A Review on the Use of Life Cycle Methodologies and Tools in Sustainable Regional Development

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Abstract: This review examines how life cycle methodologies are presently used by regional authorities in their sustainable development programmes. The review incorporates formal methods of life cycle assessment (LCA) as well as non-standardised approaches like life cycle management (LCM). The review describes the sustainability agenda facing regions, and a 'life cycle toolbox' that can be used at territorial level. Several parallel literature research methods were used to collect representative examples from around the world of regional life cycle approaches, identifying a variety of common and still-evolving methodologies used to address sustainability issues and applications. Results show that regional use of various life cycle methodologies from the toolbox is growing although scope is often constrained to short life chains, and with limited consideration of secondary (“spillover”) impacts. The conclusions confirm earlier findings that current life cycle tools are not always ideally structured for public sector organisations, with some not yet mature for addressing regional sustainability issues, such as biodiversity, land use and social impacts. Regional data aggregation is currently insufficient for certain methods. Further research is needed to adapt certain life cycle methodologies for regional application, but many available tools could already be further applied than is currently the case.

Keywords: life cycle management; life cycle assessment; life cycle approaches; life cycle toolbox; territorial development; sustainable development; sustainable regions; regional material flows; regional footprint

1. Introduction

While firmly embedded within defined nation states, regions have also become major actors in sustainable development, with increasing responsibilities and budgets for local programmes, and a heightened embrace of sustainability objectives that are in tune with public demand. There is now a widespread search for new policy measures, innovation of all sorts, and increasing local initiatives. Regions are experimenting with economy 4.0, with industrial ecology, with circular and bioeconomies, with smart technology, and with resource efficiency in various forms. Many of these system concepts are based on information and management techniques with which regions are not always familiar. They imply an awareness of life cycle dynamics, an understanding of the way sustainability issues are linked, and a use of a more holistic approach to resource efficiency [1–3]. Some of the regions in Figure 1 are trying to lead the way in adopting such approaches, many others, including regions also beyond Europe, have yet to adopt such a mind-set.

The need for a new approach is becoming more urgent. We hear, on a daily basis, about the serious degradation of our global life support system, with deteriorating land conditions, acute shortage of water in many places, loss of biodiversity, dramatic climate impacts, and the social conflicts that follow. We understand better now that many of these issues are linked in a series of interdependent life cycles.
Ignoring these life cycle considerations has a deleterious impact on sustainable development generally, including at regional level. At the very least, it imposes unnecessary costs on society. At worst, it damages our natural resource base and our health. Negligent upstream practices contaminate our food and manufactured goods. Ignoring end of life issues imposes clean-up costs on future generations (if not ourselves). Ignoring spillover effects (see Box 1) along the life chain of goods and services negates the beneficial results elsewhere along the chain. The UNSDSN report [https://www.unsdsn.org/](https://www.unsdsn.org/) (accessed on 14 September 2021) as well as various publications of the International Resource Panel [https://www.resourcepanel.org](https://www.resourcepanel.org) (accessed on 14 September 2021) contain numerous examples of the high societal costs of ignoring unwanted life cycle impacts. These publications stress the importance of a preventive action rather than costly remediation. Life cycle management is an essential component of such a preventive approach.

Despite the urgency, there appears to be little coherence in the way various social partners are moving on the sustainability agenda. While we see an increase in sustainability initiatives of all sorts and at all levels, there has so far been no comprehensive global study of how regions are using life cycle approaches for this purpose, even when such methods are already widely used in the business sector. Nor, indeed, has there been a study of the adequacy of the current life cycle methodologies themselves for use at regional level, addressing sustainability objectives and management approaches that are specific to territories rather than to materials and products.

The personal experiences of the authors with regional officials suggests that life cycle thinking is not always deeply embedded in the practices of regional institutions. ‘Life cycle’ is not a term that immediately resonates with public sector administrators, and yet it is deeply related to everything they do. As major procurers of goods and services, regions should ideally understand the ‘world behind the product’ if they are to purchase sustainably. As regulators, they would do well to understand the characteristics and origins of products and materials that are imported into their local markets. As producers and exporters, regions make decisions that have life-chain consequences beyond their own boundaries. Life cycle management is thus implicated in some way or other in nearly every aspect of regional decision-making, often hidden from view but with important potential consequences. The life cycle toolbox in Table 1 shows the variety of methods that can be applied to this end. While they are already useful, further research to study the relevance
of these tools at regional level is urgently needed. At the same time further effort is needed to adapt (if not develop) tools for easier ‘territorial’ application.

Table 1. Selected life cycle tools, procedures and concepts for the effective implementation of SDGs at regional and business levels.

| Life cycle systems and concepts                      | life cycle thinking |
|------------------------------------------------------|---------------------|
|                                                      | circular economy    |
|                                                      | industrial ecology  |
|                                                      | cradle-to-grave     |
| Life cycle assessment and system-analysis tools      | life cycle assessment (LCA *) (materials, energy) |
| incorporating life cycle elements                    | environmental, ecological, carbon, water footprints |
|                                                      | materials flow analysis (MFA) |
|                                                      | environmentally extended input–output tables (EEIO) |
|                                                      | social LCA (SLCA)    |
|                                                      | life cycle sustainability assessment (LCSA) |
|                                                      | organisational LCA (O-LCA) |
|                                                      | life cycle Costing (LCC and E-LCC), total cost of ownership (TCO) |
|                                                      | chemicals assessment * |
|                                                      | risk assessment      |
|                                                      | Evolving assessment tools for biodiversity, land-use, landscape etc. |
|                                                      | eco-design           |
|                                                      | eco-labels *         |
|                                                      | environmental product declarations (EPD) * |
|                                                      | product environmental footprint (PEF) * |
|                                                      | sustainable supply-chain management (SSCM) |
|                                                      | circular materials management |
|                                                      | product-service system (PSS) |
|                                                      | sustainable and/or circular public procurement (SSP, CPP) |
|                                                      | green purchasing (GP) |
|                                                      | extended producer responsibility (EPR) |
| Life cycle management tools                          | environment management systems (EMS, EMAS) |
|                                                      | (organisational LCA (O-LCA) (see also above) |
|                                                      | environment impact assessment (EIA) |
|                                                      | environment auditing |
|                                                      | corporate social responsibility (CSR) |
|                                                      | sector-specific management codes |
|                                                      | sustainability reporting (e.g., GRI) |
| Organisational assessment and management tools        | emergency and disaster planning and preparedness (e.g., APELL) |
| incorporating life cycle elements **                 |                     |

* Some of the above have become standardized procedures under international agreements or practices. ** Other concepts such as sustainable production, resource efficiency, sustainability footprint etc. also provide useful frameworks for implementing selected SDGs.

Understanding the life cycle of regional sustainability issues is an important first step. The subsequent step, devising sustainable responses, has its own particular challenges. The global community has framed its ambitions for socio-economic advancement and long-term survival around a set of 17 agreed sustainable development goals-SDGs for
short [4] each with further subsidiary objectives and action plans. The environmentally orientated SDGs mirror many of the impacts we know under more common names such as pollution, wildlife conservation, water management, toxic chemicals and climate change. Historically much of society, and a large part of public administration, has responded to these environmental issues in isolation of each other. We now understand that they are in fact closely connected and that actions to implement each SDG separately can lead to negative effects on the others—the so-called “spillover effect” (see Box 1). The avoidance of spillovers is an important component of life cycle management (LCM).

Box 1. Connected SDGs and Spillovers *.

| All the SDGs are interconnected, with the implication for decision-makers that tackling them together, rather than independently, results in better outcomes. Bertelsmann Foundation and the (SDSN*)’s SDG index reveal that current sustainable development programmes are still largely pursued as short-term goals, vastly underperforming on sustainability. |
|---|
| Environmental spillovers include anthropogenic climate change; trans-boundary pollution and pollution embedded in trade; biodiversity loss embedded in trade; and the misuse of the global commons, such as over-fishing in the high seas. Other spillovers are related to the economy, finance, and governance sectors. |
| High-income countries tend to generate both positive and negative effects vis-à-vis the poorer countries. The inclusion of spillover indicators changes their scores on SDGs. For example, certain OECD countries lead the world on aid contributions, but also have high domestic agricultural subsidies—pointing to a need for greater policy coherence. |

* Sustainable Development Solutions Network: https://www.unsdsn.org/ (accessed on 14 September 2021)

Life cycle thinking—whether through standardised procedures or informal other methods—can assist regions to deal with the realities of extended supply chains and with multiple local issues at the same time, avoiding wherever possible the creation of spillovers. To illustrate the extent of potential life cycle applications, we show, below, some of the activities that regions already engage in to create a regional sustainability framework. Nearly all of them would best be pursued from a holistic perspective, understanding their interactions, and applying specific life cycle approaches and methods that have been developed in recent years. Some development activities susceptible to life cycle approaches include:

- Regional administration including contracting and purchasing, travel & office works,
- Regional services such as schools, hospitals, crèches, geriatric centres,
- Infrastructure management, including energy, water, transport, health services,
- Resource development activities in agriculture, minerals, forestry, energy, etc.
- Industrial development, including service sectors such as tourism
- Environment protection and waste management, land conservation
- Education, employment and social improvement programs

Against this background, the present paper prepares the ground for both further research and greater application by reviewing how the more promising life cycle tools are already used in, and by, various regions around the world. By compiling a first overview of regional practices and their experience the paper gives the LCA community a clearer vision of where further refinement would be useful, while simultaneously providing regions with a vision of how they could benefit from a life cycle approach to further evolve their sustainability programmes. Increased effort is needed on development and standardisation of life cycle management procedures to accompany the further evolution of various assessment methodologies that we are now seeing. The paper comments on the challenges still ahead in methodology, in data, and in developing deeper understanding and skills among the various stakeholders. It builds on a reference work [7] that gave a first introduction to life cycle approaches to sustainable regional development and is
here updated by a more comprehensive review of actual practices and their successes and limitations than could be achieved at that time.

2. Overview of Life Cycle Methodologies

2.1. Life Cycle Assessment—Its Development and Applications

The idea of long-term development thinking is not new, nor is the idea of taking into account upstream and downstream consequences. What is recent is the attempt to structure and standardise such life cycle thinking to enhance its effectiveness, to improve comparability, and to facilitate the exchange of experience.

Environment impact assessment (EIA) [8,9], one of the intellectual precursors of life cycle assessment (LCA), came into being in the 1970s in the US and other countries to allow systematic evaluation of the likely environmental (and ultimately social) consequences of major projects. EIA provided the inspiration for a closer look also at products and materials, leading eventually to the creation of specific instruments to assess materials flows and their consequences. In time, consideration of other issues and impacts were also added to the LCA procedure.

The LCA process is currently described in ISO 14040 [10], as shown in Figure 2. The process of LCA standardization has incorporated several features that are not always explicitly on display. The LCA procedure is built around the need to study materials and energy flows, taking into account the impacts from manufacturing inputs (raw materials), the product itself, and the outputs (products and waste). Environmental impact categories commonly considered are pollution-type and resource-consumption effects on ecology, human health and natural resources (the so-called areas of protection [11]).

![Figure 2. LCA principles and framework (Adapted from [12]).](image)

For subtler environmental consequences concerning biodiversity and ecological resilience, as well as social and supply risk related impacts, there is still a shortage of suitable data and agreed metrics to allow easy calculations in the same way as done currently for ‘traditional’ LCA studies. Accordingly, such impacts are less often considered, even if they are at the heart of many of the regional and global challenges as encompassed by the 17 SDGs.

Attempts have been made in recent years to expand LCA methodology to allow it to better address the full set of SDGs [13]. There has been progress towards social LCA [14], as well as in procedures for evaluating life cycle biodiversity impacts (See for example: [15]). On the economics side, extended life cycle costing [16] now considers also off-site social and environmental costs. A combination of these approaches results in so-called life cycle
sustainability assessment (LCSA) that is based on the holistic sustainability framework instead of a focus only on environment as done in traditional LCA [17,18].

Other related—and sometimes non-standardised—methodologies further enrich the results obtained from the above. A particularly relevant recent development for regional development is territorial LCA that examines sustainability issues on a macro scale [19]. The use of environmentally extended input–output (EEIO [20]) tables and materials flow analysis (MFA [21]) gives a more systems overview of where substances come from and where they go to (and what impact they have), of particular value in regional resource policy and in waste management. Much effort is also going to a more common approach to the assessment of land use and land-use changes—so-called LULUC—that underlie many regional sustainability initiatives, whether at the local or the district level [22–26]. Insofar as land-use changes are at the origin of many regional conflicts, an increasing refinement and application of such methods are very relevant to regional development, although hard data for quantitative analysis is often difficult to come by as regions have not traditionally pursued the compilation of such statistics.

At the same time traditional LCA can be expanded to study not only discrete products but also the organisations producing them, making use of organisational LCA (O-LCA) to map out the sustainability footprint of the organisation, as, for example, a regional administration or service [27,28].

Taken together, these more recent assessment procedures constitute a welcome complement to the traditional LCA studies of materials and services, and greatly assist regional organisations in acquiring vital information that helps them confront the ever-increasing sustainability challenges. A proposed set of life cycle assessment methods for regional use is included in Table 2.

Table 2. Example of application of the Toolbox from the Navarra region of Spain.

| Life Cycle Assessment Tools | Life Cycle Management Tools |
|----------------------------|-----------------------------|
| Calculation of Carbon emissions in services of the Commonwealth of the Region of Pamplona: analysis of services and facilities to calculate greenhouse gas emissions (water cycle, urban waste, urban transport). Registry of carbon offset and CO2 absorption projects. Fifteen organizations in Navarra have registered their carbon footprint. | Eco-design ISO 14006 |
| Carbon footprint of Navarra asparagus and the cured sheep cheese in Latxa de Lezua | Designing healthy and sustainable food menus in municipal schools |
| Oil production—oleohealth 2013—calculation of GHG emissions | Eco-label: Register of Navarra Products with European Ecological label: tissue paper napkins of SCA Hygiene Spain S. Com. P.A quilt and mattress protector from Textiles Inducam SL Hotel Rural Aribe lubricating greases from Verkol, S.A.U |
| MFA (Materials Flow Analysis)-Inventory of GHG emissions in Navarra: evaluation of GHG emissions taking into account both the sectors that originate them and the type of GHG | EPD (Environmental Product Declarations)-use of LCA to support certification EGGNOVO, has three EPD for different products derived from eggshells ACCIONA and SIEMENS GAMESA have registered EPDs for installed wind farms. |
| LCA for organic extra virgin olive oil 2008–2010: LCA, SLCA, and LCC to assess environmental, economic and social impacts. | Ecological footprint—regional environmental footprint considering material resources and waste generated for the maintenance of the production and consumption model of the community. |
### Table 2. Cont.

| Life Cycle Assessment Tools | Life Cycle Management Tools |
|----------------------------|-----------------------------|
| Footprint calculation models | carbon footprint reductions |
| UMBERTO; SIMAPRO; SIMUR; EURENERS; ENECO | carbon offset scheme for municipal energy consumption |
|                            | purchase of green energy by municipality |
|                            | energy-efficient public transport (buses) |
|                            | management systems ISO 14001 (427 certified organizations) |
|                            | and ISO 50001 (9) |
|                            | circular and sustainable materials management: |
|                            | reusing drinking glasses at parties and events for public services |
|                            | “Nights without plastics” in the Informal Room of Tafalla to reduce footprint of events |
|                            | The Olite ecological municipality; to eliminate plastic material, and decrease footprint. |
|                            | ECOCIRPLAS Project-life cycle analysis approach to waste management in the Foral Community, promoting waste reduction and its reuse and recycling as key management principles. |
|                            | green Procurement: |
|                            | LCA and calculation of carbon footprint for road cleaning tenders of Pamplona |

Source: Personal communication from Sandra Elia Hurtado, Govt Navarra, Spain.

#### 2.2. Life Cycle Management to Improve Resource Efficiency

LCA allows us to pinpoint where major impacts occur in a particular product or project cycle. The function of life cycle management is then to take the most cost-effective preventive action to sidestep the unwanted consequences [29,30]. For this to occur the various partners and stakeholders at different points in the life cycle often need to act in concert. Life cycle management is thus as much a multi-stakeholder co-ordination exercise as a technical decision, based on differentiated action to meet a common objective. Several actions such as, for example, supply chain management, have developed specific frameworks for such action partnerships. Table 2 includes some types of ‘management’ action in this direction, and we briefly mention several of these here. All management initiatives benefit greatly from life cycle assessment outcomes, although cases of life cycle management programmes without underlying LCA are also known. A useful example here is the international cyanide management code that links the substance producer to the end-user via all the intermediary agents around agreed standards under the Code [31,32].

Eco-design is at the apex of preventive management action, providing the basis for potential impacts to be minimised from the outset. Product service systems (PSS [33]) can be considered part of the design arena as they require the design of a service that has appeal to a customer while still oriented towards the SDGs.

Related to, but separate from, design is the issue of labelling. As many management decisions along a supply chain are based on label information, eco-labelling [34], environmental product declarations (EPD [35]) and the product environmental footprint (PEF) in the European space [36] are an integral part of the communication side of the LCM universe.

Sustainable supply chain management (SSCM [37]) and its public sector equivalent sustainable (or green) public procurement [38] are ways to ensure that products and services being purchased or sold minimise damaging impacts both upstream and downstream of the point of purchase. EPD and eco-labels provide important information, but it is the act of purchase or contracting that constitutes the LCM element.

Some LCM tools express themselves principally at the downstream part of the life cycle. The notion of extended producer responsibility (EPR [39]) links the supplier to
the consumer to provide an incentive to the former to take adequate measures to avoid eventual downstream liability issues.

Corporate management that takes a wider view of its operations has, itself, a life cycle reach. Regional administrations, now increasingly structured along corporate lines and driven by prominent sustainability objectives, can usefully employ some of the methods already practised by the private sector. Two items stand out: environmental management systems, and sustainability reporting. Both are already effectively standardised with sufficient experience in use to allow application also by public bodies. A number of municipalities and cities are already publishing their sustainability performance under Global Reporting Initiative format [40,41]. The management of chemical safety in various operations and preparedness for environmental and community emergencies [42] are two further programmes of regional relevance that have a clear upstream assessment phase and a subsequent post-event phase. Both are described in commonly agreed international and national guidelines under the aegis of international bodies such as OECD, ILO, WHO, EU, as well as for workplace safety in ISO 45001. These instruments all have life cycle implications and depend on various forms of life cycle thinking. Some examples are included in Table 1 and appear in various places in the discussion further on.

3. The Life Cycle Toolbox and a First Glimpse of Current Practice

Let us now look at the question “how extensive has been the application so far of LCA and LCM in promoting sustainable development, or what we now coin as the SDGs?”

While LCA has allowed a much better understanding of the potential impacts for many products, the results of such analysis depend on the length of the supply chains being considered. There is a real possibility that important impacts occur outside the chosen scope (both geographically and thematically) of a particular exercise, irrespective of the benefits at a local level. It was already mentioned that many LCA studies are oriented towards selected SDGs, (often a single SDG) without necessarily considering spillover effects. The various diverging LCA studies on biofuels and on packaging [43–45] illustrate well the consequences of such a limitation. At the same time, the increasing number of studies related to biodiversity [46] land-use and social impacts which are all vital issues for regions, show that a broader SDG view is also gradually becoming more visible.

For LCM [30], an informal view of current practice reveals a good deal of progress but also some common shortcomings. Similar to LCA, many LCM exercises have a truncated scope, and limit the number of SDGs being considered to just a few criteria that respond to immediate priorities, in particular to water, energy and climate change. It’s also important to move beyond what science can assess and take implementation into account. Inspection and auditing, important complements to LCM, is often inadequate, resulting in unsatisfactory outcomes despite the overall good objectives, as is exemplified in [47]. These observations apply in equal measure to regional initiatives and to the more numerous corporate exercises. Life cycle tools need to be sharp and used in a professional way to fulfil clear objectives if regions and their partners are to be able to fully benefit from an application of the tools shown in Table 1.

The book Life Cycle Approaches to Sustainable Regional Development [7] offered two important insights: LCA, as defined by ISO 14040, is structured around business needs, using procedures and management language that is not always familiar to regions. In particular, the social, resource management and conservation needs of regions are not able to be fully addressed by the traditional LCA framework [48]. Despite a gradual increase in the use of life cycle methods by public bodies, there remains a need to further evolve some methodologies and their underlying databases if they are to contribute more fully to SDGs at the regional level.

Regional administrations themselves need to better appreciate the potential benefits of life cycle thinking in their pursuit of sustainable development. Regional officials are mostly not sufficiently familiar with life cycle concepts—especially life cycle management—to
take full advantage of their potential (see Box 2). Officials are not participating in LCA networks, which should in any case better integrate their interests and needs.

**Box 2.** Case study of regional use of LCC for green public procurement.

Many regions have important procurement budgets; however, most purchasing is still taking place without particular regard to sustainability objectives. In particular, upstream and downstream (i.e., life cycle) impacts are not being used as purchasing criteria, or if actually used, applied on a subjective rather than analytical basis. Within Europe, the European Commission (EU) has published extensive criteria that member states and their regions are invited to use in their public procurement programmes for a range of product types [49]. The EU has also developed guidance on the use of Life Cycle Costing (LCC) to order to improve the tendering process by public authorities [50].

According to the Commission:

> “LCC may also include the cost of externalities (such as greenhouse gas emissions) under specific conditions laid out in the directives. The current (2014) directives require that where LCC is used, the calculation method and the data to be provided by tenderers are set out in the procurement documents. Specific rules also apply regarding methods for assigning costs to environmental externalities, which aim to ensure that these methods are fair and transparent”

A recent meeting of seven EU partner regions [51] exchanged information about how they used LCA and LCC instruments to improve the sustainability of their tendering and procurement. Not surprisingly most LCC assessments focused on total cost of ownership (TOC) with only minor reference to environmental costs (carbon emission cost being the main exception). Notwithstanding these limitations, several countries have introduced legislation for use of LCC in public procurement (Poland, Slovenia) [52].

A number of initiatives have recently been taken to address these obstacles, as for example through the FSLCI summer schools [53] and workshops [54], and through the Interreg project ‘LCA4Regions’ [55]. A structured analysis of current practice is shown in Section 5. But first, Chapter 4 explains the methodology by which our results were obtained and how the conclusions were derived.

An illustrative example on how the toolbox in Table 1 can be used comes from the Navarra Region of Spain [56] and is presented below in Table 2.

It is interesting to see in Tables 1 and 2 the potential tools in the light of methodologies already integrated in the work of the European Union (EU). The various decisions, directives, regulations, recommendations and communications have a solid foundation not only in general life cycle thinking, but also in formal methodologies such as LCA, LCC, EPD and PEF, carbon footprint, among others. As well, the EU is a major player in chemicals assessment and REACH [57], workplace safety, disaster preparedness, transposing also various ISO standards into internal requirements for member states and their regions. Figure 3 from a recent publication by Sala et al. [58] showed the extent to which EU work is based on life cycle concepts.

While regions do indeed follow the directions indicated in such policies, they mostly do so without really understanding their origins. Simply following EU requirements has not always led to a better understanding of the value of life cycle approaches. Further information about EU guidance and activities relating to life cycle methods of use at regional level is given in Appendix A.
4. Methods and Materials

Being remote from research environments, and not closely tied to commercial product development, regional sustainability policies and programmes based on use of life cycle tools are not well documented. Figure 4 shows how a preliminary overview of current practice was therefore based on several different parallel sources of information, including direct stakeholder interactions and the so-called grey literature in addition to scientific literature searches, as commonly used for academic review publications.

Figure 4. Methodological approach.

On-going participation by the authors in a number of multi-regional capacity-building programmes gave direct insights into examples of life cycle-based initiatives by certain regions, and especially into the difficulties and challenges they face in implementing such approaches. Particularly useful were the LCA4Regions project supported by EU Interreg programme [55], the cities network of ACR+ [59], and the learning programmes of FSLCI comprising summer schools [53], workshops [56] and related publications aimed at LCA professionals and regional officials alike. The case studies identified from these projects, and the insights they provided, have proven invaluable in helping to understand how
regions and municipalities can use a holistic approach to deal with their sustainability challenges and initiatives. To support such approaches, intergovernmental organisations such as the EU or the OECD [60] and other pan-regional structures (such as the French regional association [61] for example) have produced important guidance documents based on actual experience. All the above sources referred also to relevant reports by various government administrations that are not easily found in the scientific literature, but which contain examples of interest to our study.

Numerous regional examples and case studies are also found in the scientific literature. The review drew on the results of a quantitative information search for regional life cycle studies and practice, as reported in a previous work of the authors [62]. This search was in the form of a bibliometric analysis of research literature published between 1976–2021. It used a set of over 5000 published papers from the Scopus database to map the quantity and evolution of research in LCA studies that have a strong regional focus. A co-word analysis was used to identify the thematic relationships between the main subject areas covered by the publications identified in this search. Although somewhat constrained by lack of clear definition in the desired keywords related to the concepts of ‘region’ and ‘regional life cycle methodologies’, the search was still able to give a good picture of the temporal and spatial origin of scientific research work on the topic, including its subject focus. The analysis should be seen in a context where bibliometric analysis covers scientific literature and therefore excludes policy papers and reports, thus missing many of the platforms on which regional activities are regularly reported (e.g., institutional reports mentioned above). This is well demonstrated in Figure 5, where the working disciplines imposed by the Scopus database do not reflect adequately the main policy and sustainability preoccupations of regional governments, as pointed out, already, in the Introduction to this review.

![Figure 5](image-url)

**Figure 5.** Results of the bibliometric analysis with regard to the number of total publications per working discipline, as obtained by Bezama et al. [62].

To complement the investigation methods above, additional information sources were explored through a third approach, a direct manual search using a popular free search engine. This allowed a more subjective expert-based evaluation of the relevance of the items brought to light than could be made by an automated search. Keywords were similar to those of the bibliometric analysis and checked for relevance in each case. A cross-check between these search methods revealed striking differences. The automated and highly structured bibliometric search was able to scan vastly more articles corresponding to the
chosen keywords but was also flooded by numerous peripheral publications that fitted the keywords but not the regional or subject context being investigated. The manual search screened fewer candidate items, but these could be more easily judged individually for their relevance to our examination. Together the use of all three methodologies in parallel gave enough regional LCA case studies to permit the analysis shown in Section 5.

The case studies coming from the above searches were assessed from a two-fold perspective—which life cycle tools did they employ, and which SDGs and other sustainability challenges did they address. An attempt was made to identify cases to cover as many of the tools in Table 1 as possible to see which ones had been the most useful, and also to see which SDGs were susceptible to being addressed by these tools. While there is no shortage of standard LCA applications, it was also important to include the less mainstream tools such as LCC, MFA and social LCA, to quote just three examples. It was also pertinent to discover how various life cycle management tools had been applied. Finally, beyond the identification of usage, it was particularly interesting to learn something about the actual experience of regions in their application. The above led to a selection and analysis of case studies based on the following criteria:

- Extent and trends in the overall use of tools in Table 1
- Extent of the use of assessment versus other tools
- Extent to which non-mainstream assessment tools were employed
- Extent and type of LCM tools employed
- Adequacy of full life-chain consideration in application
- Extent to which LCA led to management action
- Extent to which life cycle system frameworks were used effectively
- Extent to which tools were difficult to apply
- Extent to which SDGs and other sustainability issues were addressed
- Concentration and diversity of activity sectors involved
- Extent to which regional functions were implicated
- Concentration and diversity of regions surveyed

It should be mentioned that the examples from the various searches are not necessarily unique, nor are they always perfectly structured and executed. They do not, and are not intended to, capture the very extensive LCA studies that have been carried out in certain sectors such as building, energy, waste, agriculture etc., each of which is subject to a vast library of specific information. Instead, the examples aim to illustrate the variety of life cycle tools available and the extent of their potential application to regional development issues. As well, they highlight the supporting role of overarching life cycle concepts, systems and approaches such as SDG objectives, circular economy, industrial ecology and other holistic concepts. The reader will easily find additional references in the wider life-cycle literature. As well, the structure of the case studies varies widely. Some relate directly to the details of regional action. Several are published as theoretical LCA research that has potential relevance to regions. Many do both, illustrating generic LCA methods as well as providing one or more regional examples.

5. Results and Discussion

5.1. General Observations

From the bibliometric analysis the authors found a rapid growth in scientific publications on region-related LCA activity over recent years. The analysis revealed a strong concentration of academic LCA research in a rather restricted number of countries, institutions and journals. The co-word analysis indicated that the scientific knowledge base about regional LCA is strongly oriented towards issues of waste, transport, energy and the building sector, with ecological topics being underrepresented. The LCA focus is predominantly on physical products, oriented towards scientific or engineering applications, rather than on management of public issues and natural resources (see Figure 5). In addition, the analysis shows that the conducted research is more concerned with human productivity, with less emphasis on regional nature or resource management. This means that academic LCA
studies focus relatively less on the potential impacts of regional value chains than with for example global industrial or consumer products. Furthermore, social and organizational issues were not found in this particular analysis. There was also a noticeable gap between MFA analyses and regional decision-making, suggesting the dominance of an academic research agenda rather than of policy application.

Table 3 shows a selection of case studies identified through the manual search. This method identified better the regions/countries using a variety of life cycle tools, for both assessment and for management. It should be noted that many of the examples here were not drawn from the traditional scientific literature, being often sourced from governmental and interagency project reports, and were thus often absent in the bibliometric analysis. Appendix B gives further details on the case studies from this table, while the discussion at the end of Appendix A gives some further examples of the use of life cycle methods by the partner regions in LCA4Regions project mentioned earlier.

Table 3. Examples of manual search for life cycle methodologies from selected regions.

| TOOLS (see Table 2) | Application | Case Studies (see Appendix B for More Details) |
|---------------------|-------------|------------------------------------------------|
| LCA                 | for identifying and prioritizing regional waste streams for circular economy | Scotland |
| LCA                 | of regional waste disposal technologies | Asen region, Chile; Lombardy Italy |
| LCA                 | to assess local impact and suitability of EVs | Lithuania; Brazil |
| LCA and MFA         | regional circular economy | South Australia; Geneva; Burgundy |
| LCA and LCM         | of chemicals | generic international programme of IOMC. and REACH Lithuania |
| LCA and EPD         | in the approval process of renewable energy projects | Spain and Mauritius |
| LCA and EPD         | to protect and promote regional agriproducts | Australia |
| LCA and LCM tools   | to improve sustainability in buildings | France; Lithuania; Nepal; Spain |
| LCA, LCC and Footprinting | to identify sustainable city school lunch menus | UK; Spain |
| Territorial LCA     | urban materials-flow optimisation | Lille; France; Tunisia |
| Footprinting        | for water resource management | Leshan, China |
| MFA                 | to inform resource management in regional economies | Iceland; Trinidad and Tobago |
| EEIO                | for regional assessment | Denmark, Finland, Wallonia Belgium |
| Social LCA          | to guide bioeconomy policy and programmes–forest sector | Germany |
| LCSA                | sustainability assessment from a regional perspective | generic discussion |
| O-LCA               | to address GHG reduction in public sector organisations | Norway |
| E-LCC & TCO         | for public procurement | Denmark; EU |
| LCM                 | to ensure sustainability in resource exploitation | global sector; USA |
| Life cycle evaluation | regional forest sustainability and multi-functionality | Canada BC; Europe |
Further details on the listed items and their references can be found in the short case studies in Appendix B. The analyses overall respond adequately to the question: what life cycle methods have come into use at regional level, and what is their substance? Tables 2 and 3, as well as several anecdotes and boxes in the text, present illustrative individual case studies in the context of the toolbox in Table 1. Together they show considerable diversity in content and application. A synthesis of the collective experience is presented below in Table 4 and discussed in more detail in Section 5.2.

Table 4. Overview of the collective regional experience with life cycle approaches.

| Number | Statement |
|--------|-----------|
| 1.     | Standardized life cycle assessment tools e.g., LCA, are already used in various regions. |
| 2.     | The use of life cycle management tools is not systematic as many are non-standardized. |
| 3.     | LCSA is not yet much used due to its unfamiliarity and its intrinsic complexity. |
| 4.     | Most LCA and LCM exercises are based on truncated supply chains. |
| 5.     | LCA often does not lead to a subsequent LCM phase (i.e., no implementation). |
| 6.     | The effective use of life cycle system frameworks is still limited, despite much talk. |
| 7.     | Many life cycle tools as currently used address only a limited set of SDGs or issues. |
| 8.     | Several SDGs require complex specialized assessment and management tools. |
| 9.     | Some tools are not getting traction for a range of practical, scientific and data reasons. |
| 10.    | Data and metrics gaps are hampering use of territorial life cycle approaches. |
| 11.    | Many regional activity sectors are susceptible to application of life cycle methods. |
| 12.    | Most regional SDGs can be addressed through life cycle approaches and methods. |
| 13.    | The same tools may be used in different ways by different actors. |
| 14.    | Life cycle methods should be understood in the context of regions’ multiple roles: |
|        | (a) Life cycle tools for regional service providers |
|        | (b) Life cycle management for regional regulators |
|        | (c) Life cycle methods to support policy |
|        | (d) Life cycle tools for governance of regional corporations |

The above observations have a number of important implications for regional use of life cycle approaches, as we will see in the synthesis. They also have implications for the direction of on-going research into the adaptation and further development of assessment tools for use at the macro (i.e., territorial) level as was mentioned in the Introduction, and for the identification or refinement (including standardisation) of life cycle management tools that could potentially be used by public sector organisations.
5.2. Synthesis and Discussion

This section elaborates on the experiences drawn from the various sources identified in the general observation sections as well as from the case studies in Appendix B (as summarised in Table 3). It examines more closely the interface between life cycle methodologies and regional development, looking, in particular, at the way regions are using the various tools available. The discussion should be seen in the context of Table 1, which divides life cycle tools into four groups, respectively of life cycle systems, assessment tools, management tools, and life cycle-oriented corporate management methods. It is important to stress that not all items within these groups are universally considered ‘tools’, nevertheless, all depend on some level of life cycle thinking, and all can be considered to fit into the thematic framework of this review.

The synthesis and discussion below are structured around the collective regional experience, as summarised in Table 4, to see how life cycle methodology is pertinent from a regional public sector point of view. Each observation is referenced to one or more of the case studies so as to confirm that the conclusions are drawn from actual practice, imperfect as that may sometimes seem. It becomes clear that, despite a wider use of life cycle methodologies in, by and for regions, many challenges remain.

1. Standard assessment tools are already extensively used in various regions.

Through the case studies we can see that use of life cycle tools in a regional context is already taking place, even if the application is uneven, and many applications are for, rather than by, a region. The greatest use is of standardized assessment tools of various types, often in the form of simple carbon footprints and increasingly also as product-oriented LCA, and to a more limited extent certain issue-specific uses such as materials flows, full costing, social issues, organisational footprints, landscape and biodiversity, and chemical risks. A range of footprinting methods often underpins sustainability-oriented policy decisions. Examples include LCA to inform electric vehicle (EV) policy in Lithuania, LCA for building options in remote regions of Nepal, MFA for plastic bottles in Trinidad or for nitrogen flows in Burgundy’s agricultural land, and for resource allocation in Iceland. There are examples of water footprinting in Leshan (China) and carbon footprinting in Navarra, of waste technology assessments in Italy and Chile, biodiversity LCA for Swiss agricultural land use, and various forms of LCA for forest products in Canada and in Germany. Additional examples can be found in Appendix B, and in the wider literature. The fact that nearly all the assessment tools in Table 1 have been used somewhere in a regional context indicates the usefulness of such tools in general.

2. Use of life cycle management tools is not systematic, as many LCM procedures are not standardised.

Life cycle management tools are used less systematically, due in part to the widely varying interpretations of what LCM actually is. This review takes a broader view than many other sources. While many LCM exercises focus on only a limited portion of the life cycle and address only a truncated set of SDG criteria (see Item 4 below), we do see a wide use by many regional actors of individual LCM components such as eco-design, product-labelling in its various forms, application to purchasing, some degree of EPR, and holistic regulation and standards—see, for example, the use of LCM elements by the Navarra region in Table 2. Since full life cycle consideration is still rare in public sector use of LCM there is little evidence of strong life cycle stakeholder partnerships that bind the entire value chain into an agreed set of sustainability objectives. Such partnerships are better known in industrial supply chain-management practices of large corporations like Walmart [63] or in certain sector-specific initiatives such as the cyanide management code in the mining industry [31]. One regional example of building life cycle stakeholder networks that we can note are the LCM procedures pertaining to the building sector in the Hauts de France region [64]. Overall, the use of structured LCM at regional level is neither extensive nor systematic, even though some individual LCM elements, such as EPD and labelling, are becoming more visible. Most LCM applications still appear to
be single-dimensional exercises, very often greenhouse-focused, but rarely integrating multiple SDGs, nor with a long life-chain reach. All in all, a further evolution of systematic LCM procedures and their eventual standardization would be of huge benefit to regions.

3. Full life cycle sustainability assessment (LCSA) is not yet much used.

In view of their growing development responsibilities, most regions need to address the full set of 17 SDGs, making LCSA a potentially attractive tool for them. Nevertheless, various limitations put LCSA, which is designed to evaluate a total sustainability impact, in a delicate position with respect to regional application. LCSA is only slowly moving out of the research arena by developing and testing methodologies and metrics to try to create a tool that can be applied more widely in the future. Work is on-going within UNEP’s Life Cycle Initiative to allow this tool to address the full set of SDGs [65]. A recent review paper established generic LCSA principles for a more standardized approach to application [3]. It is hoped that this standardization together with the further evolution of LCSA will fully take into account the regionally relevant SDGs that flow from a territorial as well as a materials/products consideration. For the present, there are few examples of formal application of LCSA by regions, although it can be assumed that many of the relevant SDGs are taken into account informally in actual development policy decisions. A review report on LCSA from the scientific literature is found in [65].

4. Most LCA and LCM exercises are based on truncated life cycles and supply chains.

Based as they are on vast global trade networks, many of the life cycles of society’s materials and services are intrinsically complex. Identifying rigorously the ‘suppliers of the suppliers’, and the impacts at all levels, is a herculean task. In practice the scoping phase of life cycle exercises must restrict the consideration to something more manageable. Even with this caveat, we can nevertheless observe that in many regional exercises the life cycles are still short, especially when we know that further upstream additional important SDGs concerns may come into play. This is the case also of the downstream side, where issues of end-of-life have long been neglected, as for example the disposal of packaging, abandoned industrial land, and initially unplanned decommissioning of power plants. Our regional case studies display the problem of short life cycles in various ways, in LCA and MFA for waste technologies, in public procurement and even in assessment of healthy school menus. The above shortcomings are in large measure a consequence of administrative fragmentation within the regional institutions, where separate departments each deal with only a limited set of SDGs. Short life cycles thus reflect the limited territorial reach of regions in a globalised world, but also a desire to simplify the assessments in the context of a particular project. Such simplification risks to ignore spillover effects in the life cycle that can easily present a burden on future generations. That a wider consideration is nevertheless feasible is confirmed by the example of Scotland’s zero waste programme where consideration of the complete life cycle of waste materials has been incorporated into its LCA procedure. As a final comment we can note that the above issue is one of proper application rather than a shortcoming in methodology.

5. LCA often does not lead to LCM because management was disconnected from assessment.

It is noticeable that many LCA studies do not throw much light on LCM procedures that could help implement the findings of their assessments. Along with a lack of deeper exploration of ‘key player’ influence (a major factor in decision-making), a bridge to management solutions is sadly missing from many LCAs. For example, while LCA informs the building sector on physical and technical details, it is not always clear to what extent regional building permits are based on the results of such life cycle studies. An interesting Lithuanian research study on impact of EVs in that country did not look at how a transition away from conventional vehicles could be managed. This assessment–management disconnection is an unfortunate feature of many otherwise excellent and useful LCAs. LCA is at its most powerful when in addition to studying the problem, it also clarifies and even proposes
workable solutions beyond the traditional, third-person “it must be done by someone” formulation. A number of our examples go a small way in the management direction, as the MFA in Trinidad, the O-LCA in Norway, the LCA for zero waste in Scotland, and the extensive LCM programme for the building sector in Hauts de France [66]. Many others could go much further than they did. That said, it has to be acknowledged that skill in assessment is different from skill in public or corporate management. An effective LCA–LCM symbiosis is best achieved through some form of project partnership that guides the study from the beginning. We recall the conclusions about the need for a stronger link between the LCA community and regional decision-makers [7]; but, a more structured approach to preparing the implementation section of LCA studies would be a great help.

6. Effective use of life cycle system frameworks is still limited, despite much talk. Due to a lack of standardisation and an absence of agreed metrics, holistic life cycle system concepts such as circular economy, bioeconomy, industrial ecology, and total cost of ownership are unevenly applied, often in an ad-hoc fashion with only limited consideration of the full life cycle, and mostly with a very partial consideration of SDGs. That said, it can nevertheless be observed that many LCA and LCM studies invoke, for example, circular economy (CE) as the objective of the exercise, revealing a growing consciousness of the need to address system (rather than—or as well as—point-) -specific performance. Overall, despite the frequent rhetoric, the implementation of life cycle systems is still more talk than walk, and not yet mainstream in either the public or the private sectors. Several encouraging examples were nevertheless found as for example Scotland’s zero waste circular economy [67], and more generally the examples of industrial ecology arrangements in some business parks in Europe. It can be added that the considerable on-going work on materials-based circular economies [68] has raised the visibility of this concept, even if it has not yet been structured into a form that can be easily translated into holistic regional policy (it currently has a strong focus on the business sector and product-specific initiatives). Regrettably, for many regions (and other actors) the circular economy is simply another term for recycling, giving a new name to something that regions are already doing. For most of them, the notion of a full materials cycle is too difficult to address given the global nature of supply chains. It can also be noted that most CE talk is not especially focused on SDGs. To a significant extent the CE concept has been captured by the waste sector, and its metrics are focused on the volumes and weights of materials.

7. Most life cycle applications take only a limited number of SDG criteria into account. As we have already seen above, a common feature of all the case studies here is that most life cycle applications are carried out to assess only a small number of sustainability criteria. Climate issues and GHG (and its surrogate, energy), water and waste dominate the SDG agenda in assessments. Social issues, biodiversity and land-use are less frequently incorporated as we saw above, and when the subject of study the range of other SDGs is again very constrained. Few studies provide a justification for their limited selection of SDGs, and even fewer discuss possible secondary effects on the non-included SDGs. Certainly, single-issue LCA and LCM has the advantage of simplifying the evaluations, but at the risk of creating unwanted spillover impacts as was previously mentioned. Several regions have expanded their LCA criteria, as Scotland for the circular economy and British Columbia, Canada, for forest resources. The discussion paper by the European Academies Science Advisory Council (EASAC) on use of forests for carbon capture has also extended the discussion on offsetting to acknowledge secondary impacts and broader SDGs [69]. While incorporation of the complete set of SDGs may well be impractical, we can take inspiration from the manner in which some industry sectors have identified the priority SDGs that they need to address, as shown in Figure 6.
8. Several SDGs require complex specialised assessments.

Certain SDGs require the use of highly specialized assessments. For example, the recognized importance of national (if not global) chemical safety and health objectives has resulted in these sectors establishing their own criteria, methodologies and stakeholders, developing prominent multi-agency programs, often harmonized at international level. To the extent that they take into consideration upstream and downstream aspects of chemical exposure they are de-facto life cycle procedures. Regions already rely on national or international standards for any health and chemical exposure assessments that need to be carried out by their experts. We have not included examples of health or chemicals assessment in this discussion. It should be noted however that standard LCA already considers health and ecosystem impacts in its procedures, using published ecosystem and human health criteria in the assessment of mid- and end-points. Certain LCM tools such as EPD, eco-labels, and PSS can and do already take the outcomes of chemicals assessment into account. A few of the case studies in Appendix B incorporate international chemical safety criteria in their assessments and eco-labels, however we have not included examples of actual chemical assessment in this review.

9. Some tools are not getting traction.

While the usefulness of product- or material-specific LCA is gradually entering the public sector consciousness, at regional level a number of other helpful tools and methods have difficulty in gaining traction. There are many reasons for this, some of it is due to mindset, and some of it is concerned with data and metrics. For example, biodiversity assessment—important at the regional level—is conceptually complicated by numerous situation-specific parameters, making it difficult to develop universal data sets and models that can be applied by all regions. The Switzerland example illustrates the difficulty in moving from research study to policy application. Another example is the lack of wider use of extended LCC (E-LCC) and total cost of ownership (TCO). Despite the encouraging Denmark exercise on public procurement, TCO is still often handicapped by our inability (and sometimes unwillingness) to put a monetary cost on all the impacts and benefits. Finally, the assessment of social impacts depends greatly on cultural and political values, again making universal assessment criteria difficult to establish. Overall, while there are numerous research papers on these methodologies, we have found fewer examples of life cycle assessment and management for such non-traditional criteria than regular materials-focused LCA. Even then many are either at company level or as academic research projects rather than actual application to regional situations. Nevertheless, as an indication of what is possible, we can cite the biodiversity assessment in the agricultural sector in Switzerland, the social LCA methodology for the forest bioeconomy in Germany, and
emerging landscape assessment methods from Italy and Belgium. The example of O-LCA in the public sector in Norway should encourage the wider potential use of this method also elsewhere. As a general comment we can also note that many of these ‘extended’ life cycle methods have themselves a rather narrow focus and most do not take other SDGs into account. As such they should be considered as a complement to wider regional studies and decision-making. In the meantime, it would be useful for life cycle professionals and regional officials to collectively address some of the above issues.

10. Data gaps and lack of suitable metrics hamper the use of territorial life cycle approaches.

Data at the regional level are needed for the use of life cycle assessment and the related system-analytical tools mentioned in Table 2 if the studies are to fully address the regional context.

Existing LCA databases [71] do not cover well the issue of regional differentiation, while newly developed regional impact assessment methods [72] focus on world regions but not regions within nation states. In general, regional administrations do not gather appropriate information to underpin the systematic use of certain tools like LCA and MFA or the execution of biodiversity, social and landscape assessments, although the examples show that this information can be obtained when a project is funded. Territorial LCA studies have mainly been undertaken as research projects so far. Application of EEIO is hindered in many regions because economic input–output tables have only been built at the national level. As highlighted by the International Resource Panel [73]: “Improved insights could be highly facilitated by aligning and harmonizing ongoing data gathering efforts and institutionalizing a monitoring and comparative analysis of the data” for a broader use of life cycle approaches. We think that not only international but also regional organizations can be encouraged to explore practical collaborative actions in this field”.

11. Many regionally significant sectors are susceptible to application of life cycle methods.

A number of industry sectors are already regular users of LCA and of LCM procedures, and several have become associated also with the system concepts mentioned above. It is interesting therefore to see which of these sectors also feature in regional-level life cycle studies. Renewable energy, building and construction, tourism, food and agriculture, forest, transport, manufacturing and chemicals, etc. are among the sectors that regions aim to attract to provide investment and employment. Our case studies confirm activity in most of these sectors. Some cases are simple assessments; others include mention or even implementation of LCM components such as eco-design, eco-labels and EPD/PEF as well as procurement, based on life cycle considerations. In view of the already extensive current use of LCA and LCM in such sectors there is no reason why regions should not generalise their use in their own development policies (although this would imply a life cycle competence by the region itself to evaluate the technical studies and monitor implementation).

12. Most regional development issues (SDGs) can be addressed through life cycle methods.

As a complement to the sector focus, we can also turn the discussion around and see which LCA methods are relevant to particular development issues. Many issues involve multiple interconnected SDGs expressing themselves at various points in the upstream/downstream life cycle. A number of cases in this review deal with life cycle methodologies for studies of water allocation and resource exploitation, choice of sustainable energy technologies, environment protection and waste reduction, sustainable consumption via improved procurement practices, healthy food, sustainable transport among others. In addressing these issues, we already see a range of uses of life cycle tools such as footprinting, LCA, MFA, EEIO, LCC, SLCA, territorial LCA, landscape assessment, as well as intervention tools of LCM such as eco-design, product labelling, EPD/PEF, sustainable purchasing, EPR, PSS among others. By way of example, we can briefly elaborate on a particularly topical development issue for many regions—that of the use of forest resources for various purposes in a future bioeconomy and/or as a means of mitigating
or offsetting GHG emissions. The estimation of the value of young vs. mature forests in influencing GHG levels requires considerable skill, the more so if other SDGs less amenable to quantitative evaluation than carbon flows are to be factored in. Several of the case studies touch on the use of LCA methods for forest resources, in particular the report from British Columbia, Canada and that by the EASAC [69]. Looking further into the matter, Germany has also used social LCA to study the consequences of regional forest resources for a bioeconomy. The wider use of such life cycle tools would put regional decision-making in this sector on a firmer footing.

13. Similar tools may be used in different ways by different actors.

The same life-cycle tools are often used by different actors in various sectors, but not always in the same way. Purchasing is a good example; SSM, SPP and GP, are being promoted for corporate, public and consumer use respectively. All purport to take a life cycle view of the products being purchased, but the length and complexity of the life cycles they actually take into account can vary significantly. The priorities of the SDGs invoked may also be different. Thus, public authorities focus strongly on functionality and cost of items they purchase, community groups want to know about the social impacts in the supply chains, and industry looks more deeply into product quality and waste liability issues among its suppliers. There are guidelines, practices and networks specific to each sector. Yet, while the assessment of life cycle impacts may be similar, each actor has different possibilities in managing the life cycle, resulting in a strong differentiation of LCM options. Thus, large corporations have considerable leverage over their supply chain to modify the quality of the products they purchase and of their impacts. Large regions and national governments can also use their purchasing power and contracting procedures to choose more sustainable suppliers. Smaller regions have less leverage, being mostly limited to a buy–don’t-buy action, although there is considerable opportunity to shape service contracts towards sustainable PSS as shown by the provision of lighting services in Denmark. At the present time, the formal use of LCA, LCC and supply-chain management by purchasing departments is still evolving; they still mostly rely on sustainability information from indirect sources and from producers. The label thus becomes one of the key tools for sustainable purchasing, underlining the importance of standardised eco-labels, EPDs, PEFs and materials safety data sheets (MSDS) for chemical products to inform purchasing decisions, while manufacturers use the same methods to market their product. Increasingly labels also look at end of life issues, invoking take-back, recycling and other EPR principles. Case studies from Spain, Denmark, Italy and UK show use of LCA, LCC, TCO, and eco-labels, EPD and PEF in public purchasing of office equipment, energy or lighting services, and food items. Interestingly, public consciousness of EPR is growing in India.

14. Life cycle tools need to be understood in the context of regions’ multiple roles.

The various case studies in their totality show well the multiple roles of public authorities as both service provider (e.g., transport, energy, water, education, health etc.) and regulator (projects, products, operations, environment). Regions are also major corporations in their own right and are subject to life cycle considerations in their internal financing and governance. Accordingly, the use of life cycle tools may have several distinct purposes within the same organisation. We briefly look at some of these cases here following the four points highlighted in Table 4.

- Life cycle tools for regional service providers

The role of infrastructure and service provider gives regional administrations a function that resembles that of a corporation. The motives for undertaking LCA are similar—understanding the life cycle consequences of the product or service being provided, identifying mitigation options, perhaps using the outcomes for marketing. Some examples of this were already shown above for the waste sector, in energy supply, or in municipal food menus. In its role as a ‘producer’, the public authority thus needs skills and insights to undertake LCA work, perhaps using outside experts in the form of consultants or researchers. It is still rare for public authorities to undertake LCA internally, although the
example of Finland and Scotland shows that it is feasible; but, even commissioning an LCA is not without its pitfalls. The agency needs to clearly frame the purpose, scope, outcome and timetable of its study, and to manage the consultant during the course of the study. In particular, it is important that the public authority comprehends and acts on the implications of the results. Among the case studies we see examples of LCA for energy services, footprints for improved water management, LCA for school lunches, LCA and MFA for public waste facilities.

- **Life cycle management by regional regulators**

  As a regulator, the public authority sits in judgement of commercial proposals and of community behaviour. Increasingly this implies an ability to understand corporate LCA studies and related LCM reports, as for example the LCA study of energy options in Mauritius. A critical review is especially important if there is an approval or permitting step ahead, as for example for the wind farm in Australia or for the use of cyanide for a gold mining project in Romania. A potential public review of an LCA could follow a similar path as the already established procedure for validating an EIA for a major project. We note, however, that public review is not built into ISO 14040. In practice many LCA studies will concern smaller industrial products to be launched on the local market, such as use of certain agricultural products, some types of packaging, or use of forest products.

- **Life cycle assessment to support regional policy**

  Life cycle tools can provide powerful inputs to regional sustainability policy. The LCA studies of farming options in Australia helped regional governments there to address local sustainable agricultural futures. Several case studies concern commissioned or in-house research related to waste management options in Aysen in Chile, and in Trinidad and Tobago, or the policies required to support EVs in Lithuania, as well as appropriate regional policy for expansion of agricultural products in Italy, Spain, Greece, or forest resource development in Canadian provinces. The case studies of water footprint, O-LCA and GRI show ways of using such tools to better describe the sustainability footprint of an entire city or region, as well as a way of benchmarking against stated sustainability objectives. Such footprint reports can significantly support a region’s effort to attract investment projects from major companies, conscious of their own sustainability image. PSS is a useful umbrella concept for regions looking for innovative pathways towards new development models based on a service industry as was seen in the example of the Brussels Capital region in Belgium.

- **Life cycle tools for governance of regional corporations**

  Reflecting their various parallel roles of regulator, service provider, development agency and protector of resources and the environment, many regions are now structured as public-sector corporations; partly entrepreneurial and partly constrained within the wider national political structure. The governance of such a corporation mirrors practice in the private sector, with some of the same corporate management procedures being applied. This includes life cycle sustainability management, with instruments such as O-LCA, EMS [74], EMAS [74], CSR [75] and GRI being used both for optimisation of internal procedures as well as for public relations and as an information tool. We have seen the use of O-LCA in Norway, and a steady increase in public sector GRI reports from Asia, USA, Europe and Middle East. While not formal LCA exercises, a use of these management tools is now more or less required to allow a broad view of the organisation’s responsibilities and action, reflecting the totality of the SDGs, and paying regard also to implications of their actions in faraway places in their supply chains. One of the most immediate applications of corporate sustainability is in public procurement where SDG issues can be given more complete consideration than in the past. Another area of application is the adoption of development principles for a circular economy, a bio-economy, etc. based on life cycle thinking as a framework for further progress towards sustainability. Due to their importance these concepts were placed at the highest level in the toolbox in Table 1.
6. Conclusions

We can conclude from the above examples and discussions that a range of life cycle methods is now readily available to enhance regional sustainability policies and programmes, for potential use as much by the regions themselves as by third parties on their behalf. We see that certain regions have already employed selected life cycle approaches in limited ways to address priority sustainability issues, often, but not exclusively, related to pollution, carbon emissions and energy use. The use of LCA for certain regionally important products and materials reflects perhaps also the currency of such procedures already in the business sector. In addition to the common use of standard LCA as specified under ISO 14040 and ISO 14064, the methods applicable at regional level include a variety of assessments of land-use and landscape, biodiversity, social impacts, resource efficiency and territorial flows among other ‘macro’ issues. Many of these are still more in the research domain than in current practice among regional socio-economic actors. It is encouraging to see the growing use of LCC by regional bodies, although extended environmental LCC is still rare. Sadly, among the promising instruments for making regions more sustainable, the potentially powerful use of Organisational LCA is still almost completely absent. It is also hoped that regional use of sustainability reporting, as for example, GRI, picks up in the future.

While use of life cycle approaches is gradually increasing, some important limitations remain. A significant conclusion from the analysis was that many LCA studies do not clearly identify effective management instruments for a holistic administrative response to the multiple SDG issues facing regions. And conversely, many actual regional management measures continue to proceed without being based on a rigorous life cycle (sustainability) assessment step, relying instead on a subjective (and often single-issue) personal appreciation of upstream and downstream issues. The growing practice of green public procurement (GPP), in the absence of such a framework, is a particular case in point.

On the other hand, we do see a significant increase in the use of life cycle communication tools, such as EPD and eco-labels that are now often required as contractual proof of a lower environmental impact of a particular product of regional importance. Some regions are now placing reliance on these tools as a guide to sustainable business development as for example for growing and marketing of local ‘sustainable’ agricultural products. The use of qualitative life cycle criteria in public purchasing is also growing, even if formal LCA and LCC are still significantly underused for this purpose, as mentioned above. It is likely that the lack of standardisation of many instruments (eco-labels, EPD and PEF being the exceptions) is still delaying the full exploitation of life cycle management procedures by regional bodies. It should be noted that life cycle management, unlike LCA, is not subject to international standardisation but remains as a loosely defined voluntary scheme presently mostly used by business and not yet sufficiently applied and promoted by regional administrations.

Life cycle practices at regional level mirror some common weaknesses of many LCA exercises elsewhere. We observe truncated life cycles due to limited system boundaries, and mostly a restricted set of SDG objectives, focusing in general on environmental and resource-related challenges. In some situations, there is a lack of adequate data sets for a firm life cycle analysis. Holistic system approaches are still a major challenge due to a focus on LCA rather than on LCSA. While it could be argued that full LCSA studies are for the moment still too complex, it would nevertheless be helpful for practitioners to point out at the outset of regular LCA studies the limited (from holistic sustainability perspective) scope of each exercise. An understanding of the limitations will also influence the way the results are used. As it stands at the moment, notwithstanding the current importance of climate issues, the widespread use of single-criteria LCA techniques to study, for example, carbon footprints of materials, products and organisations, has the consequence of effectively masking important side effects on land, biodiversity and social factors that also pre-occupy many regions. The same can be said for ‘renewable resource’
studies that focus on materials flows and do not always include potentially positive or negative social and land-related outcomes in their considerations.

A final point to highlight is the observed weak link between the academic LCA research projects and regional policy action. This possibly reflects the degree to which LCA is rooted in the academic agenda rather than being commissioned by regional administrations (although they often finance the research). However, it may also reflect a lack of bureaucratic confidence in applying results from a poorly understood, complex scientific evaluation process, and a lack of universal indicators for the multiple regional stakeholders. This supports our earlier conclusion about the urgent need to bring public officials more closely into contact with LCA networks, and the need for targeted capacity-building programmes. The promotion of LCA also needs to address the widely perceived misconception of the high cost of an LC(S)A study. Insufficient consideration is usually given to the benefits—both long-term as well as immediate—including economic benefits to the wider regional stakeholder community.

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Conflicts of Interest: The authors declare no conflict of interest.

List of Acronyms

ACR+ Association of Cities and Regions for Sustainable Resource Management
AOP Appellation d’origine protégée
APELL awareness and preparedness for emergencies at local level
CE circular economy
CPP circular public purchasing
CSR corporate social responsibility
EEIO environmentally extended input–output tables
ELA environmental impact assessment
E-LCC extended or environmental LCC
EMAS eco-management and audit scheme
EMS environmental management system
EPD environmental product declaration
EPR extended producer responsibility
EU European Union
FSLCI Forum for Sustainability through Life Cycle Innovation
GHG greenhouse gas
GP green purchasing
European regional institutions are slowly starting to appreciate the value of life cycle thinking, long regarded more as the domain of industrial activity. They are being encouraged by a number of independent activities, such as avniR http://www.avnir.org/EN/ (accessed on 14 September 2021), the FSLCI summer school series https://fslci.org/lcss (accessed on 14 September 2021) and various conference sessions and publications that have, in recent years, laid a foundation for the promotion of life cycle methodologies.

A particularly pertinent European initiative is the LCA4Regions project-Improved Environment and Resource Efficiency through use of Life Cycle Instruments for Implementation of Regional Policies of the European Union https://www.interregionaleurope.eu/lca4regions/ (accessed on 14 September 2021), carried out under the EU’s Interreg Europe programme. This project commenced in 2019 with the aim of a horizontal sharing of life-cycle related experience by seven European regions*. Learning from another region improves appreciation not only of LCA theory but also of the practical possibilities and obstacles to applying it by public organizations. The project will run until 2023.

To help regions enhance their existing use of such methods a framework of life cycle tools and methodologies was developed. The life cycle toolbox in Table 2 was supplemented by EU information on LCA support tools. Regions provided information via written submissions, questionnaires, and direct face-to-face meetings, informing each other of the status of their life cycle thinking, and the practical results obtained. This multiple approach allows a wide variety of initiatives to be inventoried, extending beyond traditional LCA exercises of regional relevance—electric vehicles, building renovation, waste disposal installations, etc.—to also examine life cycle management approaches such as eco-design, sustainable public purchasing, use of EPD and eco-labels on products and materials, the application of LCC to infrastructure and to public purchasing, the use of MFA to determine best management options for plastic bottles, to cite just a few examples. The table below shows some examples of activities so far reported by partners.
Table A1. Some examples of life cycle tools used by LCA4Regions partners *

| LC Instrument | Title |
|---------------|-------|
| LCA           | life cycle assessment of different types of graveyard candles |
| LCA           | comparative life cycle assessment of alternative packaging materials for beverage |
| GPP           | green public procurement in Slovenia |
| GPP, LCC      | green public procurement and LCC in practice (green vehicles) |
| LCA           | LCA in reducing CO₂ emissions in the production of building components |
| EPD           | environmental product declaration as an example of LCA application in construction |
| GPP           | Active support of the contracting authority by the Public Procurement Office through LCC calculators. |
| GPP, LCC      | Agralco S. Coop.’s transformation and valorization of winemaking by-products |
| CF, ISCC, RE  | Biosassun; an LCA from the production of organic extra virgin olive oil |
| LCA, CF       | environmental clauses in the contract for Pamplona’s street-cleaning services |

A number of associations of regions are also becoming conscious of the need for a more holistic approach to development by their members as shown in the box below.

Box A1. Regional co-operation.

It is not only individual regions that are taking notice of a need for holistic approaches. Among the various collective bodies worldwide representing regions, both at the national and international level, several have begun to embrace the idea of life cycle thinking in their communication and outreach, with some programmatic initiatives also visible. The French Association of Regions [https://regions-france.org](https://regions-france.org) (accessed on 14 September 2021) (in French only) has been supporting activities of its members on subjects such as circular economy. The Association of Cities and Regions for Sustainable Resource Management (ACR+ [https://acrplus.org/en](https://acrplus.org/en)) (accessed on 14 September 2021) gives leadership on, among other things, holistic life cycle approaches including circular economy, sustainable buildings and waste management. ICLEI (Local Governments for Sustainability, [https://iclei.org/en/Home.html](https://iclei.org/en/Home.html)) (accessed on 14 September 2021) has a series of outreach programmes based on holistic, nature-based, and circular solutions without mentioning LCA explicitly. AER, the Assembly of European Regions held a workshop on regional life cycle approaches in 2017 ([https://aer.eu/one-think-life-cycle-approaches-regional-level](https://aer.eu/one-think-life-cycle-approaches-regional-level)) (accessed on 14 September 2021). The most directly embracing life cycle solution is, without doubt, the European Interreg programme, with substantial funding for learning exchange through the LCA4Regions project as we saw earlier ([https://www.interregions.eu/lca4regions/news](https://www.interregions.eu/lca4regions/news)) (accessed on 14 September 2021). We also saw earlier how EU policies themselves are increasingly based in life cycle thinking and the active use of various life cycle methodologies. Given the global extent of regionalisation now (just in Europe, there are 60 regional associations from the 47 Council of Europe member countries) we can expect holistic approaches to sustainability—both LCA-based and informal—to be a more prominent feature of the deliberations of associations of regions in the coming years.

Appendix A.2. EU Support to LCA Tools for Regional Development

As was seen in Sala et al. [58], European policy and programming is strongly based on life cycle thinking. The EU has produced a number of guidance publications for use by member states (including regions) to assist in the effective application of LCA tools in the implementation of EU directives, regulations and procedures.

A useful starting point for further reading is the European Platform on Life Cycle Assessment [77] which provides guidance and data to facilitate LCIA. It outlines criteria against which models and indicators should be evaluated, covering both scientific aspects and stakeholder acceptability.
• analysis of existing environmental impact assessment methodologies for use in life cycle assessment (LCA)
• framework and requirements for life cycle impact assessment (LCIA) models and indicators
• recommendations for LCIA in the European context describes the indicators and models

Data used in the LCIA phase to calculate indicators are known as characterisation factors (CF). The Platform provides a database of factors in the ILCD format. A technical note helps to support the correct use of the CFs and points out some known limitations. Specific information on selected issues and methodologies can be found on the weblinks below:

• environmental footprint and PEF: https://eplca.jrc.ec.europa.eu/EnviromentalFootprint.html (accessed on 21 September 2021)
• better regulation toolbox: https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en (accessed on 14 September 2021)
• LCA and regulation: https://ec.europa.eu/info/sites/info/files/file_import/better-regulation-toolbox-64_en_0.pdf (accessed on 14 September 2021)
• LCC methods for policy evaluation: https://ec.europa.eu/info/sites/info/files/file_import/better-regulation-toolbox-59_en_0.pdf (accessed on 14 September 2021)
• resource efficiency and public policy: https://ec.europa.eu/info/sites/info/files/file_import/better-regulation-toolbox-35_en_0.pdf (accessed on 14 September 2021)
• mapping and assessment of ecosystems and their services: http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm (accessed on 14 September 2021)
• natural capital accounting: http://ec.europa.eu/environment/nature/capital_accounting/index_en.htm (accessed on 14 September 2021)
• food system flows: https://eplca.jrc.ec.europa.eu/FoodSystem.html (accessed on 14 September 2021)
• food losses and waste platform: https://webgate.ec.europa.eu/flwp/ (accessed on 14 September 2021)
• Sustainable consumption. The potential environmental impacts due to EU consumption are assessed for the entire product life cycle and include stated environmental impact categories (see graphic). A composite indicator supports policies on sustainable consumption and the SDGs: https://eplca.jrc.ec.europa.eu/sustainableConsumption.html (accessed on 14 September 2021)

Box A2. Basic EU rules referring to LCA or those directly affecting it are.

| EU Regulation or Directive | Description |
|----------------------------|-------------|
| EU Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste (amended by Directive 2018/852 of 30 May 2018) | Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU Directive 2009/125/EC of the EU Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products (amended by Directive 2012/27/UE of 25 October 2012) EU Parliament resolution of 9 July 2015 on resource efficiency: moving towards a circular economy (2014/2208(INI)) European Parliament resolution of 4 July 2017 on a longer lifetime for products: benefits for consumers and companies (2016/2272(INI)) |
Box A2. Cont.

| Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'
| Opinion of the European Economic and Social Committee on the ‘Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the loop—An EU action plan for the circular economy’ (COM (2015) 614 final)

Appendix B. Some Examples of LCA and LCM for Regions

The examples from around the world in this Appendix illustrate how an application of life cycle tools can occur in practical situations. The examples are selected to display the broad applicability of such tools, both in terms of breadth of life cycle thinking, and the diversity of regional situations. This list does not, and is not intended to, capture the very extensive LCA studies in individual sectors such as building, energy, waste, agriculture etc., each of which is home to a vast library of information. Rather, the examples intend to show the variety of life cycle tools available, and the scope of potential application of LCA and LCM to development issues of regional importance. This is a vast field of endeavour. The reader will easily find additional examples and references. The majority of the examples here describe the application of life cycle methods by or to regions or small states that often share similar development concerns and options. Several examples present results of published generic research that has immediate relevance to regions even if this is not explicitly mentioned in the research. For the most part, the examples here do both, citing generic methods as well as regional examples.

The examples below follow approximately the order of methodologies in the Toolbox, Table 2, with systems and assessment methods generally near the top, and the life cycle management examples further along. Some examples combine both LCA and LCM methodologies such as for example EPD.

Appendix B.1. Life Cycle Basis of Industrial Ecology and Business Parks

Many industrial zones have incorporated collaboration mechanisms between individual tenant companies to make more effective use of services and resources, such as shared waste, transport and other services, bulk buying of energy and water, establishment of innovation centres and training [78]. Rationalising materials inventories among diverse companies in an estate also fits in well with circular economy principles as well as optimizing financial achieving cost savings. Insofar as many industrial zones are owned and managed by regions and municipalities, there is a huge opportunity for application and co-ordination by the authorities of life cycle ecomanagement principles, including the notion of industrial symbiosis [79], a precursor of the circular economy model, to make these zones more attractive commercially as well as socially. Numerous examples of industrial symbiosis and eco-management exist around the world, depending on location, type of activity and awareness of occupants of such zones. UNEP already published guidelines on this subject in 1997 [80], numerous further examples and case studies have been published, see for example [81,82]. Such examples depend critically on understanding the underlying material flows, the life cycle impacts of industrial collaboration, and application of supply-chain management procedures.

Appendix B.2. LCA of Resource Use for Regional Agriculture (Australian Regions (States))

This study concerns a life cycle assessment (LCA) investigating energy, land occupation, greenhouse gas (GHG) emissions, fresh-water consumption and stress-weighted water use from production of export lamb in the major agricultural regions of New South Wales, Victoria and South Australia. The study used data from regional datasets and case study farms and applied new methods for assessing water use.
Fossil fuel energy demand was found to be dominated by on-farm activity and differed between regions and datasets in response to production intensity and the use of purchased inputs such as fertiliser. Excluding land use and direct land-use change, enteric CH4 contributed 83–89% of emissions, suggesting that emissions intensity can be reduced by focussing on flock production efficiency.

Appendix B.3. LCA for Identifying and Prioritizing Regional Waste Streams (Scotland)

The adage that “you can’t manage what you don’t measure” holds especially true for wastes. For sustainability outcomes we also need to take into account not only the wastes on hand, but also the life cycle of the products that have become waste since there are major impacts all the way along the chain. LCA is a convenient way to understand—i.e., measure—this. LCA of priority waste streams leads to more holistic solutions at the global level, alongside implementation of circular economy solutions closer to home. The Scottish approach acknowledges the entire supply chain in the context of an expanded set of SDGs. Various individual methodologies such as LCA and the ‘carbon metric’ are packaged into a ‘zero waste’ programme on circular economy [67].

Appendix B.4. LCA of Regional Waste Disposal Technologies (Chile, Italy)

There is much literature about the assessment of alternative waste technology options e.g., specific regional examples abound as for example in Chile [83], in Lombardy [84], in Madrid, Spain [85], and in Nagpur, India [86]. The range of SDGs being considered varies greatly. The scoping of regional studies often restricts the exercise to the moment of actual disposal, with upstream reduction and downstream end-of-life issues treated less extensively. Generic reviews, such as some of the examples, above are more inclined to cover whole of life impacts and issues.

Appendix B.5. LCA, LCC and Footprinting to Identify Sustainable Municipal School Lunch Menus (UK and Spain)

Many regions and municipalities provide food for schools, aged care home, canteens and other establishments. In recent times we have seen efforts to improve both the nutritional value and sustainability of the menus proposed (Including providing an outlet for local producers). A range of life cycle tools can assist in defining more sustainable food, including LCA, LCC, footprinting among others. In addition to the menu design, food labelling and SSCM are examples of life cycle management methods that act on the information the assessments provide. The study below has combined several of these methods into its “EATS” decision support tool for use in catering services for British local schools. EATS is especially focussed on identifying carbon and water footprints rather than the wider range of SDGs. Similar, if less elaborate, approaches are known in other regions, based on optimising parameters judged to be local sustainability priorities. These studies do not necessarily consider food waste and waste food, also an important sustainability issue for regions, so a further study examining specifically the use of LCC for food waste generally is also shown in [87].

Appendix B.6. Use of LCA and EPD in the Approval Process of Renewable Energy Projects (Examples from Australia and Mauritius)

There is still much debate about the sustainability performance of various energy options. Regions choosing or approving and permitting renewable energy projects need to take into account a broader life cycle view than just local impacts. And while climate impacts and carbon budgets are important, so are other SDGs that are often overlooked.

The LCA and EPD of a regional wind farm in Australia is a useful example of what assessment criteria can now be expected for such projects. The life cycle tools include both assessment (LCA type) tools and LC Management procedures such as environmental design, EPD and EPR. A wide variety of SDGs were incorporated in this study [88], broadening the LCA to include also ecological and social criteria. These results can usefully
be seen in the context of the comparative analysis of generic energy options on a range of sustainability criteria as shown in the table here [89].

As a concrete example, an LCA study of alternative energy options—both installation and operation—in the island state of Mauritius that currently imports most of its energy indicated the potential of a much-reduced impact from renewable resources, in line with the government’s declared national target of 35% by 2025 [89].

Appendix B.7. Use of LCA and EPD to Protect and Promote Export of Regional Produce and Products. (Examples from Australia and from Europe)

Quality assurance of export products is not new. But the range of performance criteria increasingly demanded for premium products, taking into account life cycle sustainability impacts in addition to product quality, gives an important role for life cycle assessment and life cycle management procedures. Assessment criteria regularly include carbon reduction and climate change, biodiversity and conservation (vulnerable species), land-use (e.g., rainforests), and social (e.g., child labour and fair trade) impacts. Organic produce is still on a steep growth curve. Together these factors often demand a full life cycle investigation, covering a diversity of SDGs in addition to the intrinsic ‘fit for service’ quality of the product. LCM procedures include product design, eco-labels, SSCM for raw materials, product certification, and perhaps even EPR.

The example below describes the use of LCA to support the export a certified regional oil-seed crop to the EU by Australian growers. It covers many of the above points, even if it is primarily aimed at meeting European GHG targets [90].

A related issue is the protection, and subsequent promotion, of regional product identifiers, such as the well-known AOP or IGP. EU policy aims to protect the names of specific products to promote their unique characteristics and qualities, linked to their geographical origin as well as traditional know-how.

Product names can be granted with a ‘geographical indication’ (GI) if they have a specific link to the place where they are made. The GI recognition enables consumers to trust and distinguish quality products while also helping producers to market their products better. Recognised as intellectual property, geographical indications play an increasingly important role. Such product identifies can be considered as a type of EPD (but non-standardised) [91].

Appendix B.8. Social LCA to Guide Bioeconomy Policy and Programmes (Germany)

A bioeconomy relies on the optimisation of renewable bio-based resources for the provisioning of food, materials, and energy to meet societal demands. Biomass development has significant impacts also on other aspects of sustainable development, effects that can best be studied through various life cycle methodologies.

SLCA helps us to assess and monitor social implications from biobased products. The example below deals with wood products from a German bioeconomy region. Such assessment can be adapted to the socio-economic conditions in any region, allowing each producer or public authority to evaluate the bioeconomy’s social performance pertaining to the particular products involved. This example gives a regional insight into social implications of forest sector and bioeconomy development [92].

Appendix B.9. Life Cycle Evaluation of Regional Forest Sustainability and Multi-Functionality (Europe and Canada)

Many regions are aiming to meet their ‘zero carbon’ ambitions partially through the use of forestry resources as a contribution to reducing GHG. This includes the use of wood as a renewable fuel resource, planting forest as GHG offset on behalf of commercial interests, and as an important element in their bioeconomy ambitions. The full sustainability advantages of these proposals are quite site-specific and depend greatly on the SDGs being considered (commonly restricted to GHG). They all depend critically on long-term—and stable-management regimes that may span many decades. The results of LCA studies
depend on the objectives and on the scoping boundaries of the exercise. Many proposals are advanced without any LCA considerations at all. The EASAC is cautious about the value of some current regional policies pertaining to the use of forest resources to address climate change and other SDGs (see below). Their report makes a number of important recommendations about the use (and misuse) of LCA methodology to justify (or not) regional exploitation of forest resources [70].

As well, a recent Canadian report reviewed the use of a variety of life cycle methodologies—LCA, O-LCA, SLCA and EPD—to evaluate from a broader SDG perspective the use of timber in the built environment [93].

Appendix B.10. Footprinting for Water Resource Management (Leshan, China)

Water resource management is an important responsibility for regions. A water footprint allows a convenient overview of sources and uses of water, providing a basis for water allocation and charging.

The example below presents an assessment of urban water footprint in the period of 2001 to 2012 in various districts of Leshan City, China. The footprint is calculated as the sum of the water footprints of various sectors, i.e., crop production, animal products, industrial processes, domestic waster, eco-environment, and virtual water trade. Over the study period the water footprints of the various sectors increased by up to 55% in some sectors, with a total increase of 43.13% over 11 years. Crop production and animal products were the most water intensive sectors, accounting for almost 70% of the total water use. Tracking of the spatial distribution of water use also reveals the impact of urbanisation [94]. For a study of the national water footprint in China, see [95].

In the context of the SDGs (especially #12–sustainable consumption and production) water footprints pertaining to individual products provide further insights into regional development policy. As animal products generally have a larger water footprint than crop products, from a freshwater resource perspective it more efficient to obtain calories, protein and fat through crop products than animal products [96].

Appendix B.11. O-LCA–Organisational LCA to Address Public Sector Organisations (Norway)

The concept of organisational life cycle assessment (O-LCA) considers multiple life cycle impacts from the total activities of an organisation. It is comparable to but more structured than the better-known concept of organisational footprint. O-LCA is thus a compilation and evaluation of the inputs, outputs and potential impacts of the activities associated with the organization from a life cycle perspective, including its upstream suppliers and downstream clients. Like traditional LCA, O-LCA can take into account a range of SDGs, although the example below has limited the scope to GHG emissions from military installations in Norway. The results showed that when only the direct emissions were included, the greenhouse gas emissions were dominated by fossil fuel use and particularly the use of fossil fuel in aircrafts and in naval operations. However, the overall results showed 60% contribution from indirect emissions originating from production of goods and services for the sector. Most important were the emissions relating to building and construction activities. The results have major implications for contracting and purchasing as well as from direct operations. The study showed that O-LCA might be a valuable contribution to assess the life cycle impacts on a range of SDGs for a diverse organisation such as a regional administration, as well for major companies [97].

Appendix B.12. Extended Life Cycle Costing (E-LCC) and Total Cost of Ownership (TCO) for Public Procurement (Denmark, Summary for Europe)

“Life Cycle Costing (LCC) is an assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle (supplier, producer, user/consumer, EOL-actor (End Of Life-actor), with complementary inclusion of externalities that are anticipated to be internalized in the decision-relevant future” [98]. The European Commission has launched a new LCC Tool, which includes direct
costs (acquisition, use, maintenance and end-of-life costs) and indirect costs (environmental externalities as external costs). The tool initially assessed the four environmental impact categories: human health, ecosystem, resource availability and climate change. Syddjurs Municipality in Denmark has used a comparable technique—Total Cost of Ownership (TCO)—to calculate the costs of their lighting tender. This showed that LED bulbs are six times less expensive than halogen bulbs when looking at the total costs over a useful life of 15 years. The tool showed that it was possible to save money on energy consumption, but also that there were savings to be made on working hours when the lamp is not to be changed as often [99].

This is an example of a purely economic evaluation. A more rigorous SDG-based approach would have included some other key criteria also.

Note: In 2012, a study measured the level of uptake of core GPP criteria by procuring authorities in the EU27 (Centre for European Policy Studies and College of Europe, 2012). Public authorities then were still not frequently using Life Cycle Costing (LCC) and Total Cost of Ownership (TCO) methods. The most commonly used criterion was still the purchasing cost (64%), followed by a mix of the latter and LCC or TCO (30%); and finally, by the predominant use of LCC/TCO (6%). This order did not change when results were broken down per type of authority (central, regional and local governments, independent regulatory authorities or other). A follow-up study (in different format) to ascertain the situation in recent years was published by ICLEI in 2017. Further examples are found in [100].

Appendix B.13. Biodiversity LCA for Sustainable Regional Agriculture (Switzerland)

Despite its essential nature in sustainable development, farming and agriculture have numerous secondary impacts that have been subject to a multitude of studies. As agriculture displaces other uses of land, including wilderness values, full life cycle studies need to address a large number of other SDGs simultaneously. Biodiversity LCA is intrinsically location-specific and needs to be carried out using local ground truth and SDGs. This example pertaining to cropland and agricultural production comes from Switzerland. The methodology can be applied to both regional as well as farm-scale situations. Being specific to biodiversity, the method is not considering other SDGs [101].

The furthering of research for improved methodologies is exemplified by the article below by de Braan. Land use is one of the main drivers of biodiversity loss. However, many life cycle assessment studies do not yet assess this effect because of the lack of reliable and operational methods. Here, we present an approach to modelling the impacts of regional land use on plants, mammals, birds, amphibians and reptiles. Our global analysis calculates the total potential damage caused by all land uses within each an eco-region and allocates this total damage to different types of land use per eco-region [102].

Appendix B.14. LCSA–Sustainability Assessment in Regional Perspective (Generic Discussion, Regional Relevance)

A combination of life cycle approaches that combine environmental, social and economic assessment methods can be combined into Life Cycle Sustainability Assessment (LCSA) that considers a wider set of SDGs than traditional LCA. This is a complex procedure, faced with numerous difficulties concerning terminologies, datasets, boundaries and calculation models. Translating the results, necessarily subject to different interpretations, into an identification of regional development paths and policies is not a simple exercise [103].

A number of studies have attempted to model this transition from assessment to action. The reference below reviews the current best practices for sustainability assessment and identifies the needs of regional systems, also proposing the concept of a regional sustainability assessment methodology (RSAM). It includes natural, social and economic capital transfer accounting through extended input–output tables and cyclicity analyses. RSAM reflects static and dynamic qualities of regional systems for the assessment of
development paths and policies effectiveness. It concludes that further methodological development of the concept’s findings is needed [104].

Appendix B.15. LCA to Assess Local Impact and Suitability of EVs (Examples from Lithuania, British Columbia and SE Brazil)

While EV technologies have a high degree of global standardisation and performance, their usefulness and their demand for appropriate government infrastructure varies from one region to another. Region-specific LCA studies remain necessary in each case, insofar as these invariably point to the necessary policy and infrastructure conditions that would allow EVs to operate. A number of different SDGs should in principle be included in the study boundary. It should be noted that the outcome of such study depends critically on the number of upstream and downstream impacts that are considered, not only the immediate operation of an EV [105–107].

Appendix B.16. Territorial LCA (Examples from Brazil, France)

An assessment method based on LCA principles can assist regions with land planning issues and programmes. Such ‘territorial’ LCA can also provide a strategic environmental assessment under European Directive (EC/2001/42). The outcome of territorial LCA can be an assessment of a specific activity or supply chain anchored in a given territory but may also encompass all production and consumption activities located in a territory, including all environmental pressures embodied in trade flows with other territories. The procedure can take multiple forms as seen in the examples below. The formal methodology is currently still evolving to overcome issues of databases, indicators and criteria, with the added need for social buy-in from important stakeholders, as well as the territorial population as a whole. Examples of application and case studies include the two regions of Thau and Lille in France, and a semi-arid region in Tunisia. A special issue of Sustainability has also been published on this subject (see below).

Appendix B.17. Territorial LCA (Example of the Lille Metropole Region, France)

Faced with increasingly complex issue of access to resources at a time when urban waste generation is increasing, large cities are increasingly looking at circular economy solutions. The Metropole of Lille in France is employing a territorial life cycle assessment concept to develop decision-making tools for circular resource management for urban planning and operation. The approach is based on a symbiotic relationship between a diverse range of city actors to coordinate the management of finite resources while simultaneously addressing problems from locally generated wastes. The project includes digital tools to identify supply and demand for resources—both primary, and secondary from the recovery of wastes—that are processed to create high added-value materials for on-going urban growth. Resource feedstocks are identified through the use of material passports hosted on a digital platform. Advanced AI tools can establish links between materials and waste on offer and in demand. The digital platform also integrates materials information from the design phase of new buildings to provide information about the type and location of future resources that can be tapped at an appropriate time [108–111].

Appendix B.18. Life Cycle Approach to Landscape and Land-Use Assessment (Examples from Italy and Brazil)

A major challenge in the field of LCA is spatial and temporal differentiation in life cycle impact assessment (LCIA) methods, especially impacts resulting from land occupation and land transformation. Land use characterization modelling has advanced considerably over the last two decades and many approaches have recently included crucial aspects such as geographic differentiation. Land uses are a multidisciplinary matter with intertwining environmental and sustainable development policies. Land-related issues are important to many regional development plans, impacting on a range of sectors from agriculture, forestry, minerals, transport, tourism to name just a few. They cut across
various SDGs involving water resources, energy and climate change, pollution and social sectors, necessitating a range of separate but related life cycle methodologies for a complete assessment. Standard LCAs mostly focus on environmental impacts excluding socioeconomic implications of land occupation [24]. Land use-characterization modelling has advanced considerably over the last two decades and many approaches have recently included crucial aspects such as geographic differentiation. A number of characterization models show sufficient scientific robustness and environmental relevance for potential use and adaptation, as for example in Brazil [111]. Already, in 2009, Achten et al. proposed a life cycle land use impact calculation methodology [22] while Beltramo developed a methodology for landscape assessment in Italy that would, for example, be useful to regional tourism development [23].

Appendix B.19. MFA to Inform Resource Management in Regional Economies (Examples from Iceland and from Trinidad and Tobago)

Many regional economies, in common also with many small countries, face complex resource management options, as well as highly constrained waste management possibilities. Both export/import options as well as domestic materials consumption require a detailed knowledge of resource flows. The MFA study below of two small island states is relevant also to many continental regions trying to frame a coherent economic development policy that respects longer-term sustainability policies in the context of the SDGs. MFA and LCA are relevant also at more local levels, as the study of management options for empty plastic bottles shows. Waste options—especially those in a circular economy context—depend crucially on volumes and timings of waste generation.

The studies: “Resource Use in Small Island States-Material Flows in Iceland and Trinidad and Tobago,” [112] and “Materials flow analysis in support of circular economy development: Plastics in Trinidad and Tobago” [113] reveal a number of crucial issues concerning data availability and interpretation. Both focus mainly on the assessment phase, without exploring in much detail the management options that a public administration might put into place.

Appendix B.20. LCM to Ensure Sustainability in Resource Exploitation (Global Sector; Examples from USA and Romania)

The increasing use of SSCM methods has led to a number of LCM instruments being developed by business sectors, sometimes with broader stakeholder participation from governments and NGOs. A particularly interesting example of management control over the full product life cycle, from production to end of life, is the International Code for Cyanide Management. All stages of the life cycle of this hazardous substance are subject to strict technical guidelines, the application of which is monitored by independent auditing and transparent reporting. Only Code members are permitted to enter commercial transactions concerning cyanide manufacture and use. LCM elements include formulation of the substance (solid rather than liquid), packaging and labelling (EPD), technical standards for transport and use, extended producer responsibility (EPR) and risk management and emergency planning. The code is focussed especially on SDGs covering health, safety and ecological impacts [32]. A key feature of the Code is its rigorous certification and auditing of suppliers and operations, for examples see [114,115].

The Code is complementary to other substance-management instruments, as shown in the case study of chemicals management below. Similar instruments with greater or lesser life cycle reach and management procedures are known in such sectors as forest, fisheries, jewellery, electronics and food, focussing on a range of SDG criteria pertinent to each sector. While these Codes are not developed explicitly for regional or municipal use, it is important for public authorities to understand their functioning during project or product certification and approval processes.
Appendix B.21. LCA and LCM Tools to Improve Sustainability in Buildings at Regional and Local Levels (Examples from France, Lithuania, Nepal and Spain)

While LCA for the building sector is well established, we give three short examples to illustrate how local or regional authorities can use such methods to improve energy performance of their building stock, and perhaps optimise some other social and environmental parameters as well.

A LCA study of traditional vs. modern buildings in the Himalaya region of Nepal found that use of traditional materials avoided high impact of manufacture, transport and use of modern materials [116]. In Spain, the use of specially developed LCA software helped the San Sebastian municipality to better position its building retrofitting strategy vis-à-vis its sustainability objectives such as GHG, mobility, urban amenity and waste, and identify the most efficient ways to achieve them [116], p303. In Lithuania, an LCA study on the retrofitting of Soviet-era housing stock led to the effective selection of materials and design to greatly improve energy efficiency [117]. In northern France, the collaboration of various actors in the building supply chain allowed more efficient retrofitting and new building through a multi-stakeholder LCM framework [118].

Appendix B.22. Use of Eco-Design and Eco-Labels in Regional Purchasing (Spain)

Barcelona City Council, in accordance with the strategies outlined in the 2012–2022 Citizen Commitment to Sustainability, the Barcelona City Council Sustainable Timber Plan of Action, and the 2014 Policy Decree on Responsible Procurement of Timber from Sustainable Forests, considers it essential to keep working towards reversing the trend of deforestation and to minimise the environmental impact of furniture production through the procurement and use of office furniture with sustainability guarantees. These technical instructions are an answer to the 2013 Government Measure on Responsible Public Procurement with Social and Environmental Criteria and the Mayoral Decree on Responsible Public Procurement using Social and Environmental Criteria of 20 November 2013, which establishes the publication of technical instructions that define specific environmental criteria that must be applied in the purchasing and contracting of groups of products and services that have been defined as priorities, which include office furniture [119].

Appendix B.23. Eco-Labels, EPD and PEF (Examples of Nine Agri-Food Product Chains in Six European Countries)

European surveys and national studies show how the market demands more sustainable products. There are several options of identifying such products through approved or regulated labels, as for example the ISO 14024 standard for eco-labels, or environmental product declarations (EPD) based on ISO 14025 and EN 15804. The EU’s Life EFFIGE project explores adoption of Product Environmental Footprint (PEF) quality label [120] for regional products and services in four manufacturing sectors, foundries, furniture, agro-food and catering. Companies participating in the project improve the environmental footprint of their products by creating more sustainable products that can also make them more competitive. An example of this initiative is the PEFMED initiative “Innovation and sustainability in the Mediterranean agri-food systems” that describes the main environmental and socio-economic components of PEF in seven agri-food product chains (cheese, wine, olive oil, meat, mineral water, animal feed) [121].

Appendix B.24. PSS-Product–Service Systems as a Life Cycle Management Tool (Example of Brussels-Capital Region)

To meet the rapidly evolving challenges of sustainable development regions are looking towards new innovative business models within a re-localised, circular and inclusive economy framework. Many are looking at adopting, and adapting, the ‘servicisation’ of activities that seek added value and future employment through a service rather than the sale of a product. PSS, like other strategic approaches, benefits from a life cycle vision of its structure and impacts. It is at the same time a life cycle management method–reducing
pollution, waste and energy and water consumption by weighing the life cycle impacts of a service against that of a physical product—and a sustainability strategy, in its own right, by dematerialising society to its barest materials essentials. As a concept it can stand alone, in its application its success depends on further use of life cycle methodologies.

The experience of the Brussels-Capital Region in developing and testing a product-service system (PSS) confirms the many opportunities for value creation from new activities rather than on an extension of existing manufacturing activities. Public authorities can create favourable conditions for such innovative, sustainable and inclusive entrepreneurship by selecting the type of entrepreneurship desired, through public procurement and support structures, network creation, and supporting the testing of prototypes. Other cities and regions are introducing individual activities such as city bikes, the rental of domestic appliances, and on-line entertainment instead of physical venues. In the public sector the biggest locomotive of PSS is undoubtedly public procurement [122].

Appendix B.25. EPR–Extended Producer Responsibility in LCM (Example of Mumbai)

EPR is a simple concept that expects the manufacturer and/or distributor of a product to take part of the responsibility of managing the impacts thereof after sale, including end-of-life issues. EPR can apply to food packaging, consumer goods as well as to major infrastructure items such as power stations and railways. Thus, the increasing management costs and pollution of waste packaging has led to numerous regional or local authorities around the world to involving the packaging producers in shaping the solution [123]. EPR is a complex area, touching a number of priority SDGs and where the entire supply chain is implicated in the solutions. EPR provides the motivation and impetus through which other LCM methods such as eco-design, eco-labels, EPD and PSS shape a response that leads to the outcomes desired by regional governments and acceptable to producers and the public. The following link includes a mention of the status of EPR regulation and practice in India, with particular reference, also, to Mumbai [124].

Appendix B.26. GRI as a Component of Integrated Territorial LCM (Examples from Atlanta, Singapore, Jönköping (Sweden and Ajman Regions)

Organisational reporting on sustainability performance is now a regular part of corporate sustainability programmes, and a major component of CSR. Such reporting has been standardised as a voluntary measure under the GRI [40,41].

While so far predominantly used by corporations, GRI is eminently suitable also for public bodies. See example of regions, cities and municipalities in the references below*. Their reports inform about the key SDGs being addressed by the organisations, including issues that have life cycle implications, as for example, waste management, public procurement, and water resources. While GRI is not commonly considered as a specific life cycle tool, it straddles both LCA and LCM logic through its consideration of SDG objectives, and its checklist of sustainability management actions that have a strong life cycle dimension. Its collection of upstream and downstream information, its template for data presentation, and its key role in identifying holistic action in implementation allow it to fit well into the LCM framework of action. The HBP town report is especially explicit in its structuring the reporting around the SDGs, as is also that from the Ajman region [125,126].

* Examples of public sector GRI [40,41,127] include the Austrian Postal Service, Yorkshire Water (UK), Vienna Cityworks (Austria), Western Australia Land Authority (Australia), VGP Parks (Belgium), Vancouver Airport (Canada) Universities in Mexico, Australia, Colombia, Chile, Molina Hospital (Spain), Dubai Electricity (UAE), Ajman Emirate (UAE), Jönköping region (Sweden), HBP Town Council (Singapore), Municipalities in Greece and Turkey, City of Atlanta (USA),
Appendix B.27. EEIO for Regional Assessment (Examples from Denmark, Finland, Region of Walloon (Belgium))

A widely applied life cycle method is the environmentally extended input-output (EEIO) tables, which use sector-level economic statistics in combination with various environmental data on emissions and resource use (Eurostat Manual of Supply, Use and Input–Output Tables [128]. EEIO models have been applied at national and global scales [129] however there is a growing need for their use also at subnational levels since provinces have an interest in encouraging economic growth and protecting public and environmental health within their borders. A regional EEIO model presents numerous challenges as most provinces do not produce individual input-output tables, and trade may not be well tracked between provinces in the same way it is across international borders. A short discussion of its relevance to regional development is given by [130]. Examples of EEIO can be seen in the study of environmentally important manufacturing sectors in Denmark [131].

And in the investigation of the sustainability impacts of Finnish forest industries [132] it has also been applied to reduce the environmental impact (energy and GHG) of the Walloon wood construction sector, one of the significant industries in the region that is under both economic and environmental pressure [133].

Appendix B.28. LCA and MFA for Regional Circular Economy (Examples from Canton of Geneva and the Region of Burgundy)

LCA and MFA can be used to study the materials flow dynamics in a region, leading to improved initiatives toward a circular economy. At the local level such assessments also reveal options for closing the loop on individual materials that can be recovered as secondary resources. Several regional examples are referenced here [134,135].

A useful example of a policy application is the use of MFA to underpin the French law, LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte [136]. Examples of LCA and MFA as basis of CE in building sector are compiled under the EU Interreg programme [137].

Appendix B.29. Life Cycle Assessment and the Management of Chemicals (Generic International Programme of IOMC: Example of Lithuania)

The Inter-Organization Programme for the Sound Management of Chemicals’ (IOMC) Toolbox supports countries to identify the most appropriate and efficient national actions to address specific problems related to chemicals management. The toolbox identifies the available IOMC resources that will help the country address the identified national problem(s) or objectives. Special focus is given to identifying simple cost-effective solutions to national chemicals management issues. The IOMC, which comprises of nine participating organizations, aims to strengthen cooperation and increase coordination in the field of chemical safety. The development of the toolbox has been supported by the European Union. As a complement, LCA can be used in the development and simplified assessment of alternative chemical products [138].

Appendix B.30. Disaster Life Cycle Assessment and Preparedness for Major Accidents at Local Level (Generic International Guidance–Regional Case Studies from UN Handbooks)

A comprehensive assessment of major accident or disaster risk takes all the precursor conditions into account, evaluating also all likely downstream impacts and consequences. The most effective programmes rely on multi-stakeholder participation to identify key risk factors and devising the most effective preparedness and response measures. The methodology can be used for industrial accidents in the chemicals and mining sectors, for major human-generated risks, and for natural disasters [69].
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