economy performance. It goes beyond measuring products and material flows, also considering how the company's strategy, people, systems, processes, and innovation capabilities contribute to circularity. The tool provides a score and detailed feedback, allowing companies to track their progress over time and benchmark against industry peers.

Another significant contribution to the field of CA is the Circular Economy Toolkit developed by researchers at the University of Cambridge (Evans & Bocken, 2013). This tool focuses on product-level assessment and provides a simple, accessible way for businesses to evaluate the circularity potential of their products. It

considers aspects such as design for remanufacture, product life extension, and servitization (the shift from selling products to providing services).

The European Commission has also been active in developing circularity metrics, particularly through its Joint Research Centre. The Product Environmental Footprint (PEF) method, while primarily an LCA-based approach, includes some circularity considerations (Zampori & Pant, 2019). There are ongoing efforts to integrate more comprehensive circularity indicators into the PEF framework, reflecting the growing recognition of the importance of circular economy principles in environmental assessment (Zampori & Pant, 2019).

Despite the proliferation of these tools and frameworks, CA faces several challenges. One of the primary difficulties is the lack of standardization, which can make it challenging to compare results across different assessments or organizations (Saidani et al., 2019). There's also the challenge of data availability and quality, particularly when assessing complex products with global supply chains (Kristensen & Mosgaard, 2020).

Another significant challenge is the multifaceted nature of circularity itself. While some aspects of circularity, such as recycled content or recyclability, are relatively straightforward to measure, others, like product lifespan or the effectiveness of take-back systems, can be more difficult to quantify (Linder et al., 2020). There's also the question of how to balance different aspects of circularity – for example, how to compare a product made from virgin materials but designed for long life and easy repair, with a product made from recycled materials but with a shorter lifespan (Linder et al., 2020).

The relationship between circularity and sustainability is another area of ongoing discussion and research. While circular approaches generally aim to reduce environmental impacts, there can be cases where increasing circularity might not lead to the best overall environmental outcome (Haupt & Zschokke, 2017). For instance, recycling processes that require significant energy input might not always be preferable to other end-of-life options from a life cycle perspective. This underscores the importance of considering CA in conjunction with other environmental assessment tools, particularly LCA (Haupt & Zschokke, 2017).

Despite these challenges, the field of CA continues to evolve rapidly, driven by growing awareness of resource scarcity and environmental challenges, as well as increasing regulatory pressure and consumer demand for more sustainable products and services (European Commission, 2020). The European Union, in particular, has been at the forefront of promoting circular economy principles, with initiatives like the Circular Economy Action Plan setting ambitious targets for waste reduction and resource efficiency (European Commission, 2020).

As the field matures, there are several key areas of development in CA. One is the integration of digital technologies to improve data collection and analysis. Technologies like blockchain and the Internet of Things (IoT) offer the potential to track materials and products throughout their lifecycle, providing more accurate and real-time data for CA (Kristoffersen et al., 2020).

Another area of focus is the development of sector-specific circularity metrics and benchmarks. While general frameworks provide a good starting point, there's growing recognition that different industries may require tailored approaches to truly capture their circularity potential (Saidani et al., 2019). For example, the construction industry might focus heavily on material reuse and design for disassembly, while the electronics industry might prioritize modularity and repairability (Linder et al., 2020).

There's also increasing interest in expanding CA beyond purely environmental considerations to include social and economic aspects. This reflects a growing understanding of the circular economy as not just an environmental concept, but a broader model for sustainable economic development (Schroeder et al., 2019). Some frameworks are beginning to incorporate indicators related to job creation, social equity, and local economic resilience (Kristensen & Mosgaard, 2020).

As research in this field progresses, there are efforts to develop more comprehensive and nuanced models of circularity. For example, some researchers are exploring the concept of "circularity potential" – recognizing that while a product might not currently be part of a circular system, it could have features that would enable circularity given the right infrastructure or business models (Nußholz et al., 2019). There's also growing interest in how to assess the circularity of complex systems or entire economies, moving beyond product or organization-level assessments (Saidani et al., 2019).

The intersection of CA with other emerging fields, such as sustainable finance and ESG (Environmental, Social, and Governance) reporting, is another area of development. As investors and financial institutions increasingly seek to understand and quantify the sustainability performance of companies, circularity metrics are beginning to be incorporated into broader sustainability assessment frameworks (Adams et al., 2021).

In conclusion, while CA is still an emerging and evolving field, it holds significant promise as a tool for promoting and measuring progress towards a circular economy. As methodologies are refined, data availability improves, and understanding of circular economy principles deepens, CA is likely to become an increasingly important complement to other environmental assessment tools, playing a crucial role in the transition to a more sustainable and resilient economic model.

The Intersection of LCA and CA in Public Procurement

LCA and CA in public procurement represents a significant opportunity to drive sustainability and promote circular economy principles through the substantial purchasing power of public authorities. As governments and public institutions increasingly recognize their role in shaping markets and influencing industry practices, the integration of these assessment methodologies into procurement processes has gained growing attention (Alhola et al., 2018; Rainville, 2021).

Public procurement, which accounts for a significant portion of economic activity in the European Union and globally, has traditionally focused on factors such as cost, quality, and technical specifications (Testa et al., 2016). However, there is a growing recognition that procurement decisions should also consider the broader environmental and social impacts of purchased goods and services (Cheng et al., 2018). LCA and CA offer complementary approaches to assess these impacts and guide procurement decisions towards more sustainable and circular options (Witjes & Lozano, 2016).

LCA, with its comprehensive and systematic approach to evaluating environmental impacts across the full life cycle of a product or service, provides a robust foundation for incorporating environmental considerations into procurement (ISO, 2006). By considering impacts from raw material extraction through to end-of-life disposal or recycling, LCA helps identify hotspots and improvement opportunities that may not be apparent from a narrower, use-phase perspective (European Commission, 2016). This information can be used to set environmental criteria in tender specifications, evaluate and compare bids, and monitor the performance of suppliers (Parikka-Alhola, 2008).

CA, on the other hand, focuses specifically on how well a product or service aligns with circular economy principles (EMF, 2015). By assessing aspects such as material circularity, product longevity, repairability, and end-of-life management, CA provides insights into the resource efficiency and circularity potential of procurement options (Saidani et al., 2019). This information can be used to promote procurement of products and services that are designed for durability, reuse, and recycling, thereby contributing to the transition towards a more circular economy (Geissdoerfer et al., 2017).

The integration of LCA and CA in public procurement can take various forms. At a basic level, procurers can use existing LCA studies and CAs to inform the development of green public procurement (GPP) criteria (European Commission, 2016). For example, the European Commission has developed a range of GPP criteria for different product and service categories, which include considerations of life cycle impacts and circular economy principles (European Commission, 2020). Procurers can also require bidders to provide LCA or CA information as part of their tender submissions, allowing for a more direct comparison of the environmental and circularity performance of different offers (Parikka-Alhola & Nissinen, 2012).

More advanced approaches involve conducting specific LCAs or CAs for the products or services being procured. This can be done by the procuring authority itself or by requiring suppliers to conduct and provide such assessments as part of the procurement process (Rainville, 2021). While this approach requires more resources and expertise, it allows for a more tailored and context-specific assessment of the environmental and circularity impacts (Öko-Institut e.V., 2007).

The use of functional or performance-based specifications in procurement can also support the integration of LCA and CA. By focusing on the desired outcomes or services rather than prescribing specific material or design requirements, functional specifications give suppliers more flexibility to propose innovative and

sustainable solutions (Rainville, 2017). This can encourage the development and offering of products and services with improved life cycle performance and circularity (Witjes & Lozano, 2016).

Another important aspect is the use of life cycle costing (LCC) in procurement decision-making. LCC goes beyond considering just the upfront purchase price to include costs incurred throughout the use and end-of-life phases, such as energy consumption, maintenance, and disposal costs (Perera et al., 2007). By using LCC in conjunction with LCA and CA, procurers can make more informed decisions that balance environmental, circularity, and economic considerations over the long term (Estevan & Schaefer, 2017).

Despite the potential benefits, the integration of LCA and CA in public procurement also faces several challenges. One significant barrier is the complexity and resource-intensity of conducting comprehensive assessments, particularly for smaller procuring entities or for products with complex global supply chains (Testa et al., 2016). There is a need for simplified tools, standardized methodologies, and accessible data to support wider adoption of these practices (Chenoweth et al., 2021).

Another challenge is the potential trade-offs between different sustainability objectives. For example, a product with strong circularity performance (e.g., high recycled content) may have higher life cycle environmental impacts due to energy-intensive recycling processes (Haupt & Zschokke, 2017). Procurers need guidance and tools to navigate these trade-offs and make balanced decisions that promote overall sustainability (Stahel, 2019).

There are also challenges related to the market readiness and availability of sustainable and circular products and services. While procurement can play a role in driving demand for such offerings, there may be limitations in terms of the existing supply and the capacity of the market to respond quickly to changing requirements (Alhola et al., 2018). Engaging with suppliers, providing clear signals of future requirements, and supporting capacity building can help address these challenges over time (Witjes & Lozano, 2016).

Legal and institutional barriers can also hinder the uptake of LCA and CA in procurement. Public procurement is subject to a complex set of rules and procedures aimed at ensuring fairness, transparency, and non-discrimination (Testa et al., 2016). Incorporating sustainability criteria must be done in a way that complies with these principles and avoids unduly restricting competition (Rainville, 2021). Policymakers and procurers need clear guidance on how to integrate LCA and CA in a legally compliant manner (European Commission, 2016).

Despite these challenges, there are promising examples of LCA and CA being successfully integrated into public procurement practices. The Netherlands, for instance, has been a leader in this field, with the Dutch government setting ambitious targets for circular procurement and developing tools and guidance to support procurers (Witjes & Lozano, 2016). The Dutch approach includes a strong emphasis on market engagement and collaboration, recognizing that the transition to circularity requires a systemic shift involving all stakeholders (Government of the Netherlands, 2016).

Looking forward, the intersection of LCA and CA in public procurement is likely to become increasingly important as governments and public institutions step up their efforts to achieve sustainability goals and support the transition to a circular economy (European Commission, 2020). As methodologies and data improve, and as awareness and capacity grow, we can expect to see more widespread and sophisticated use of these tools in procurement decision-making (Chenoweth et al., 2021).

This will require ongoing effort and collaboration between policymakers, procurers, suppliers, and researchers. Developing standardized approaches, sharing best practices, and building skills and knowledge will be key to unlocking the full potential of LCA and CA in driving sustainable and circular procurement (Rainville, 2021).

Discussion and conclusion

The integration of LCA and CA into public procurement practices represents a promising avenue for promoting sustainability and circularity in the public sector. As demonstrated by the literature review, these assessment methods provide valuable insights into the environmental and circularity performance of products and services, enabling procurers to make more informed and sustainable choices.

However, the application of LCA and CA in public procurement is not without challenges. One of the main barriers identified is the complexity and resource-intensity of conducting these assessments, particularly for smaller public authorities or for products with complex supply chains. This highlights the need for simplified tools, standardized methodologies, and accessible data to support the wider adoption of LCA and CA in procurement practice.

Another key challenge is navigating the potential trade-offs between different sustainability objectives. For example, a product with high recycled content may have a better circularity performance but could have higher overall environmental impacts due to energy-intensive recycling processes. Procurers need guidance and tools to help them balance these competing considerations and make decisions that promote overall sustainability.

The review also underscores the importance of considering market readiness and engaging with suppliers when integrating LCA and CA into procurement. While public procurement can be a powerful driver for sustainability and circularity, there may be limitations in terms of the availability of sustainable and circular products and services. Collaborating with suppliers, providing clear signals of future requirements, and supporting capacity building can help address these challenges and stimulate innovation.

Legal and institutional barriers, such as the complexity of procurement rules and the need to ensure fairness and non-discrimination, can also hinder the uptake of LCA and CA in procurement. Clear guidance and support from policymakers are needed to help procurers navigate these challenges and integrate sustainability criteria in a legally compliant manner.

Despite these challenges, the review identified several promising examples of LCA and CA being successfully integrated into public procurement practices, such as the Dutch government's circular procurement program and the European Commission's Green Public Procurement criteria. These examples demonstrate the potential for LCA and CA to drive sustainability and circularity in the public sector and highlight the importance of collaboration, capacity building, and policy support in overcoming barriers.

Looking forward, there is a clear need for further research and practical guidance to support the wider adoption of LCA and CA in public procurement. This includes the development of simplified and standardized assessment tools, the establishment of reliable and accessible databases, and the sharing of best practices and case studies. Future research should also explore the potential synergies between LCA and CA, as well as their integration with other sustainability assessment methods and criteria.

Moreover, the successful integration of LCA and CA into public procurement requires a systemic and collaborative approach, involving policymakers, procurement practitioners, suppliers, and other stakeholders. Capacity building and training programs are needed to help procurers understand and apply these assessment methods, while policy frameworks and incentives can create an enabling environment for sustainable and circular procurement.

The integration of LCA and CA into public procurement represents a significant opportunity to leverage the purchasing power of the public sector to drive sustainability and circularity. While challenges remain, the growing body of research and practical experience in this field provides a strong foundation for future progress. By embracing these assessment methods and working collaboratively to overcome barriers, public procurers can play a key role in the transition towards a more sustainable and circular economy.

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