



LCA4Regions: application of life cycle methodologies for regional sustainability in Europe

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Abstract

Purpose Even as regions become important players in the attainment of the UN Sustainable Development Goals (SDGs), effective action is often handicapped by the absence of an integrated life cycle approach to the various interconnected issues that regions confront. This study investigates the uptake and application of life cycle thinking by seven European sub-national regions, describing the use by their selected regional institutions of certain life cycle methodologies already in common use to enhance their sustainability initiatives.

Methods The EU Interreg project ‘LCA4Regions’ brought together seven regions from Finland, Italy, Lithuania, Poland, Portugal, Slovenia, and Spain, respectively, to share their experience with various life cycle tools to enhance resource efficiency, circular economy, and waste management. Through engagement with stakeholders, a set of ‘Good Practice’ case studies were compiled showing various life cycle-based activities in the regions, and the underlying issues being addressed.

Results and discussion Over 100 examples were identified of the life cycle-based initiatives of various sorts that were profitably employed by these regions. Overall, however, public institutions struggle to apply life cycle approaches systematically across their entire organisations, often limiting initiatives to isolated actions of restricted scope. Institutions mostly address SDGs individually rather than as an interdependent set, and there is a reluctance to take all parts of the supply chain into account.

Conclusion The lack of familiarity by regional officials with LCA procedures is exacerbated by the rigid structure and language of LCA that is not especially adapted for use by public administrations, thereby creating a gulf between research-oriented LCA and potential regional clients. Nonetheless, the LCA4Regions study shows an encouraging example of an increasing use of life cycle thinking for regional development in some parts of Europe. Further research is needed to understand the uptake of LCA and LCM in other European regions, and around the globe more generally.

Keywords Sustainable development · Life cycle thinking · Life cycle management · Life cycle assessment · Regional life cycle assessment · European regions

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1 Introduction

Regions are increasingly important actors in the global movement towards sustainable development. For this study, we understand ‘regions’ to be discrete, sub-national, political, and administrative entities with a delegated responsibility for economic and social development, in the manner also of large cities, for example. In concert with the national agencies of the countries to which they belong, they develop and manage local natural resources, they have significant budgets, and often also have the important responsibility of maintaining environmental quality and health. In parallel to their economic development objectives, many regions have

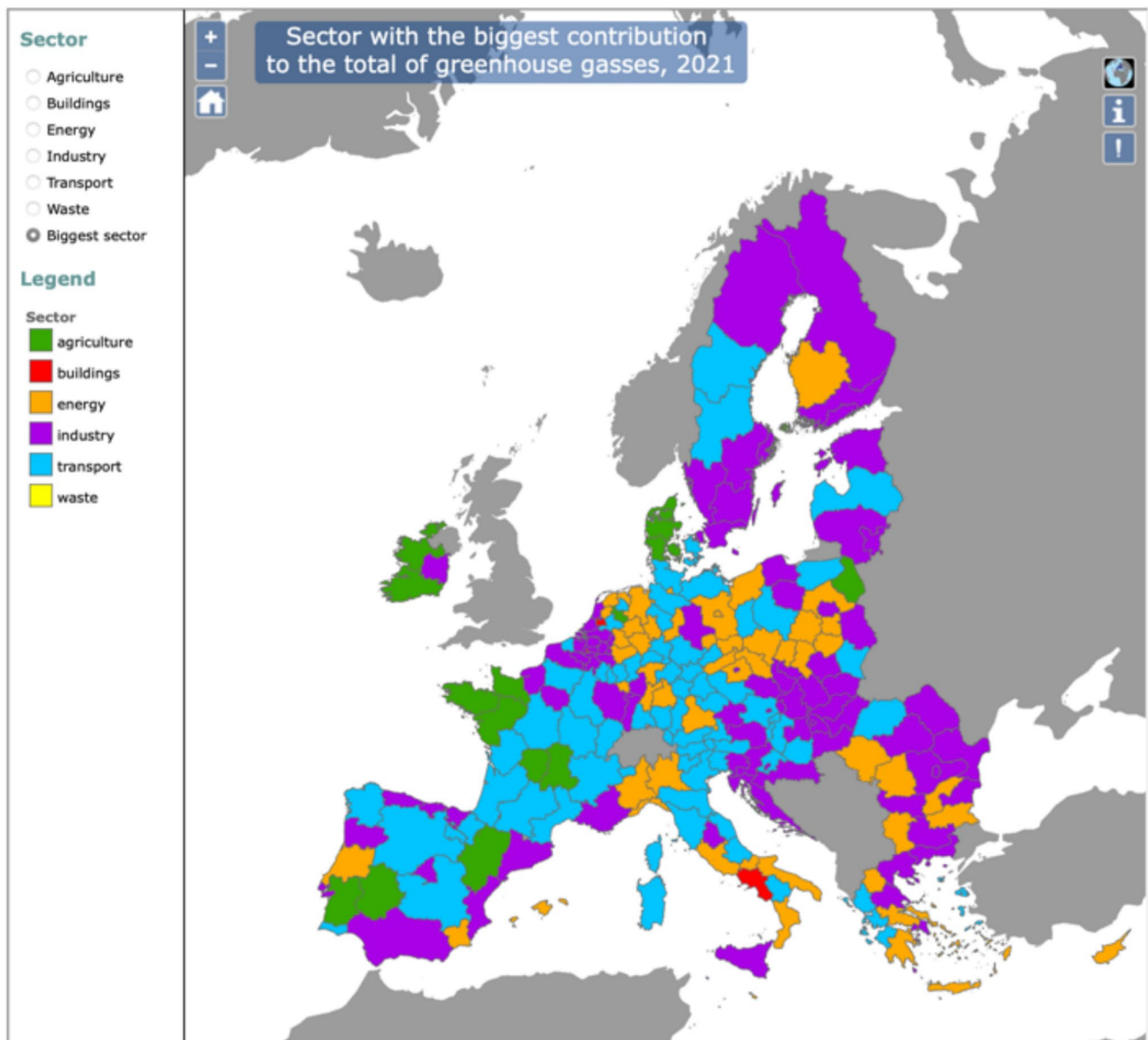


Fig. 1 Greenhouse gas sources in European Regions (European Union, [n.d.](#))

articulated ambitious sustainability objectives in the framework of the 17 UN SDGs (UN 2015). Achieving around 65% of the global targets is estimated to depend on input from local and regional authorities (European Committee of the Regions 2019). Numerous regions and cities, including in the European Union (EU), have expressed support for the SDGs, and many have integrated them in their policy frameworks. The European Parliament (2022) has outlined the relevance of the SDGs in regional development. The EU Interreg programme has dedicated substantial funds to assist European regions to meet the SDG challenges (Interreg Europe, [n.d.](#)).

As an illustration only, Fig. 1 indicates the number, size, and diversity of European regions, their level of industrial

development, and their sustainability challenges, here exemplified by the origins of their carbon footprints. It does not show the diversity of administrative responsibility, nor their commitments to sustainable development. While regions (like cities and entire countries) often create specific bureaucratic structures for sustainable development, achieving this efficiently requires coordinated contributions from all levels of all administrative units, if not also from the outside stakeholders and consumers with whom they interact. The sustainability agenda implicates regional officials from all levels.

To effectively implement solutions that are truly ‘sustainable’, it is important that regions situate their action in the framework of both national and local initiatives. Regions

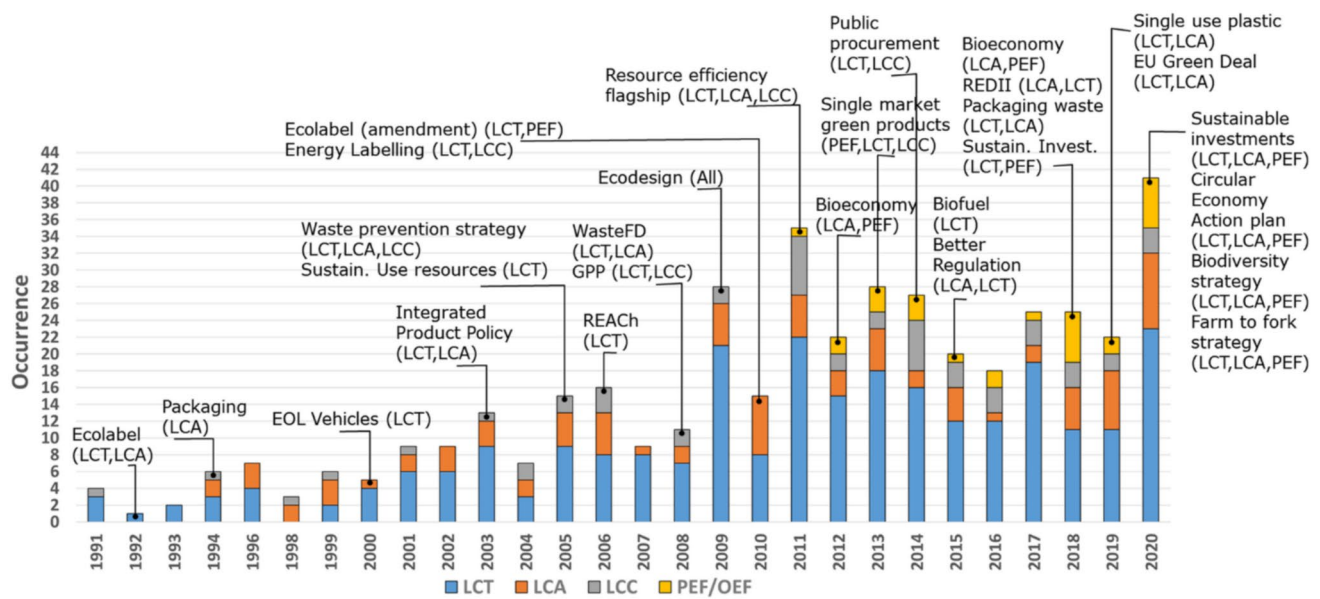


Fig. 2 Use of life cycle tools in policies of the European Union (Sala et al. 2021)

need also to integrate the dynamics of a larger world into their decision-making. They operate in a world of extended supply chains, upstream and downstream impacts, and national objectives that flow from the 17 international SDGs. The most effective regional response will be based on some form of life cycle thinking (LCT) where the various dimensions of the problem, and of the solutions, are integrated into a more holistic vision of what to do. There are a number of life cycle approaches that can be adopted by regions including life cycle assessment (LCA) and system analysis tools (Balkau et al. 2021; Bezama et al. 2021; Massari et al. 2017). Of particular importance to regions is the use of life cycle management (LCM) concepts (Sonnemann and Margni, 2015) that expand their vision further up and down various supply chains. Overall, life cycle thinking can be applied in many ways and at many levels of sophistication and complexity as demonstrated by the case studies in Massari et al. (2017). Thyssen and Zeller (2017), in their review of the Walloon wood sector, emphasised the importance of a regional application of LCA in comparison to a national approach when ‘diverging technologies and energy mixes are used across regions’.

A number of reviews have been conducted on the application of LCT in regional sustainable development. In their review, Balkau et al. (2021) found increasing application of LCA concepts and methodologies; however, this was often restricted to short life cycles. Further, they noted that not all life cycle (LC) methods are well structured for application by public organisations or for regional applications. A review conducted by Bezama et al. (2021) highlighted the increasing importance of Life Cycle Management (LCM)

in regional sustainable policy and programme development. Despite the assertion by Yang and Heijungs (2016) that regional LCA is gaining in popularity amongst academia, Bezama et al. (2021) noted that little research had been conducted on a regional scale. This may be a potential reason for the limited adaptation of LC methods for regional application.

To reinforce the relevance of life cycle methods at a regional level, we can also refer to the recent overview of life cycle methods already employed to shape the sustainability dimension of policies and regulations in the European Union (Sala et al., 2021). Figure 2 clearly shows an extensive use by the EU of the life cycle methods such as LCA, LCC, and PEF, generally incorporating the idea of life cycle thinking as a universal backdrop. These approaches are all included in Table 2 among a range of other assessment methods and LCM options. As the EU mechanisms apply at all levels of governance in Europe, they serve as direct guidance also to regional policies and thus provide a further platform for the LCA4Regions project.

Various past attempts to propagate life cycle thinking by giving it a firmer system structure have met with limited success, as for example, Industrial Ecology, Factor 4, Circular Economy, The Natural Step, Eco-efficiency, etc. It seems unlikely for now that any holistic model can deal with the totality of the challenge in a single step. Instead, it may be that a life cycle ‘toolbox’ that offers a range of solutions appropriate to the diversity of local circumstances will be more immediately helpful to decision-makers (discussed further in Section Methodology). These methodologies can be conveniently divided into life cycle assessment approaches,



Fig. 3 Key life cycle concepts for LCA4Regions

and various follow-on options for life cycle management (LCM) action.

This paper investigates the uptake and application of life cycle thinking at a regional level in the European context. It describes the use by selected regional institutions of life cycle methodologies already commonly used by other societal sectors, e.g. in companies and in research, and is also visible in the current EU policy. The paper is an outcome of a recent Interreg Europe-funded project ‘LCA4Regions’, financed by the European Regional Development Fund. ‘LCA4Regions’ is one of the many research projects funded by Interreg, an official EU organisation that leads research into regional issues within the EU. Information about the conduct of the project, and about Interreg itself, can be found through the URL (Interreg Europe, [n.d.](#)).

Following a ‘call for project ideas’, the concept of researching the extent and variety of life cycle approaches being used attracted interest from seven regions. The project brought together officials from these regions to share their experiences with the actual methodologies being used and, indeed, with the life cycle thinking in general (LCA4Regions, [n.d.](#)). The project documented the regions’ current life cycle practices in the three Interreg focus areas of resource efficiency, waste management, and sustainable public procurement. Throughout, consideration is given to the full life cycle, from upstream resources to downstream waste management.

Section [Methodology](#) describes the methodology used to investigate the application of life cycle concepts and tools by the partner regions using the life cycle toolbox to provide a common structure to the notion of ‘life cycle methodology’ and to facilitate comparisons of good practice examples. Section [Results](#) presents the results of the project, detailing the LCT approaches employed. This is followed in Section [Discussion](#) by a comprehensive discussion of the results, contextualising them within the scope of previous research. Limitations and future research prospects are presented in Section [Limitations of the project and future prospects](#).

The Interreg project is, to our knowledge, the first study of its kind. We are not aware of any prior formal study of the application of a life-cycle approach in regional policy, or of any overview of how regions are using it today. There

has not been a flood of research publications, and there is little evidence of a rigorous discussion on this subject within the life cycle community. Nor is there a visible demand by regions themselves. Formal institutionalised LCA training does not seem to consider regional needs, which are anyway more immediately oriented to LCM than to LCA.

2 Methodology

Seven sub-national regions from Finland, Italy, Lithuania, Poland, Portugal, Slovenia, and Spain, respectively, undertook a joint 3-year activity in which they identified within their constituent agencies and stakeholder networks significant examples of activities incorporating, or based on, some degree of life cycle thinking.

2.1 Case study development

A set of ‘Good Practice’ case studies were compiled by each region identifying various life cycle-based development activities and the instruments being used (see Supplementary Information A). Within the LCA4Regions project, ‘Good Practice’ was defined according to the current Interreg practice, using a specific data template that showed the criteria required. Details are available on the LCA4Regions URL (Interreg Europe, [n.d.](#)). The tools and methods in Table 2 and Fig. 3 are used to provide participants with a common structure to the notion of ‘life cycle methodology’ and facilitate the search for good practice examples. Examples were not limited to agency activities. Regions were encouraged to build local stakeholder networks through which further examples of LCA and LCM application from beyond their administrative institutions could be identified. Project partners were expected to share their experience with these case studies and to identify local success stories that could be replicated in other regions. They were also expected to develop action plans for expanding their own experience with life cycle methodologies based on what they had learned from other project partners.

The final Good Practice compilation together with other information gleaned from the ‘transnational learning journeys’ (see Section [Stakeholder meetings](#)) was summarised as

a set of regional ‘Life cycle Inventory Tables’ to display each partner’s examples in a comparable format. The structure of these tables, including a listing of underlying information sources, is shown in Fig. 3, using an extract from the inventory of the region of Satakunta (Table 1). From these tables, the regional case studies could be compared for their use of life cycle assessment methods, the employment of any life cycle management approaches, the scope of the consideration (upstream/downstream for example), and the number of SDGs considered. Also shown was whether the life cycle studies had been performed in-house or by external experts. Of particular importance was the relevance of the case studies to regional or national policy on the three Interreg focus areas, any policy implementation actions being taken, and the potential of an eventual transfer of experience to other regions.

As an aide memoire, shown at the bottom of these tables are the key concepts (Fig. 3) that should ideally be considered in the case studies being compiled. The complete list of inventories for the seven regions is available in Supplementary Information B.

While they give a valuable overview, the cumulative results based on these tables need to be treated with some caution. Some case studies reported by the partners were based on qualitative data and non-standardised terminology that is not easily incorporated in a meaningful statistical analysis. In some cases requested data was not provided. Where identified, inappropriate or erroneous and inconsistent inputs were screened out during the course of the project. Some partners were not closely in touch with their various regional institutions where LC practices could potentially be found, or knew about institutions where LCA is being taught or research is taking place. It can be supposed that the real level of life cycle activity in some regions is actually greater than what was reported.

2.2 Stakeholder meetings

Each region built its own stakeholder network during the 3-year timeframe of the project, subject to the regional situation and cultural practices of their consultation procedures. A number of stakeholders participated officially in project meetings and information exchange, presenting also examples of their own use of life cycle procedures. Many were curious about practices in other regions—both technical and administrative—even if the regulatory context varied greatly between regions.

In parallel with the Good Practice case study compilation (LCA4Regions, 2022), an inter-regional exchange of experience (a *sine qua non* for Interreg) took place through a series of face-to-face and online meetings. This included regular group meetings for further regional analysis and benchmarking exercises, and structured peer reviews through what was

termed the ‘transnational learning journey. Project partners also identified LCA training capacities in their respective regions. Peer-to-peer sessions brought to light some interesting feedback from regional officials and their immediate stakeholders.

2.3 Regional profile development

To also capture important feedback from regional personnel during the various face-to-face encounters, the inventory tables were complemented by narrative-based regional profiles that include important qualitative points, as for example the position of LCA responsibility within an administration. These are shown in Supplementary Information C. Using both these approaches allowed a more complete picture of each region’s efforts to be built up. Figure 4 shows an example of life cycle-oriented actions by the Navarra region in Spain. This type of presentation also shows more clearly the relationship between life cycle assessment and management functions.

The case studies, face-to-face meetings, and regional profiles together provide a ‘snapshot’ of the current state of life cycle thinking in the partner regions. The project also had an eye on the future. As a way of converting project learnings into concrete action each region was required to propose two items for immediate follow-up implementation. These are included in the regional profiles in Supplementary Information C.

2.4 SWOT analyses

Several other project mechanisms provided opportunities to glean additional inputs of a more qualitative nature. SWOT analyses were conducted at the outset by the project secretariat based on the regional profiles submitted by the partner regions. The results as shown in Table 4 are available on the project website, building a more complete picture of the socio-economic circumstances in each region. This exercise was undertaken in the early stages of the project before the compilation of Good Practices had commenced.

2.5 Questionnaires

To supplement the above formal procedures, short partner questionnaires (see Supplementary Information D) were administered towards the end of the project. The questionnaires facilitated a more personal input about the applicability of the study results. While a number of useful comments were collected, these individual views were not amenable to statistical analysis, being too few in number. However, several of the more relevant comments are reflected in the Conclusions.

Table 1 Extract from the life cycle inventory of the region of Satakunta

Region (or regional company)	Descriptor (theme focus, Res efficiency, waste mgmt., G procurement)	Info source (° GP, CS, FV, RA)	LC assessment tool (ref, toolbox graphic)	LC management method (ref, toolbox graphic)	LC scope (Life-chain? Integrates US/DS*? EoL*?)	SDGs or environmental issue addressed	LC study (client, author, date/year)	Reference or source	Policy link, implementation, actions	Comments & info, transferability
A Satakunta	B Construction works	C GP #4REGP1, RE	D LCA, ISO14040, EN15978, LCC	E Eco-design	F Some us/ds	G # land, #13 climate, #14 eutrophication, #15 acidification	H Vantaa municipality, Ramboll co, 20,182,019	I https://www.energiailoikka.fi/resurssiviisasta-viherakentamis-ta-vantaalla (Finnish)	J Vantaa, municipal park redevelopment, completed works	K Construction based on LCA, good transferability
Satakunta	Building energy efficiency	GP #4REGP2, RE	LCA, EN15978, LCC	Eco-design	US/DS incl	#13 climate	Finland, Bionova Ltd., 2018	https://julka.isut.valti.oneuvosto.fi/handle/10024/161783	Building code	Building based on design & materials, calculation tool
Satakunta	Biowaste, Aner Digest	GP #4WMGP1, WM	LCA, ISO14040	-	No us/ds, no EoL	#13 climate, #14 eutrophication, #15 acidification	MoEnv, F Env Inst, 2016	https://julka.isut.valti.oneuvosto.fi/handle/10138/159940	C credit, pollution, biofuel, regulation	Looks at LCA of process, not of waste

* US upstream, DS downstream, EoL end of life

° Info source codes relate to internal project components - see Supplementary information B. # SDG identification number



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. 15 organizations in Navarra have registered their carbon footprint.

Carbon footprint

- Navarra asparagus and the cured sheep cheese Latxa de Lezaun.
- Oil production - oleohealth 2013- calculation of GHG emissions.
- Departments activity in Government of Navarra.
- Navarra household waste management.
- Sanfermines festiva by Pamplona Town Hall.

Ecological Footprint – regional environmental footprint considering material resources and waste generated for the maintenance of the production and consumption model of the community.

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.

LCA for organic extra virgin olive oil 2008-2010: LCA, SLCA, and LCC to assess environmental, economic and social impacts.

Footprint calculation models

UMBERTO; SIMAPRO; SIMUR; EURENERS; ENECO

Indicators: See section 4.5 on the regional analysis



Eco-design ISO 14006

- LCA for designing healthy and sustainable food menus in municipal schools.

Eco-label: Register of Navarra Products with European Ecological label:

- Tissue paper, Sofidel.
- Quilt and mattress protector from Textiles Inducam S.L.
- Lubricating greases from Verkol, S.A.U.
- Accommodation: Hotel Rural Aríbe, Arantza Hotela and Markulluko Borda.

EPD (Environmental Product Declarations) - use of LCA to support certification

- EGGNOVO, has 3 EPD for different products derived from eggshells.
- ACCIONA and SIEMENS GAMESA have 6 and 9 registered EPDs each for installed wind farms.

Carbon footprint reductions

- 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), **EMAS** (4).

Circular and sustainable materials management:

- Reusing drinking glasses at parties and events for public services.
- "Nights without plastics" in Informal Room of Tafalla to reduce footprint of events.
- 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.
- Lourdes Renove: buildings rehabilitation, energy savings and efficiency to reduce CO₂ emissions.

Green Procurement:

- LCA and calculation of Carbon Footprint for road cleaning tenders of Pamplona.
- Sustainable food menus in municipal schools.

Fig. 4 The use of life cycle toolbox in the Navarra region

Table 2 Life cycle tools and methods* used to screen case studies and good practices in the LCA4Regions project

LC Assessment	LC management	System	Corporate
LC assessment (LCA)	Ecodesign	Circular economy (CE)	EMS, EMAS
LC costing (LCC)	Eco-labels	Circular materials management	CSR
Carbon footprint (CFP)	Product information (EPD, PEF)	Industrial ecology	Sustainability reporting
Eco footprints (EF)	Extended producer responsibility (EPR)	Integrated pollution management	
Materials flow analysis (MFA)	Public procurement (SPP, GPP)	Cradle to grave/cradle	
Input–output tables (I/O)	Sustainable supply-chain management (SSCM)	Product-service systems	
Social LCA (SLCA)			
Organisational LCA (OLCA)			
Territorial LCA			
Chemical assessment (CA)			
LC sustainability assessment (LCSA)			

*Some of the above methodologies have been standardised by supranational bodies such as ISO or the EU to provide users with an internationally agreed action framework

2.6 The regional life cycle toolbox

An overview of life cycle approaches and methodologies for regional development was already sketched out by Masari et al. in 2017. This framework was further refined by Balkau et al. (2021) into a 'life cycle toolbox' that provides a firmer foundation to the notion of 'life cycle thinking' and 'life cycle methodologies'. The toolbox incorporates current readily available life cycle methodologies as composed

of several groups: 'systems and concepts', 'assessment and analysis', and 'life cycle management' approaches. A fourth category, 'organisational assessment and management', focuses specifically on corporate entities, whether companies or administrative institutions. This set of sustainability management instruments has recently been reviewed by Fet (2023).

The toolbox structure was used as the basis for screening the case studies and good practice examples compiled by the

regional focal points in the LCA4Regions project. Table 2 below shows the main methodologies used to evaluate the relevance of the case studies prepared by the partner regions in the LCA4Regions project (i.e. did a particular case study report a use of LCT methods or not?).

In this project, it was clear that different methodologies are selectively used by distinct user groups or stakeholders along various value chains of goods and services. Thus, LCA is commonly in the domain of expert consultants or researchers investigating the impacts of products and services, while procurement and supply chain management are more typically administrative functions of organisations (both public and private) aimed at influencing options along distribution chains. The role of LCM in the business sector is extensively discussed by UNEP (ref UNEP/SETAC Life Cycle Initiative 2007), but no comparable study has been carried out for public bodies. Table 2 lists the most common life cycle methodologies—both assessment and management—in current use by the regional partners.

3 Results

From the inventory tables we can see over 100 examples of life cycle methods as reported by the seven partner regions of the LCA4Regions project. The acronyms used in the following discussions can be found at the end of the text. Table 3 gives an initial numerical summary of the frequency of use of various LC methods, their scope, and the main SDGs being addressed. The degree to which LC procedures resulted in governmental policy changes is also identified.

Among the LC methods in use were 33 examples of regular LCA, 28 on CFP, and 11 on LCC, although the latter are of uneven quality. On LCM, we observed 15 examples on eco-design and EPD/PEF, and a noticeable focus on sustainable procurement (15), as stimulated by the Interreg project objectives. There were seven mentions of circular economy; however, none of these reported any concrete programme or policy initiatives. While together these figures provide a valuable perspective, the small sample size and the uneven quality of responses caution us for the moment against a more detailed statistical analysis. More specifically, a number of case studies contained irrelevant data or missing entries. These were eventually deleted from the study.

Notwithstanding these cautions, it is clear that a significant amount and variety of life cycle-related activity is occurring in some of the partner regions. Important examples include assessment of selected industrial products produced or used within the region as, for example, building insulation, chemical products or electric vehicles (e.g. Poland, Lithuania, Slovenia). Others were related to waste management (Satakunta, Lombardy, Navarra), resource recovery, and energy efficiency (Lithuania, Navarra).

Changes in land use were subject to LCA in Finland. There were applications to government administrative machinery as, for example, in public tendering and purchasing (Navarra, Slovenia, Poland). Some regions/countries see life cycle information as a marketing advantage for local agricultural products (Lombardy, Navarra). Carbon footprinting was common (28 examples from six regions). Biodiversity assessment was not mentioned. Isolated embryonic examples touched on social LCA, organisational LCA, and territorial LCA, but with insufficient detail to be able to judge quality. The data in the tables stands on its own for the moment.

While it might have been interesting to correlate the use of life cycle approaches with relevant socio-political impact drivers and other stakeholder groups such as non-profit and community organisations, the terms of reference (and funding) of the study precluded such analysis. This could constitute a potential future study to be pursued with the same partners as a follow-up exercise. For the moment Interreg has precluded an extension of the work, favouring projects in other priority areas.

From the tables, we see that there were fewer management initiatives (39) than assessments (82), suggesting that many LCA studies remained in academia as ‘frozen’ research exercises. It also suggests that perhaps regions are not sufficiently proactive in capitalising on work done by others, as for example, not benefitting from others’ LCA studies to promulgate performance standards for buildings, for insulation, or for waste policy (Poland, Lithuania, Slovenia). Product optimisation via eco-design, EPD, PEF showed strong activity, often aimed at strengthening markets for local agricultural products, or to support the permit application for infrastructure. The examples of LCC in procurement were interesting, and overall, there were 15 examples around the topic of public purchasing. LCC became a focal point in the project dialogue on public procurement, providing a good example of the integration of assessment with management. There were no examples from corporate stakeholders of their supply chain management practices.

Also, interesting to note, although not entirely surprising, was the absence of any use of advanced life cycle methods in Table 2 such as LCSA, territorial LCA, PSS, EPR, CSR, or sustainability reporting. For many regional partners, the concept of LCA has not yet matured sufficiently to embrace such methodologies. But it may also be that these were not immediately recognised as life cycle methods by regional officials.

The seven regions could be seen to vary greatly in the manner in which they enact life cycle methods. Many assessments were academic studies in universities as for example in Lithuania (EVs, waste management, buildings), and Slovenia (graveyard candles), and did not always have a clearly defined client who commissioned the study and who would implement the outcomes. A few studies were carried out by

Table 3 LCA4Regions: frequency of reported regional use of life cycle methodologies and applications

Region (cases reported)	Activity sectors	LC assessment tool	LC management method	LC scope	SDGs environmental issue	LC client & author	Policy links
Lithuania (8)	Waste management Industry Building Transport	LCA, 6	Ecodesign, 2	Yes & no, 5	#7 Energy #12 RCP #13 Climate	Academic study	Company adopts LCA training
Lodzkie (12)	Industry Pollution Procurement	LCA, 4 LCC, 1	EPD, 1 SPP, 1	Limited to immediate impacts	#12 RCP #13 Climate	Company, 2 National government, 1 University, 1	LCA training (PP not linked to SDG)
Baixo Alentejo (10)	Agriculture Waste management Land management Procurement	No LC methods applied	No specific LCM tools Promotion of CE, 4	Not specified	#12 RCP #13 Climate #14 Eutrophication #15 Land	Municipal initiatives	Not reported
Lombardy (20)	Agricultural products Waste Buildings	LCA, 5 LCC, 1 CFP, 4 Territ LCA, 1 sLCA, 1	Ecodesign, 1 PEF, 4 EPD, 1 SPP, 1?	Limited to immediate impacts	#3 Health #7 Energy #11 Cities #12 RCP #13Climate #14 Water	Business association Regional government Company University	Not reported
Navarra (24)	Municipal services Waste Agriculture Industry	LCA, 6 CFP, 16 SLCA, 1 OLCA, 1 LCC, 2 MFA, 1	CE, 2 SPP, 4 Ecodesign-2 EPD, 2 Offsets, 2 Internal RE-1	Moderate scope	#3 Health #7 Energy #11 Cities #12 RCP #13Climate	Regional government Companies	Several (waste, GHG)
Satakunta (25)	Agriculture Waste management Land management Procurement	LCA, 10 LCC, 3 CFP, 8 SLCA, 1 MFA, 4	SPP, 5 Ecodesign-1 CE, 1	Mostly limited scope, some u/d	#13 Climate #14 Eutrophication #15 Land #15 Acidification	Municipality Consultancy	Several (waste policy)
Slovenia (9)	Products	LCA, 2 LCC, 4	Ecodesign-1 SPP, 4	Mostly limited scope	#7 Energy #12 RCP #13Climate	National government Academia	Yes, on SPP (product ban)
Total (108)	Agriculture Industry Buildings Transport Land management Waste management Municipal	LCA, 33 SLCA, 3 OLCA, 1 Territ LCA, 1 LCC, 11 CFP, 28 MFA, 5 Total, 82	Ecodesign-7 EPD/PEF, 8 SPP –15 RE/CP, 1 Offsets, 1 CE, 7 Total, 39	Mostly limited us/ds	#3 Health #7 Energy #11 Cities #12 RCP #13Climate #14 Water #15 Land 3, 7, 11, 12, 13, 14, 15	National government Municipal Company Business association Academia	Some policy implementation, but often missing

independent consultants under government contract, as in Finland (land transformation, waste management options), or Navarra (municipal services), or Lombardy (waste management, agricultural products). Some studies were carried out internally by government institutes (Finland). There were also cases of internal company initiatives from the stakeholder network such as in Poland (building products) and Navarra (agricultural products, renewable energy installations). In two studies (Navarra) government institutions examined the footprints of their own services, and of their

operational impacts, such as the Pamplona food bank, and the efficiency of municipal cleaning and water services. Both studies led to remedial actions.

Many of the LCA exercises were competently carried out in accordance with current international (ISO) standards. Others showed significant limitations. In most cases the scope of studies tended to be rather constrained. Few of the ‘life cycle’ initiatives took account of dynamics or stakeholders very far up or down the life cycle, with most limiting their consideration of impacts within a close regional

boundary. For example, for the drink container collection scheme in Lithuania, no information was available as to where (i.e. to which country) the collected empty containers were subsequently being exported for disposal. Further, most studies still perpetuated the single-issue conundrum.

Although the project required identification of all relevant SDGs (see Table 3 column 7), there was little consideration of potential spill-over effects. While the SDGs were extensively mentioned at project meetings, only a limited number were explicitly shown in the various case studies and good practice documents. Common components were GHG, energy, waste, pollution and occasionally land and water. Understandably, there was more focus on EU targets and directives than on the global SDGs even if the latter are anyway already the basis of much EU policy. The constrained scope was also evident during partners' verbal exchange of their experiences.

Several other observations can be made on the listings in Table 3. LCA dominates the assessment agenda (33 examples), mostly aimed at products produced or consumed in the region. The significant number of carbon footprint studies (28) reflects the current national and international priority on climate change, with several applications to municipal building stocks or building components e.g. insulation (Navarra, Lithuania, Lodzkie). More noticeable is the lack of activity in territorial LCA, in resource flows, and in biodiversity issues that ought in principle to be a priority for regions. Of the three social LCA studies mentioned, there is little information about methodology, outcomes or follow-up action.

On the LCM side, it is curious that in a waste-dominated agenda only one life-cycle action on resource efficiency and RCP was listed, and the circular economy was not anywhere treated in depth. Offsets were mentioned only once (Navarra). It could be that the application of these tools is too much of an organisational challenge for regions right now; possible also is that regional officials were not aware of the existence of these tools or did not associate resource issues with LCT. But it may also be that such actions were the responsibility of other sections of the administration that were not formally involved in the project (the silo effect) and were thus not contributing to this study.

Second, the tables allow us to see how regions move (or not) from assessment to management action. Following a strong effort on LCA (82 examples) there is a corresponding focus on action responses such as eco-design, EPDs and PEF and SPP as is evident from Table 3 column 4 (32 examples). Curiously, beyond some general mention of CE, this concept prompted relatively little regional action on resource efficiency or on SDG #12, (Responsible Production and Consumption). It can be supposed that the limited value-chain scope of many of the LCAs is partly responsible for this, but further study would be needed to confirm.

The ready acceptance by all partners of the potential usefulness of LCC in public procurement became a bright spot in the project, with several inspirational examples (Slovenia (regulation), Poland (national law), and Finland (training of municipalities)) that raised interest by other regions. Fifteen initiatives were reported overall, some strong, others less so. This interest was ultimately translated into several regional action plans (Navarra, Baixo Alentejo, Lithuania). Regrettably, the reported LCC were purely oriented towards in-use product performance; the wider 'sustainability' dimension is still absent in these examples.

Table 3 shows the frequency of use of specific life cycle methods across all partners, but it does not lead to an easy appreciation of how a particular region builds up a complete life cycle action programme, and which tools and methods it employs. Based on the inventory table of good practices, Satakunta's use of life cycle methods (to select just one region) can be seen in Supplementary Information B. It shows regular but isolated 'tactical' use of LCA rather than an overall strategic approach. In Fig. 4, we use a different format to display a profile of the Navarra region, and its use of the toolbox. This shows various sustainability actions based on LCT in a more systematic but ultimately still largely tactical fashion. In fact, despite some commendable applications, none of the seven regions has fully integrated LCT into its overall approach to sustainable development.

The picture does not change radically when we add the qualitative feedback from regions – SWOT, Peer to Peer, questionnaire, session feedback—into the conclusions. Supplementary Information C shows short LCT profiles in narrative format for all of the partner regions, drawn from various discussions and meetings with regional personnel. Examples of LCT again included LCA, CFP, MFA, LCC, and in LCM, use of EPD and PEF, eco-design and SPP, as well as product specification (or outright ban). Overall, while there was certainly an increased interest by regional partners in, and reported use of, life cycle procedures, there remained a lack of structure in their application, with much recourse also to traditional loose notions of 'green' as a substitute for standardised terminology and quantitative targets.

Although it was required in the case study template, there was a surprising lack of reporting on policy linkages, leaving many of the good life cycle assessments stranded without subsequent implementation. Awareness of the limits of life cycle studies were common, with data availability frequently mentioned, and occasional comments that LCA studies were expensive (reluctant however to acknowledge their benefits). Ultimately, regional administrators felt that life cycle management procedures were more immediately relevant to their needs than basic LCA. The notion that better data leads to better policies still struggles to be accepted.

Much of the above discussion flows directly from the catalogue of LC methods reported in good practice case

Table 4 Selected feedback from SWOT exercises

Strengths <ul style="list-style-type: none"> • Regions already have primary, complementary or delegated authority for many SD-related tasks • Various sustainability ‘systems’ are being explored in some regions and could be shared e.g. CE, RCP, SPP, etc Opportunities <ul style="list-style-type: none"> • Can build on existing interest in, for example, CE • Benefits can flow from following more closely EU procedures and directives 	Weaknesses <ul style="list-style-type: none"> • Regional-level data is often unavailable for assessments and action plans • Administrations are not appropriately structured to effectively engage in transversal (holistic) initiatives Threats <ul style="list-style-type: none"> • Worthwhile but complex and unfamiliar procedures are not pursued, or even attempted • Lack of in-house cooperation and coordination
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studies and from informal discussions during the project. Conversely, the SWOT analyses and peer-to-peer sessions gave insights not so much into the use of individual LC approaches as to the overall context in which they operate. Key elements include the structure of regional administration and its receptiveness to wider (sustainability) horizons, its willingness to use a different approach for certain issues, the availability of skills and resources to pursue a different line of thinking, and whether or not there is data to support a new approach. Perceptions of high costs of LCA were already mentioned above. Table 4 shows some selected feedback from the SWOT analyses.

Although short, the questionnaire brought several issues forward. All respondents to the questionnaires viewed LCT as a concept applicable to business and public administration alike. Nevertheless, uptake of the LCT experience in this project has been mixed, with several regions showing interest in expanding its use, while others remained within the boundaries of their current local initiatives in waste and energy management. While all respondents agreed that senior officials and managers need to take the lead on introducing and supporting LCT, they also felt that higher-level managers are too preoccupied with their present workload to be interested enough to make the transition. Similarly, none of the regions reported an interest at the political level for a more holistic approach, with the result that LC management tools such as eco-labels and circular economy are applied in an ad-hoc manner at a lower (administrative) level. The present project exercise will thus result in a limited number of small steps by subordinate staff within each region, aiming to gradually broaden the sustainability vision in current programmes (e.g. introduction of LCC in GPP), and to promote an increase in teaching and training on LCA and related procedures. Until higher level interest can be stimulated in both companies and public institutions (including at political level) LCT will remain a slow incremental process.

Table 2 was regarded as providing a useful framework for LCT, and for training on LC methods generally. Specialists with LCA skills found the toolbox a useful way to organise ideas and research. While partner regions only reported use of a selected few of these methods it helped to open

their eyes to additional tools that could be applied in future. Social LCA was mentioned as being of interest, while LCC was considered a useful basis for GPP. Carbon footprint calculations were seen as providing a base for regional climate and energy targets. Overall, the use of LCA-type tools was judged to be too institutionalised for public administrators to apply in-house although an understanding helps them in any potential contracting process. Conversely, LC management approaches are of immediate relevance to public authorities in framing policies and programmes on sustainability objectives. Eco-labelling (including EPD, PEF) was much quoted alongside public procurement (SPP), circular economy and zero emission.

4 Discussion

The use of life cycle methods for the further development of sustainability policies is well established within the EU (Sala et al., 2021). Regions are eventually constrained by national and global policies, however this has not by itself led to a greater use of such tools at regional level.

This project found that some regions are already employing life cycle approaches to address certain issues, but many times through ad hoc initiatives, and without a clear vision of their place in a wider programmatic context. Many LCA studies within this project and in the wider world beyond have been undertaken but have not necessarily been followed by a subsequent policy response due in part to local political and administrative dynamics. The influence of political dynamics was exemplified in Chile where learnings from an LCA study of regional waste management options (Bezama 2017) were not implemented because in the words of the author ‘the mayor changed, and so did the contact persons from the local environmental ministry’. (Bezama A. Pers Comm). It also recalls the experience in South Australia where a useful CE study was initially shelved after a change in regional government. A subsequent further change in government has seen CE now fully embraced (Devlin et al. 2023). Although not explicitly brought forward during the

LCA4Regions project, it is likely that similar constraints operate in most if not all of the partner regions.

Through the LCA4Regions project, as complemented also by some earlier work (Balkau et al. 2021), we have seen that certain regions nevertheless are already basing at least some of their sustainability actions on a life-cycle vision, with encouraging results. Certainly, not all issues are being addressed, only a few of the available tools are being used, often with limited scope. More generally, many initiatives are stalled at the assessment stage without resulting in concrete (life cycle based) action. The regions are still in the learning phase, testing the usefulness of LCT methods as a way of addressing their sustainability challenges. Through this project they are learning from others' experiences.

To facilitate a wider future regional adoption, the project employed the life cycle toolbox already proposed at an earlier time. From this toolbox, regions can select the most appropriate methods for assessing, and then managing, their sustainability journey. Feedback from regions suggests that LCM is of more immediate value to them than detailed LCA. Widespread use of common 'green' terminology is anyway often a substitute for quantitative results from a formal assessment. Eco-design, eco-labels, EPD and PEF have become common management tools for moving towards sustainability, and regions are becoming more aware of their utility. SPP and its industrial equivalent SSCM, are arguably the two tools potentially capable of making the biggest impact on the sustainability agenda. The suite of life cycle tools employed by the EU has reinforced the value of such a formal 'toolbox' in policy development.

Disappointingly, through this study we have again observed the absence of effective links between regional administrations and the LCA community, except perhaps for work on carbon footprints. When they began their involvement in this project, most partner regions knew little of any LCA expertise, research, or training residing in their local institutions or companies. Does the paucity of LC initiatives in their respective regions suggest that they are not regarded as significant clients by life cycle specialists? Presently much LCA activity is related to business sector interests. The divide is exacerbated by many universities seeing LCA as an academic research field for post-graduate students rather than as an active contribution to societal sustainability programmes. This divide was already observed by Balkau et al. (2021) wherein they highlight that LCA is often rooted in academia. Valdivia et al. (2024) seem to echo this dilemma noting that uptake of LCSA occurs principally in academia. In their review, Bezama et al. (2021) identify a lack of knowledge transfer from conducted research to policy makers for regional life cycle management.

On the side of the authorities, there is still too much fear of the cost of LCA without also calculating the benefits, and their inability to dedicate resources to data collection.

Further, Balkau et al. (2021) suggest that there is a lack of confidence by administrators to apply LCA which they view as a complex process. Massari et al. (2017) noted that the difficulty in reaching out to senior administrators and political representatives about the potential value of LCA is a key factor holding back its regional use. Thus, there is now an urgent need for these two worlds to come closer together to create improved synergies and mutual support. A recent encouraging example in this direction is the collaboration project initiated by the Swedish Life Cycle Center (IVL) to link twelve agencies and over 60 life cycle participants in a regular dialogue and knowledge exchange to drive the sustainability policies of the authorities (Wikström et al. 2024). Another welcome sign is the emphasis by the regional government of Navarra on internal collaboration. Chapter 7 of their climate action plan CCRN states 'Establishing bodies and governance tools that will help us to completely integrate the fight against climate change into the different policies, overruling the sectorial vision of traditional policies, is key for CCRN implementation' (Government of Navarre 2017).

Some important obstacles confront regions as they and their multiple stakeholders continue to struggle to put a life cycle approach into practice. Life cycle thinking remains simple when it is not quantified. But data is often scarce. The adage that 'you cannot manage what you don't measure' is as true for public administration as it is for business. For the present, formal life cycle assessment leading to a subsequent practical management intervention is not an easy subject for public administrators, touching as it does on methodological complexities they have not been trained to deal with, and requiring data they do not have. In general, awareness among administrators of the existence, let alone the value, of LCA is low, and it is not at all familiar to politicians.

5 Limitations of the project and future prospects

While the project generated valuable insights and outcomes, it also showed some limitations to what can be achieved with a small group of self-appointed regions, in the framework of an established and rigid EU administrative structure. Since much useful feedback came from informal discussions with officials, in retrospect it would have been worthwhile to allow additional time for personal relationships to mature into a richer sharing of information. The unforeseen travel constraints during the COVID era further reduced the horizontal learning opportunities during the project.

The bureaucratic structure of any regional institution can make internal cooperation on transversal issues difficult. In this study, some of the project focal points came from administrative services rather than from technical or

policy units, often lacking a personal knowledge of how LCT functions, nor having a clear idea about who the key players were in their respective regions. This was reflected in the generally weak responses concerning policy implications and cross-linkages. For example, some focal points did not know of, nor effectively searched out, LCA training capacity in their regions thus cutting themselves off from LCA case studies that might have been compiled. Their relative isolation from the policymakers was a limiting factor for identifying good data on the application of life cycle methodologies in the regions and for building an effective stakeholder network. The lack of circular economy case studies that were identified at a time when most regions have CE ambitions is an example of the consequence of insufficient coordination within regional organisations. The 'lack of coordination between different levels of governance and different policy departments' was already raised in the report to the European Parliament in 2022. In brief, then, future projects of this kind could usefully spend more time training the regional focal points to reach out internally and to recruit effective life cycle ambassadors in their home organisation(s).

Despite these drawbacks, this project has given us valuable insights. It therefore invites comments about how to take this work to the next level. In addition to more extensive project team building, some important structural factors could also be usefully addressed.

The first of these concerns the functional links between SDG objectives and conventional LCA endpoints. The 17 SDGs are transcribed into 169 targets and 231 indicators, many of them based on policy objectives and outcomes. Conversely, LCA methodologies deal principally with scientifically determined impact categories. There is a need to bring these into closer concordance if regional policymakers are to more easily embrace standardised LCA outcomes. This point, already raised by Valdivia et al. (2024), suggests a further evolution or adaptation of LCA procedures, especially in LCSA, as this deals with an expanded group of SDGs. In this sense also, a stronger outreach by the LCA community to the ongoing UN review process of the SDG structure could be helpful.

In the meantime, it would be valuable to prepare for each region an inventory of LCA (and LCM, as this is what regions want most) training capacity in academic institutions where local skills are being developed. A recent initiative by FSLCI (Viere et al. 2024) could be a useful starting point, examining how to expand from LCA training in its pure procedural form to put additional emphasis also on its interpretation and implementation.

Finally, direct measures to bring the LCA community closer to regional administrations are necessary if policy initiatives are to be more effectively based on a holistic view of the SDG challenges. The first steps can be taken by

academic institutions, i.e. LC researchers, to build effective bridges to public sector institutions. Professional LCA/LCM conferences could usefully include specific sessions aimed at regional issues, with possibility of real-life outputs. Such measures would gradually build a wider stakeholder base interested in applying LCT to public policy.

It goes without saying that further research to confirm and enrich the findings of this project would be useful in tapping into the experience of more than seven regions on only a single continent.

6 Conclusions

The Interreg Europe project described in this paper is a first attempt to see how extensively life cycle thinking can contribute to enhanced sustainability policies in European regions. It is an expansion on earlier work by the authors, but with a sharper focus and more details on the use of LCT by, for, and in, selected regions. By working directly with a group of seven regions we have been able to learn more about the way in which life cycle methodologies are employed, their relevance, and the challenges in their application. Due to the small sample size and diversity of the regions involved, the results are indicative rather than quantitative. All the same, some important conclusions can already be drawn.

The life cycle toolbox is a useful construct for regions to visualise the range of methodologies available to address their sustainability challenges. While some evolving methodologies can still only be used on a pioneering basis or depend on availability of specific data, most mainstream LCA and LCM methods are already eminently suitable for immediate regional use. With an eye on the future, the toolbox also includes some evolving methodologies that are slowly coming into more visible use such as LCSA, sLCA, O-LCA. Others such as territorial LCA, biodiversity LCA, and extended LCC are still some way off regular use due in part to unresolved issues over data, metrics, and methodology. Once mainstream, these would help regions more easily address a wider range of SDGs. Further work is also needed to link more systematically the LCA endpoints and the multiple SDG targets.

This study found that the effective use of LCT in general, and recourse to established methodologies in particular, varied greatly from region to region, with some showing effective application, alongside other partners not yet showing any real capacity for implementation. Within the Interreg framework, the main application of reported LCA appeared to be for products (industrial, agricultural), and for waste management, with some examples also of land use. There was use of carbon footprinting for buildings, services, and products.

Application of LC methods by the seven partners included 33 examples of regular LCA, 28 on CFP, and 11 on LCC, although the latter are of uneven quality. On LCM, we observed 15 examples on eco-design and EPD/PEF, and a noticeable focus on SPP (15), as stimulated by the Interreg project objectives. There were seven mentions of circular economy; however, none of these reported any concrete programme or policy initiatives. While together these figures provide a valuable perspective, the small sample size and the uneven quality of responses cautions us for the moment against a more detailed statistical analysis.

A range of SDGs was invoked in the various case studies, with climate, energy, waste, water, and land dominating, a distribution that again reflects the Interreg project objectives of resource efficiency, wastes, and SPP, and also the mindset of many administrators who have not yet grasped the full potential of LCT. In many cases, the SDGs were not identified by name; instead, more traditional impact categories such as ‘pollution’, ‘waste’, and ‘recycling’ were quoted. The duopoly of energy/climate often dominated the regional sustainability agenda. With some notable exceptions most of the case studies can be rated as ‘good, but could do better’ by, for example, widening the spectrum of SDGs, giving greater upstream/downstream consideration, and expanding the scope to include more stakeholder groups.

We note an important gap between the assessment phase and subsequent policy or regulatory initiatives. Results from LCAs initiated directly by regional institutions tend more often to be implemented, while LCA research in academic institutions is more likely to remain without a policy follow-up. We note also that a variety of management actions have been taken by regions without a preceding LCA phase, as for example in SPP, eco-labelling, and recycling. Such management actions would benefit from a being taken within a broader life cycle perspective, as was shown for example by the Lithuanian container deposit initiative.

Within the LCA community, much regionally relevant LCA is undertaken as academic research in universities, often without a link to an eventual identified policy ‘client’. The lack of a significant body of published regional LCT studies was already identified by the bibliometric study of Bezama et al. (2021), suggesting that regional application is not a popular research field. Similarly, a glance at current LCA/LCM conferences and monographs shows limited content on regional needs, only occasionally including some studies within regions, fewer for regions, and very few by regions. However, the reverse is also true. Few of the outcomes of studies by governmental agencies such as LCA4Regions project reach the academic community, reinforcing the disconnect between scientific and administrative communities. This divergence is possibly exacerbated by current LCA training being more focussed on the formal structure of the LCA process than on its

eventual implementation. It is not surprising then that few of the project partners were aware of LC training possibilities in their regions, even though several local universities do in fact include this in their syllabus. It is telling that the regional government of Navarra undertook its own information outreach and training on LCA for its stakeholder community, while the local university concentrates on academic research. The recent survey by FSLCI of the state-of-the-art teaching on LCA teaching also underlines this point (Viere et al. 2024). The survey concluded that ‘LCA curriculum development and programme planning remain significant challenges...for the global LCA community’. The gap is still wide.

The LCA4Regions project has advanced consciousness and motivation of the use of LCT among the seven partner regions. It will be interesting to see how these ideas and practices inspire further incorporation of LCT into their regional policies and programmes, and the extent to which closer links can eventually be forged with LC expertise already resident in their regions. It will also be interesting to see if and how if the life cycle community can increase its outreach and further evolve its methodologies to help address regional priorities in sustainable development.

Acronyms CFP: Carbon footprint; EPD: Environmental product declaration; EPR: Extended producer responsibility; EU: European Union; EV: Electric vehicle; *Factor 4*: Fourfold increase in resource efficiency; GPP: Green public purchasing; ISO: International Organisation for Standardisation; LCA: Life cycle assessment; SLCA: Social life cycle assessment; OLCA: Organisational life cycle assessment; LCC: Life cycle costing; LCT: Life cycle thinking; LCM: Life cycle management; LCSA: Life cycle sustainability assessment; MFA: Material flow analysis; PEF: Product environmental footprint; RE: Resource efficiency; SSCM: Sustainable supply chain management; SDG: Sustainable development goals; SPP: Sustainable public purchasing; SWOT: Strengths weaknesses opportunities and threats

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