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Life cycle assessment for the impact assessment of policies

Life thinking and assessment in the European policies and for evaluating policy options

Sala, S., Reale, F., Cristobal-Garcia J., Marelli, L., Pant R.

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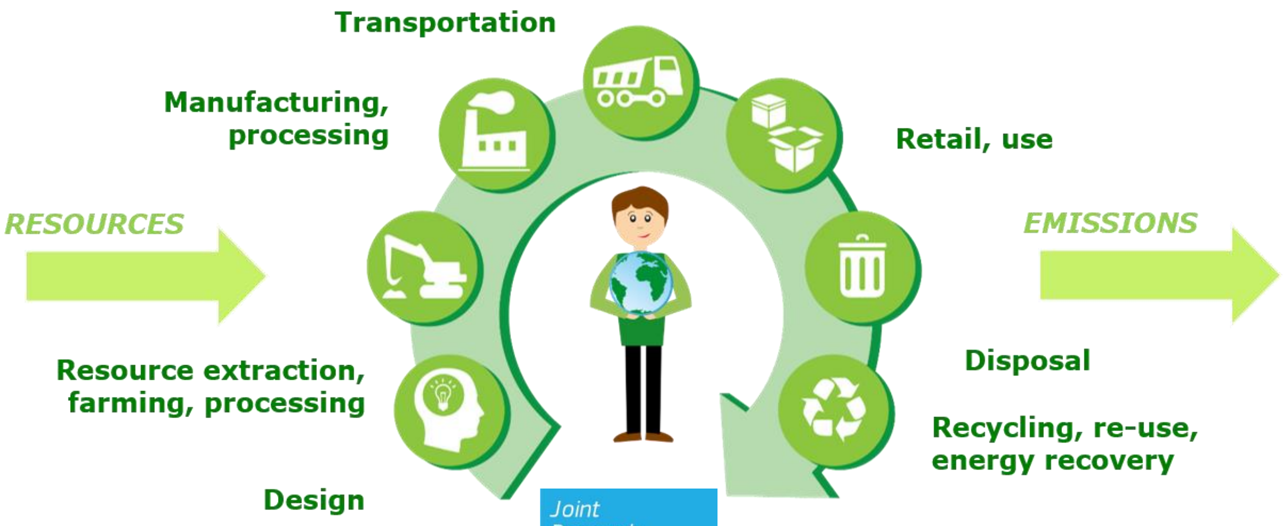

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Contact information
Name: Serenella Sala
Address: Joint Research Centre, Via E. Fermi 2749, Ispra (VA), Italy
E-mail: serenella.sala@ec.europa.eu
Tel.: +39 0332 786417

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Abstract

The European Commission has released in 2015 a Communication on Better regulation (CEC 2015a) in order to improve the policy development process. The Communication has been complemented with a Better Regulation toolbox, which reports and describes models and methods for the Impact Assessment (IA) of policies. The IA of policies addresses all dimension of sustainability, i.e. economic, social and environmental. Life Cycle Analysis/Assessment (LCA) has been listed among the tools that aim at supporting the assessment of impact and benefits associated to different policy options. A number of LCA features are particularly relevant for addressing sustainability problems, such as: (i) the life cycle perspective (from extraction of raw material to end of life, when assessing supply chains); (ii) the identification of the most important burdens and most relevant life cycle stages contributing to environmental and social impacts; (iii) the identification of environmental (and social) "hot spots" of goods/ services/ systems/ technologies/ innovations/ infrastructures; (iv) the identification of unintended burdens shifting between environmental (and/or socio-economic) impacts (reducing one impact while increasing another), and over life cycle stages. Originally, LCA for has been applied for supporting decision making in the business context. To date, LCA is more and more adopted uses for supporting policy-making. However, the use of LCA for supporting the impact assessment of policies is still relatively limited. A broad and international discussion on the need of a guidance for the application of LCA in the policy is ongoing. In this context, the present report pursues a two-fold aim: (i) to provide a first framework of potential roles of the LCA in the whole policy cycle, with particular reference to the impact assessment of policies, (ii) to provide discussion elements and inputs for enhancing the use of LCA along the different steps of the policy cycle. The proposed framework has been built upon the review of: (i) existing environmental policies; (ii) Staff Working Documents relating to policies on Energy, Climate and Environment topics; and (iii) the examples of application of the most advanced state-of-art of LCA methodology. Due to its main features (Life cycle perspective and systemic approach), LCA may play a relevant role all along the policy cycle, from policy anticipation and problem definition, to the policy evaluation. LCT and LCA have been integrated in several EU environmental policies over the last two decades and LCA is mostly mentioned as implementation measure. The review highlights that LCA play a key role for tackling the challenges posed by environmental sustainability assessment, as it can provide support to policy-makers towards more transparent and evidence-based decisions, as requested by the Better regulation. However, several aspects should be improved to ensure robust results of the LCA evaluation, including: improving data quality; providing guidance on modelling approaches and methodological choices; integrating uncertainty analysis of the results etc. Hence, further guidance tailoring LCA for policy impact assessment are needed, capitalising existing knowledge and ensuring coherence with other assessment tools and methodologies.

1 Introduction

In a world characterised by multifaceted challenges, there is a growing request of evidence-based policies, in which scientific evidences are considered and discussed during the process of policy development. A significant decoupling of environmental impacts from economic growth requires the definition of specific policies aiming at reducing burdens associated to production and consumption of goods and services, enhancing sustainability of production and consumption, where the sustainability concerns economic, social and environmental aspects.

The European Commission, in order to improve the policy development process, has released a Communication on Better regulation (CEC 2015a) in 2015. A Better Regulation toolbox complemented the Communication, reporting and describing models and methods for the Impact Assessment (IA) of policies. Life Cycle Analysis/Assessment (LCA) has been listed among the tools that aim at supporting the assessment of impact and benefits associated to different policy options.

Life Cycle Assessment (LCA) is a standardised methodology (ISO 2006a,b) for assessing potential environmental impacts associated to a product, a process or a system, along its life cycle, namely from the extraction of raw material to the end of life. By accounting for inputs and outputs (respectively materials, energy and emissions) at each step of the product life cycle, it supports the identification of hotspot of impacts and the comparison of options. The LCA is a multi-criteria assessment methodology as it covers a wide variety of pressures and impacts associated with human health, ecosystem health, and resources. The LCA is one of the methodologies the makes the Life Cycle Thinking (LCT) operational; in particular, LCA is widely recognized as the best framework for assessing the potential environmental impacts of products, process and systems (CEC 2003). In a policy context, by applying a life-cycle methodology, priorities can be identified more transparently and inclusively and trade-offs can be assessed. Hence, policies can be targeted more effectively so that the maximum benefit is achieved relative to the effort expended.

LCT is indispensable in supporting decisions towards more sustainable consumption and production patterns (Pennington et al. 2007) and it is the backbone of several European environmental policies, relating to both public and private sector. In fact, assessing the whole life cycle of a product/process/system and considering several environmental criteria, allows avoiding burden shifting from one stage of the life cycle to another one and/or from one environmental impact category to another one.

Examples of LCT-based European environmental policies are the Communication on Sustainable Consumption and Production (CEC 2008a) and the Communication on Circular Economy (CEC 2015b). The first one addresses the overall environmental impact and consumption of resources associated with the complete life cycle of goods and services, and includes a set of actions to increase the demand of better products/services, to improve production as well as to support better choices, based on a more coherent and simplified labelling. The second one intends to foster the transition to a circular economy, ensuring that the value of products, materials and resources is maintained in the economy for as long as possible and the generation of waste is minimised. The life cycle perspective informs the policy, looking at all stages of production and consumption, from extraction of raw material to waste recycling and disposal.

At international level, the role of LCT is recognized and several initiatives have been launched. An example is the 10-year framework of Programmes on Sustainable Consumption and Production (10 YFP on SCP, started in 2012), a global framework of actions to enhance international cooperation in order to speed the moving towards a sustainable production and consumption pattern in both developed and developing countries. Actions in support of capacity-building as well as for technical/financial assistance for developing countries are a relevant part of the programme which overall aims at developing, replicating and scaling up SCP and resource efficiency initiatives, at national and regional levels. Another example is the Sustainable Material Management (SMM) initiative, promoted by the Organization for Economic Co-operation and Development (OECD), following the need of adopting integrated solutions for addressing environmental concerns. The initiative is strongly based on the life cycle thinking, in particular promotes the concept of waste-to-resources and the use of a material-based approach oriented to a "cradle-to-cradle" thinking.

Moreover, the LCA has a strong link with the Sustainable Development Goals (SDGs). In fact, LCA may play a role in assessing impacts and benefits associated to several goals, both environmental and socio-economics ones. For example, through LCA it is possible to account for climate change-related drivers of impact and the associated potential damage to ecosystems due to production and consumption patterns. Similarly, the assessment framework may cover impact on water, land, resources etc. When Life Cycle Thinking is applied to social issues (Social LCA), the supply chains related impact could be assessed, e.g. those related to poverty or inequalities.

The potential of the LCT and the key role of the LCA to address environmental issues is demonstrated by the initiatives put in place at European and International level, finalized to the promotion of the LCA and to its further development. The European Commission has developed the European Platform on LCA (EPLCA[1]), to support the use of LCA in both business and policy contexts. The United Nation Environment Programme (UNEP), in collaboration with the Society for Environmental Toxicology and Chemistry (SETAC) launched the Life Cycle Initiative, to disseminate and implement the LCA worldwide. As mentioned above, the European Commission published the Communication "Better regulation for Better results – An EU Agenda" (CEC 2015b) to ensure that policy goals are achieved at minimum cost and deliver maximum benefits to citizens, businesses and workers while avoiding all unnecessary regulatory burdens. The LCA is included in the list of tools for the implementation of the Better regulation, with a specific role in the stage of the impact assessment.

While the application of LCA in the context of business has a longer tradition (starting in the 70's), the array of options for the use of LCA in policy making is not yet completely deployed.

In this context, with the overall objective to facilitate the implementation of the Better Regulation, the present report pursues a two-fold aim: i) to provide a first framework of potential roles of the LCA in the whole policy cycle, with particular reference to the impact assessment step, ii) to provide discussion elements and inputs for LCA enhancement in the context of policy cycle. The proposed framework and related discussion elements/inputs has been built through the review of: (i) existing environmental policies developed in the last two decades,(ii) Staff Working Documents related to policies on Energy, Climate and Environmental topics in the last 5 years; (iii) application of state-of-art of LCA methodology in the policy context.

The report is organised as follows.

In chapter 2, the LCA methodology is introduced, including the reference to the main ISO standards and the description of typical applications thereof. Main aims, key issues and procedural steps are presented as well as limits and benefits of the methodology. Other methodologies using a LCT approach and complementing LCA for a complete sustainability assessment are briefly explained.

In chapter 3, current and potential uses of the LCA are provided for each step of the policy cycle as defined by the Better Regulation. Chapter 4 reports a review of the use of LCA in the EU policies in the last 20 years. Chapter 5 presents and discuss the use of the LCA in the impact assessment of policies, building upon the assessment of several SWDs. The chapter also includes a case study concerning the application of LCA in the bioenergy context biofuel.

[1] http://eplca.jrc.ec.europa.eu/

Finally, chapter 6 presents main conclusions and outlook.

2 What is LCA?

Life cycle thinking is a basic concept referring to the need of assessing burden and benefits associated to products/sectors/projects adopting a holistic perspective, from raw material extraction to end of life. LCT can be applied to both economic, social and environmental pillars. The environmental pillar of LCT is primarily supported by LCA (figure 1), an internationally standardised tool (ISO 14040, ISO 2006a) for the integrated environmental assessment of products (goods and services). Upstream and downstream consequences of decisions must be taken into account to help avoiding the shifting of burdens from one impact category to another, from one country to another, or from one stage to another in a product's life cycle from the cradle to the grave.

According to commonly adopted definitions (Guinée et al. 2002), Life Cycle Assessment (LCA), is a methodology for integrated impact assessment in which the (environmental) burdens associated to the whole life cycle of products are quantified. Such impacts refer to a wide range of categories, the so-called impact categories, such as climate change, resource depletion, ecotoxicity etc. The environmental impacts are the consequences of a human intervention on the environment, either physical, chemical or biological, such as resource extraction, emissions (incl. noise and heat) and land use (Guinée et al. 2002).

The LCA represents the technological relationships associated to a product system, through the description of all activities (unit process) occurring in its life cycle and linked each other by physical exchanges (flows, materials, energy, components) within the technosphere. The model of the technological relationships also includes physical exchanges between the technosphere and the environment, called elementary flows (materials, emissions), which are responsible for the environmental impacts. Physical exchanges occurring within the technosphere are often evaluated on market relationships, whereas the environmental impacts evaluation is made through the cause-and-effect models. LCA models are linear, static and has no dimension. Moreover, all technological systems not directly affected by the studied system are not included in the model as well as all technological systems.

Figure 1: Life Cycle Assessment basic principles of accounting resource and emissions along each step of production and consumption supply chains.

The underpinning logic of LCA could be linked with frameworks such as the "Drivers, Pressure, State, Impact and Response" (DPSIR) (Smeets e Weterings 1999) which links pressures and impacts to policy responses, and on the so called IPAT equation ("Impact =Population x Affluence x Technology (I = P x A x T)") (Ehrlich e Holdren 1971) which addresses impacts as a combination of magnitude of consumption and technological level.

2.1 Standard, procedural steps and key methodological issues in LCA

The LCA is defined by the ISO 14040 as the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 2006a). The above-mentioned standard defines LCA principle and framework, whereas operational aspects are covered by ISO 14044:2006 Environmental Management – Life Cycle Assessment. Requirements and Guidelines (ISO 2006b). Along the lines of these standards and with the main aim to support LCA practitioners in operationalizing LCA, other codes of practice have been developed. In the EU context, the Joint Research Centre of the European Commission has released the International Reference Life Cycle Data System Handbook (ILCD Handbook) (EC-JRC 2010-2012). Recently, to enhance the comparability of LCA applied to products and organisations, the European Commission has launched the Environmental Footprint Guide (CEC 2013).

LCA is based on 4 main step (figure 2): 1) goal and scope 2) inventory analysis, 3) impact assessment, 4) interpretation.

In the goal and scope step, the aims of the study are defined, namely the intended application, the reasons for carrying out the study and the intended audience. Main methodological choices are made in this step, in particular the exact definition of the functional unit, the identification of the system boundaries, the identification of the allocation procedures, the studied impact categories and the Life Cycle Impact Assessment (LCIA) models used, the identification of data quality requirements. In this step also are specified and justified all assumptions made.

In the Life Cycle Inventory (LCI) step involves the data collection and the calculation procedure for the quantification of inputs and outputs of the studied system. Inputs and outputs concern energy, raw material and other physical inputs, products and co-products and waste, emissions to air/water/soil, other environmental aspects. Data collected concern foreground processes (e.g. for a consumer good manufactures, the manufacturing and packaging of a product) and background processes (e.g. for a consumer good manufactures, the production of purchased electricity and materials). Data are validated and put in relationship to the process units and functional unit. The LCI is an iterative process. In fact, as data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goals of the study will still be met. Or, if needed, the goal and scope could be revised.

In the impact assessment step, LCI results are associated to environmental impact categories and indicators. This is done through LCIA methods which firstly classify emissions into impact categories and secondly characterize them to common units so as to allow comparison (e.g. CO_2 and CH_4 emissions are both expressed in CO_2 equivalent emissions by using their global warming potential). Example of impact categories are climate change, acidification or resource depletion and, usually cover three area of protection: human health, natural resources and ecosystem quality. Several methods are available to assess the different potential impacts on the three area of protections (Sala et. al 2012).

Finally, in the interpretation step, results from LCI and LCIA are interpreted in accordance to the stated goal and scope. This step includes completeness, sensitivity and consistency checks (Sala et al. 2016a). Uncertainty and accuracy of obtained results are also addressed in this step.

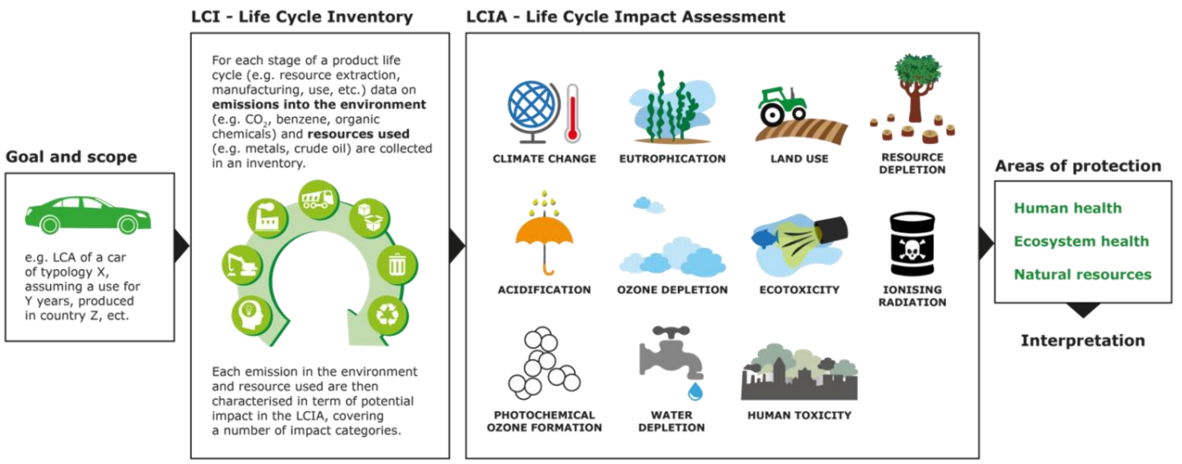


Figure 2: Life Cycle Assessment steps: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation

Five methodological aspects can be identified as key issues, as they strongly affect the results arising from the study: (i) functional unit, (ii) system boundary, (iii) multi-functionality, (iv) LCIA method, (v) type and quality of data.

- The functional unit clearly defines the studied function from several point of view (What? How much? How? How long?). Environmental impacts relate to the function performed by the studied system. Moreover, the functional unit is the main element to be considered when comparing two different systems.
- The system boundary is a set of criteria allowing defining which unit processes (activities) are included in the studied system and which not; differences exist among the norms, code of practices and guides concerning the possibility to exclude energy and material flows, whole unit processes, or whole life cycle stages.
- The multi-functionality arises when a process fulfils more than one function; it happens when a process provides more than one product or in recycling situation where the dual functions of waste management and secondary material production is fulfilled (Nakatani 2014). Different logics (allocation rules) exist to account for burden and benefit associated to multi-functional processes.
- The LCIA allow expressing the magnitude and significance of potential environmental impacts. Several LCIA methods exist based on different environmental models. Some standards do not provide any restriction to the choice of the LCIA method but just transparency and justification of choices made; other codes of practice and guides, provide a clear identification of impact categories and indicators to be provided, together with the relevant method to be used.
- The type and quality of data concern respectively the possibility to use primary and/or secondary data in the unit process and, the way of providing information on the quality (description in relationship to data quality requirement or, additionally, rating in relationship to data quality indicators).

An additional methodological issue concerns the modelling approach. The commonly used approach is the Attributional (ALCA) one also known as "accounting" approach. ALCA modelling approach simply accounts for immediate physical flows (i.e., resources, material, energy, and emissions) involved across the life cycle of a product (Earsel et al. 2011). The consequential approach (Consequential LCA – CLCA) intends to describe how physical flows can change as a consequence of an increase or decrease in demand for the product system under study (Earsel et al. 2011). Unlike ALCA, CLCA includes unit processes inside and outside of the product's immediate system boundaries (Earsel et al. 2011). Based on Weidema (Weidema 1993), the base concept underpinning the two different modelling approaches is better shown in table 1. The ILCD handbook clearly distinguishes situations that requires CLCA from situations where ALCA can be used but a unique vision does not exist and there is not a common view about benefits/limits of CLCA compared to ALCA, as also demonstrated by recent literature (Zamagni et al. 2012; Plevin et al. 2014a; Brandão et al. 2014, Dale et al. 2014; Hertwich 2014; Plevin et al. 2014b).

Table 1: Basic differences between LCA modelling approach

Modelling approach	**ALCA**	**CLCA**
Character	Retrospective	Comparative
Aim	To assess environmental performances of products/services/systems	To study possible future change between alternative product systems

2.2 The role of LCA in sustainability assessment

LCT—due to its systemic approach—is considered to provide a valuable support in integrating sustainability into design, innovation and evaluation of products and services. Evidence thereof is given in the numerous policies at European (e.g. CEC 2004; CEC 2005a; CEC 2008a; CEC 2010a; CEC 2011a, CEC 2014) and international level (e.g. UNEP 2004 and 2015) in which LCT and LCA represents the backbone. In fact, life cycle-based methodologies and- in particular LCA- are inherently rooted into sustainability science at the conceptual level (Sala et al. 2013 a,b).

The LCA, as above described, applies a linear static model based on technologic and environmental relationships in inventory and impact assessment phases (Sala et al. 2016a). This simplification makes the LCA applicable with limited efforts but, at the same time represents a limit in the context of sustainability assessment as other mechanisms should be considered such as cultural, social political relationships, economic relationships, other physical relationships. Economic relationships are partially integrated in CLCA (Zamagni et al. 2012) which is ideally dynamic, context specific and marginal (Plevin at al. 2014a). Anyway, although this limitation, the LCA presents evident strengths, namely the life cycle perspective and the systemic approach which allow to avoid burden shifting (between different stages and/or impact categories) as well as to identify possible trade-offs. For this reason, it is widely considered as the state of the art relating to the environmental dimension of sustainability (Sala et al. 2013a, Sala et al. 2013b, Finnveden et al. 2005).

While LCA focuses primarily on burdens linked to emissions into the environment and resources, life cycle costing (LCC) aims at assessing cost along the supply chain and the emerging Social life cycle assessment (SLCA) complements this in relation to working hours/conditions to more complete the environment and socio-economic analysis (figure3). Aiming to cover the different pillars of sustainability, life cycle sustainability assessment (LCSA) methodologies and applications are under development aiming at integrating better sustainability pillars, assessing the mutual interaction amongst them. Recent reviews have assessed the role of LCA in the context of sustainability assessment methodologies (see Sala et al. 2013a,b for a meta review). From the literature and the LCA practice, it is clear that LCA is a methodology, which may complement other methodologies and insights, for assessing the performance of goods/ services/ systems/ technologies/ innovations/ infrastructures/ waste management options/ regions.

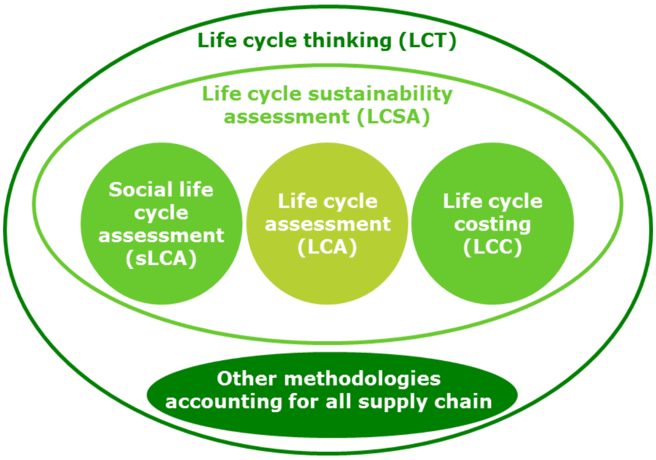


Figure 3: Life cycle thinking and the main related methodologies addressing environmental (LCA), social (SLCA) and economic (LCC) aspects.

Since the 90's, the principle of LCT has been increasingly integrated into a number of policy documents. These new policies either add life cycle elements, only slightly modifying existing policies often through caveats such as "unless resulting in an increase in environmental burden", or they fundamentally incorporate the life cycle approach and adopt an integrated overview of the environmental performance. This latter approach allows assessment of the entire life cycle of products, technology options and policy strategies, or of production sites and companies. These modern life cycle-based policies and instruments require support in the form of dedicated scientific and technical guidance –for better reproducibility and for more reliable decision-making (Wolf et al. 2011).

2.3 The role of LCA in supporting decision making

The ILCD handbook (EC-JRC 2010), tried to classify LCA application. According to this reference LCA can be applied to three different decision-contexts: Situation A - "Micro-level decision support", Situation B - "Meso/macro-level decision support", Situation C - "Accounting" (figure 4). They differ in two aspects: regarding the question whether the LCA study is to be used to support a decision on the analysed system (e.g. product or strategy) and in the interaction of the depicted system with other systems. The intention of these recommendations is to promote consistency across LCAs conducted within homogeneous application contexts.

Decision support?		Kind of process-changes in background system / other systems	
		None or small-scale	Large-scale
	Yes	Situation A "Micro-level decision support"	Situation B "Meso/macro-level decision support"
	No	Situation C "Accounting" (with C1: including interactions with other systems, C2: excluding interactions with other systems)	

Figure 4: Decision contexts in which LCA could be applied as envisaged by the ILCD handbook (EC-JRC 2010)

Typically, the Situation A refers to LCA studies of single products (or services) whose share on the total production is limited and, hence, it can be reasonably expected to cause none or only small changes in the background system or other systems of the economy that would not directly or indirectly structurally change it. A typical example can be the LCA of an electric device. The product system is usually modelled using an attributional approach (with some exceptions). Building on, inter alia, the ILCD Situation

A guidelines, the JRC has recently developed the Environmental Footprint guides (CEC 2013a, b). Based on the attributional approach and the need to quantify the business-as-usual situation, the Product Environmental Footprint (PEF) Guide represents the updated view of the European Commission recommended methods for LCA "Situation A" studies. The PEF Guide may also be used to assess baseline scenarios for products when considering e.g. future-oriented options.

The Situation B refers to LCA studies which look at changes with structural market implications beyond the foreground-system. This situation covers scenarios addressing questions like "Which pervasive technology system, raw material base, etc. is environmentally preferable over its life cycle?" Such studies are typically strategic political studies or LCA-supported strategic research studies and are modelled generally based on consequential considerations.

The Situation C refers to LCA studies that are purely descriptive accounting / documentation of the analysed system (e.g. a product, need fulfilment, sector, country, etc.) of the past, present or forecasted future, and without implying a decision-context that would account for potential additional consequences on other systems.

Table 2 reports examples of application of life cycle information focusing on micro or macro level.

Table 2: Examples of uses of the life cycle based information classified according to whether they focus on the micro or the macro level, modified from Reimann et al. 2010

Level of perspective	Possible applications of the life cycle information
Micro	Identification of Key Environmental Performance Indicators (KEPI) of a product group for Ecodesign / simplified LCA
	Hotspot and weak point analysis of a specific product
	Ecodesign, design for recycling
	Comparison of environmental profile of specific goods or services
	Benchmarking of specific products against the product group's average
	Development of life cycle based Type I Ecolabel criteria
Macro	Forecasting and analysis of the environmental impact of pervasive technologies, raw material strategies, etc. and related policy development
	Basket-of-products (or -product groups) type of studies
	Identifying product groups with the largest environmental impact/improvement potential
	Monitoring environmental impacts of a nation, industry sector product group, or product

Indeed, LCA was historically focused on products but its application has expanded lately, leading to four different types of LCAs, namely: i) original product-based scope: ii) organizational company LCA; iii) consumer LCA (analysing consumption patterns and lifestyles); iv) national-level assessments (Hellweg and Mila I Canals 2014). While the typical use of LCA has been to assess product performances, its current application is now much broader, as companies are using this tool to map key drivers of impact in their production systems and, in the area of sustainable consumption and production, "top-down" studies at national and sectorial scales help to highlighting most impacting components of consumption and production patterns. Each of these LCA typologies has a different system boundary, as well as focus, accordingly to the objective of the analysis. However, all the phases of LCA (e.g. extraction of raw materials, production, use and end of life) are generally covered, although the focus can vary significantly.

3 Role of LCA in the policy cycle

In the context of the so-called "smart regulation", there is the need of maximising the science to policy interface towards evidence-based regulations. E.g., the European Commission assesses the impact of policies, legislation, trade agreements and other measures at every stage - from planning to implementation and review, in order to ensure that EU action is effective (CEC 2015a).

A typical policy cycle -underpinning the development of a new policy- presents a number of steps (figure 5), namely:

i) Policy anticipation and problem definition: identifying problems that require government attention, deciding which issues deserve the most attention and defining the nature of the problem;

ii) Policy formulation: definition of policy options in terms of means and possibilities to achieve policy objectives;

iii) Policy impact assessment: evaluation of the environmental, social and economic impacts of the different policy options in order to identify the one that maximize benefits reducing impacts;

iv) Policy implementation: actual application of what is prescribed by the selected policy option;

v) Policy evaluation: assessment of the effectiveness of the policy.

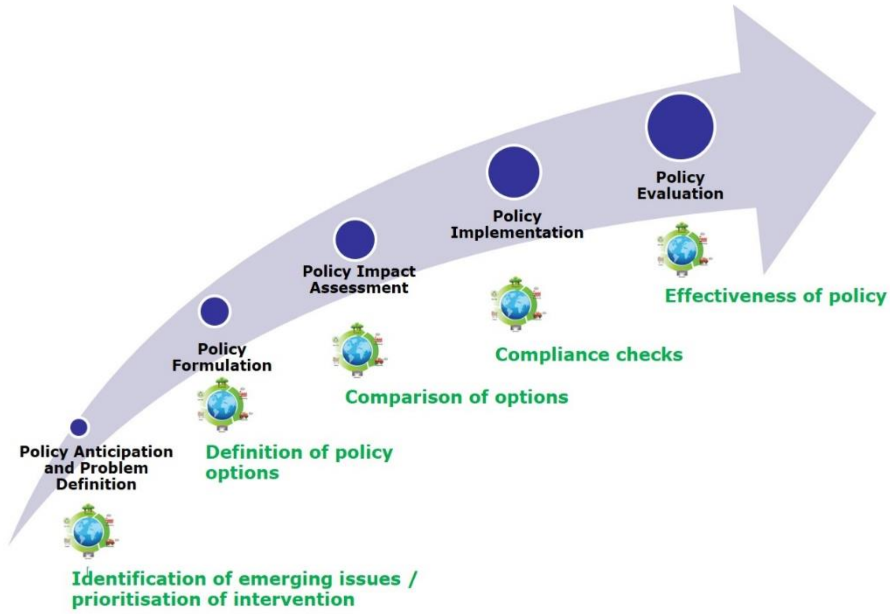


Figure 5: Main steps of the policy cycle and the possible use of LCA to support them

Since 2003, with the first Inter Institutional Agreement on better law-making[2], the European Parliament, the Council of the European Union (EU) and the Commission have agreed on the overall aim to optimize the drafting and implementation of the Union law and several specific objectives have been identified, namely i) Improving inter-institutional cooperation and transparency, ii) Promoting co-regulation and self-regulation, iii) Improving the quality of legislation, iv) Improving the transposition and application of Union law, v) Simplifying legislation. Thanks to this Agreement, the pre-legislative consultations and impact assessment in the draft legislation are become an essential part of the policy-making process.

The objectives identified by the above mentioned agreement, have been strengthened and widened by the Smart Regulation in the European Union – (CEC 2010b) reporting as first key message "smart regulation is about the whole policy cycle – from the design of legislation, to implementation, enforcement, evaluation and revision". The role of impact assessment in the new legislation is recognized as well as the relevance of similar efforts in the management and implementation of existing legislation in order to ensure that it delivers the intended benefits.

Finally, in the last communication "Better rules for better results – An EU Agenda" (CEC 2015) new "Integrated Guidelines on Better Regulation" are provided by the Commission in order to better support the policy making process and ensure that environmental, social and economic aspects are properly taken into account at each stage. Moreover, the need of maximising the science to policy interface towards evidence-based regulations is clearly stated. To this aim a Better Regulation toolbox is provided. In this context, an important role is recognized to the LCA, which is included in the Better Regulation Toolbox as tool number 58[3]. In each step of the policy development, LCA could be applied for different purposes, from problem identification up to policy evaluation (figure 4).

Indeed, life cycle assessment and life cycle based methodologies could be integrated in the policy cycle to support answering several key questions. Considering steps in policy cycle and current practice, LCA may be useful in supporting policy in different ways as reported in the Table 3.

Regarding policy anticipation and problem definition, LCA studies may present insights and warnings to be taken into account with relations to products and supply chains. for example, LCA has been the basis for the problem definition of the life cycle impact assessment in the communication "Building single market for green product" (EC 2013a); LCA studies demonstrated how some methodological choices in the application of LCA can strongly affect results and hamper a fair comparison between similar products, thus highlighting the need for a harmonized assessment methodology. Or, in the case of the construction sector, a life cycle perspective to the environmental impacts occurring in buildings brought to the attention of policy-makers the need to include also indicators associated to the manufacturing stage in the framework of core indicators for the assessment of environmental performance of building.

As far as the policy formulation step is concerned, results from LCA studies could be used to orient policy options, e.g. suggesting an overall approach focused on a LC stage or on a LC environmental impact. Moreover, environmental considerations based on LCT could suggest the adoption of requirements based on LCA indicators or support their identification, e.g. the calculation of emissions to air/soil/water or the total amount resources used throughout the life cycle (or for part of it). These requirements could be "generic", meaning that they do not establish a limit value but simply require for calculation, considering that the first step towards the improvement of environmental performances is the measurement. In other cases, LCA data could suggest a "specific" requirement, intended as a minimum performance level. Different requirements could be

[2] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Al10116
[3] http://ec.europa.eu/smart-regulation/guidelines/tool_58_en.htm

suggested/identified and used in the different policy options. LCA has been already used in the development of policy options.

Table 3: Main steps of the policy cycle and the possible use of LCA to support them.

Steps in the policy cycle	**Related possible questions in the impact assessment**	**Description**	**Current and possible use of LCA**
Policy anticipation and problem definition	What is the problem and why is it a problem?	Identification of emerging issues	LCA studies in scientific and grey literature, reporting "warnings" to be taken into account
Policy formulation	What are the various ways to achieve the objectives?	Definition of policy options	Policy options may: be based on LCA results (e.g. addressing a specific life cycle stage or relevant environmental impact, leading to impacts) to identify specific "hot spots" include some requirements based on LCA indicators (e.g. a life cycle based calculation) use LCA for identifying key elements to be monitored over time and, possibly, be standardize use LCA results to set a target
Policy impact assessment	What are their economic, social and environmental impacts and who will be affected? How do the different option s compare in terms of their benefits and costs?	Comparison of options	Supporting the comprehensive and systematic assessment of environmental aspects, and even beyond environmental aspects if including LCC and SLCA. LCA may spot impacts related to a number of different impact categories and may help avoiding shifting burden from one stage in the life cycle to another Complementary to risk assessment
Policy implementation		Country level implementation Compliance checks	If LCA indicators are used as requirements of the policy option, LCA studies will be needed
Policy evaluation	How will monitoring and retrospective evaluation be organized?	Effectiveness of the policy Evaluation of the need to revise (or phase out) the policy	Use of LCA for assessing the benefit of the policy (at macro scale) including systemic aspects Need of modifying/ repealing a legislation

Just to name few examples, LCA has been used in: i) the impact assessment of plastic bags directive where policy options has been based on tackling issue coming from a convergence of different LCA which were supporting prevention policy options (EC 2013b) ii) the Waste framework directive (EC 2008) where LCA is cited for justifying possible changes in the waste hierarchy, due to environmental concerns assessing waste management options (EC-JRC 2011a,b,c); iii) the Directive on renewable resources, there is an LCA based requirement on GHG reduction for Biofuels (EC, 2009b); iv) the Communication "Building single market for green product" where LCA is the reference methodology for product and organization assessment (CEC 2013a).

In the same way and at large scale, in the policy formulation step the need to set a target to be reached could be recognized. Thus, an LCA study could be launched to identify possible range and suggest different target options. It is important to highlight that the use of LCA may be fundamental for robust targets setting, as through the application of LCA it is possible to: i) assess environmental performance of representative products, helping in contribution analysis in terms of most important impact categories and most relevant life cycle stages implying an impact, as basis for setting the target; ii) avoid burden shifting over impact categories (increasing impact in an impact category while reducing the impact on another respecting a fixed target) and over life cycle stages (e.g. increasing impact in a life cycle stage when the target is focusing on another one); iii) run scenarios under specific assumptions in terms of production and consumption patterns to estimate impacts associated to possible future scenarios in which the target is achieved; iv) assess environmental impacts and benefits associated to the implementation of the targets (either as technological solution, behavioural change, infrastructural change).

The of use LCA to establish a minimum performance level or a target implies that LCA data have to be available and have to be of proper quality. The LCA community has been working for years in this direction promoting firstly, knowledge on LCA and LCA data sharing, secondly, further specifications for LCA application to specific products (Category Rules – CR), thirdly, data quality evaluation in relationship to specific requirements.

Regarding the step of the policy impact assessment, LCA may complement others methodology for evaluating environmental impacts. LCA may support the comprehensive and systematic assessment of environmental aspects, and even beyond environmental aspects if including Life Cycle Costing and Social LCA. Moreover, as previously said, LCA may spot impacts related to a number of different impact categories and may help avoiding burden shifting from one stage in the life cycle to another, assessing also future scenarios (De Camillis et al. 2013). In policy impact assessment, risk assessment approaches are usually adopted. The potential complementary to risk assessment is one of the key element for enhancing the use of LCA in the impact assessment step. As discussed by Cowell et al. 2002, a complementarity of RA and LCA is necessary to answer to different questions. Nonetheless, the two approaches differ on several aspects, including: philosophical approach; quantitative versus qualitative assessment; stakeholder participation; the nature of the results; and the usefulness of the results in relation to time and financial resource requirements, and comprehensibility of the results for non-specialists.

At this step of the policy cycle it is important to keep in mind that methodological choices can affect LCA results and, in turn, the outcome of options comparisons. Examples of key methodological aspects are the modelling approach and the LCIA method.

In relationship to the modelling approach, different visions exist. The ILCD Handbook recommends the use of a CLCA for those analysis intended to inform policy making and ALCA in case no decision has to be taken (Plevin et al. 2014a). Some authors (Zamagni et al. 2012) argue that CLCA is more useful for examining alternative scenarios to understand the range of potential environmental impacts rather than for predicting a single most-likely outcome. Some others (Plevin et al. 2014a) do not fully agree with the scheme proposed by the ILCD Handbook and recognize that the ALCA has a role (other than descriptive) in guiding normative considerations (how to equitably allocate impacts, costs and benefits), that it is useful as a diagnostic tool to perform sensitivity analysis and that it can reasonably provide information to aid in general decision making.

As far as the LCIA method is concerned, several LCIA methods exist, built on different LCIA models. In relation to this aspect, the ILCD Handbook (EC-JRC 2010-2012) provides method recommendations for the several impact categories; however, the study only include LCIA methods available in 2008. Moreover, studies are being conducted about the need/convenience to revise the scope of the Areas of Protections (AoP) the impact categories relate to, e.g. for the AoP "Natural Resources" where new and more comprehensive perspectives concerning "what has to be safeguarded" have been delineated (Dewulf et al. 2015). LCIA methods have been recently revised and updating proposals have been made (Sala et al. 2016b), including this aspect too.

The use of the LCA in the policy implementation step depends on policy options. At general level, policy options may be based on LCT/LCA results and/or may include some requirements based on LCA indicators. If LCA indicators are used as requirements of the policy option, LCA studies will be needed. For example, a complete LCA study may be requested before putting a certain product on the market, addressing one or more impact categories (environmental criteria); an LCA could be used to verify the compliance of a product with a specific requirement (minimum performance level) ; more LCA studies could be required to implement or further specify policy aspects such as the setting of a benchmark (national or European) for a specific product/service categories or to identify relevant environmental indicators for performance assessment.

Finally, in the step of the policy evaluation, LCA may be used for assessing the benefit of the policy (at macro scale) including systemic aspects and for spotting specific needs for modifying/repealing a legislation. For the latest, an example of use of LCA is the repeal of waste oil directive based also on a study reporting LCA evidences (EC, 2001).

4 Review of the use of LCT/LCA in existing policies

The environmental policy developed in the last 20 years is promoting integrated approaches. The overall aim of these policies is to promote the reduction of the environmental impacts (including resources use) and a use of resources that takes into account negative impacts associated to the use itself.

If we look at the history, we observe that the first policy promoting the LCT and Ecodesign arose from the waste management perspective and from the recognized relevance of consumers awareness. Following the request by the Council (Council resolution of May 7th 1990 on waste policy), the European Commission developed the Ecolabel regulation (CEC 1992) which has at his core the concept of life cycle environmental impact associated to products.

This concept was later strengthened by the Integrated Product Policy - IPP (CEC 2003). The IPP, recognizing the relevance of the dimension product in the achievements of environmental goals, promotes the LCA as the methodology to accounts for potential environmental impacts of products. In this context, the European Commission committed itself to provide knowledge and tools to support the use of the methodology and the provision of robust data. Here we can find the origin of ILCD Handbook and of the European Platform on LCA. Moreover, the IPP toolbox was created including all policies instruments to gradually greening the products and transforming the market (e.g. the green public procurement, the eco-label, standards, and so on).

In the last stage, the product dimension, has been integrated in policies addressing environmental issues at a larger scale such as the overall production and consumption patterns (the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan), the sustainable use of natural resources (the Thematic Strategy on the sustainable use of Natural Resources) or the quality of life within the limits of the planet (7th Environmental Action Programme), also recognizing the global dimension. About that, the Council Conclusions on sustainable material management and sustainable production and consumption (Council of the European Union 2010) have been significant as they acknowledge the work done by UNEP (UNEP International Panel for Sustainable Resource Management and 10 YFP on SCP) and OECD (SMM) to give a broad interpretation of resource efficiency, encompassing all natural resources, abiotic/biotic materials, water, air soil, living organisms, ecosystems and biodiversity and, to address resources productivity, environmental impacts and the management of limited resources.

The above mentioned policies built on initiatives till then undertaken such the Eco-Management and Audit Schemes (EMAS), the Eco-label Scheme, the Green Public Procurement (GPP), etc, and aim to optimizing efforts and increasing the coherence among all the initiatives put in place to decoupling the economic growth from environmental impacts. The life cycle thinking is at the core of these policies.

Figure 6 shows the number of environmental policies, since 1992 to 2015, where LCT/LCA has been integrated, whereas a list of the main EU policies addressing environmental issues is reported in tables 4-7, in subchapters from 4.1 to 4.4.

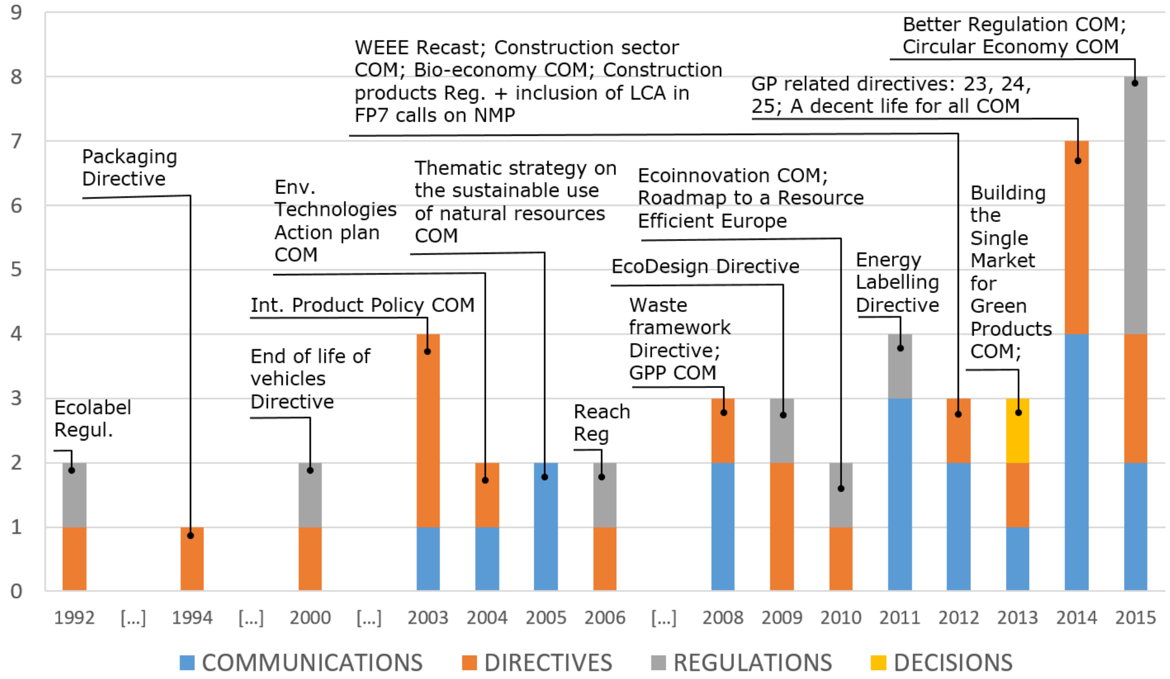


Figure 6: A selection of EU Environmental policies integrating LCT/LCA over time

It is important to underline that term policy is used for legislative acts by the EU Parliament and the Council (Regulations and Directives), for Decisions by the EU Parliament and the Council or by the Commission, for Communication from the Commission to the EU Parliament and the Council, for Recommendation by the Commission.

Tables include main policies approaching environmental issues at the highest level such as the Circular economy, the Sustainable Consumption and Production, or the Flagship initiative "Resources Efficient Europe", as well as policies addressing/integrating environmental concerns in relationship to a specific theme, product category or key strategic area (e.g. waste or use of natural resources, energy related products, construction), to emerging economies (e.g. the bio-economy) or to mechanisms/dimensions typical of the economy (public procurements, product dimension) with regard to specific categories too (e.g. the environmental technologies action plan whose main actions are i) getting from research to the market and ii) improving market conditions for environmental technologies). The list also reports the better regulation as it envisages the evaluation of environmental aspects linked to the policy being designed.

Tables show that the LCT is always adopted and most of the listed policies mention the consideration of environmental impacts along the whole life-cycle of products/service and/or LC based tools such as Ecolabel, EMAS for the policy implementation.

In some cases, there is the explicit mention of the LCA to implement or further specify the policy, for example in the communication on the resources efficiency opportunities in the building sector. In other cases, LC based methodologies (such as carbon footprint of environmental footprint) are mentioned for the future improvement of the policy, as for the End-of Life Vehicles (ELV)or Energy labelling Directives.

Sometimes, methodologies based on LC approach are mentioned for the evaluation of economic aspects, i.e. the LCC, namely in the policies concerning the public purchasing.

All these methodologies and tools are always integrated as policies implementation measures, aiming to:

- support informed choices by consumers (private and public) and to promoting the production and consumption of sustainable products/services (demand-offer),
- support the development of environmental technologies encompassing technologies and processes to manage pollution (e.g. air pollution control, waste management), less polluting and less resource-intensive products and services and ways to manage resources more efficiently (e.g. water supply, energy-saving technologies)
- further specify such policies aspects (e.g. priorities setting in waste management, core indicator selection for building environmental performance evaluation)
- support policy-making, namely the implementation of the recent Better Regulation.

4.1 Communications

15 Environmental policies are reported in the following table covering the period from 2013 to 2015 and including three important landmarks, namely the i) the Integrated Product Policy, which recognizes the relevance of product dimension to address environmental issues, ii) the Communication "Building the single market for green products, addressing the need for a harmonized methodology, iii) the Better Regulation, which appoints the LCT/LCA as one of the tools to ensure effective policies.

Table 4: Main EU environmental Communications integrating LCT/LCA

Policy initiative (Communications)	**Description of the policy and the use of LCT/LCA**	**Reference**
Integrated Product Policy - Building on Environmental Life-Cycle Thinking (COM(2003)302)	Integrated Product Policy (IPP) seeks to minimise environmental impacts by looking at all phases of a products' life-cycle and taking action where it is most effective. With so many different products and actors there cannot be one simple policy measure for everything. Instead there is a whole variety of tools - both voluntary and mandatory - that can be used to achieve this objective. These include measures such as economic instruments, substance bans, voluntary agreements, environmental labelling and product design guidelines.	CEC (2003)
Stimulating Technologies for Sustainable Development: An Environmental Technologies Action	Assessments of technologies should verify the technological performance and the claimed performance from an economic and environmental viewpoint, taking into account the whole life-cycle of the technology. Life cycle costing of technologies is also explicitly mentioned.	CEC (2004)

Policy initiative (Communications)	**Description of the policy and the use of LCT/LCA**	**Reference**
Plan for the European Union (COM(2004)38)		
Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste (COM(2005)666)	In order to secure a higher level of environmental protection, the proposal is to modernise the existing legal framework – i.e. to introduce life cycle analysis in policy making and to clarify, simplify and streamline EU waste law	CEC (2005a)
Thematic Strategy on the Sustainable Use of Natural Resources (COM(2005)670)	To have a higher impact in reversing unsustainable trends, containing environment degradation and preserving the essential services that natural resources provide, environment policy needs to move beyond emissions and waste control. It is necessary to develop means to identify the negative environmental impacts of the use of materials and energy throughout life cycles (often referred to as the cradle to grave approach) and to determine their respective significance. This should be done also capitalising on the existing policy framework: applying the life-cycle thinking to existing policies. Additionally, the communication mentions the possibility of using LCT within the Commission's integrated impact assessments, which consider the economic, social and environmental impacts of different policy options for major policy proposals.	CEC (2005b)
Sustainable Consumption and Production and Sustainable industrial policy Action Plan (COM(2008)397/3)	The Sustainable Consumption and Production Action Plan aims to reduce the overall environmental impact and consumption of resources associated with the complete life cycle of goods and services (products). The challenge is to create a virtuous circle: improving the overall environmental performance of products throughout their life-cycle, promoting and stimulating the demand of better products and production technologies and helping consumers to make better choices through a more coherent and simplified labelling.	CEC (2008a)
Public procurement for a better environment (COM(2008)400)	Green Public Procurement (GPP) is described as a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured.	CEC (2008b)
A resource-efficient Europe – flagship initiative under the	In the resource efficiency manifesto, one of the road map aims is to create better market conditions for goods and services that have lower impacts across their life-cycles,	CEC (2011a) and the related

Policy initiative (Communications)	Description of the policy and the use of LCT/LCA	Reference
Europe 2020 (COM(2011)21) Roadmap to a resource efficient Europe (COM(2011)571)	and that are durable, repairable and recyclable, progressively taking the worst performing products off the market. Transforming the economy onto a resource-efficient path will bring increased competitiveness and new sources of growth and jobs through cost savings from improved efficiency, commercialisation of innovations and better management of resources over their whole lifecycle. Changing the consumption patterns of private and public purchasers will help drive resource efficiency and can also frequently generate direct net cost savings. In turn it can help increase demand for more resource efficient services and products. Accurate information, based on the life-cycle impacts and costs of resource use, is needed to help guide consumption decisions. Life cycle approach should support the protection of natural capital (ecosystem services, biodiversity, mineral and metals, water, land and soil and marine resources) and should be applicable on different sectors, especially in the key sectors envisaged by the roadmap (food, buildings and mobility).	roadmap CEC (2011b)
Strategy for the sustainable competitiveness of the construction sector and its enterprises (COM(2012)433)	One of the basic requirements for construction works set in EU regulation (EC, 2011) state that the construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition. Moreover, in the strategy for the sustainability of the building sector (CEC 2012a), a coherent and mutually recognized interpretation of the performances through harmonized indicators is advocated. In the communication, the Commission committed to propose approaches to mutual recognition or harmonisation of the various existing assessment methods, also with a view to making them more operational and affordable for construction enterprises, the insurance industry and investors. This initiative can build on existing platforms, such as the CEN Construction Network, guides such as the JRC's guide to Life Cycle Thinking and Assessment (also LCC is mentioned).	CEC (2012a)
Innovating for Sustainable Growth: A bio-economy for Europe (COM(2012)60)	In the Communication on Bioeconomy, actions are set towards the enhancement of bioeconomy markets and competitiveness. This requires providing the knowledge-base for sustainable intensification of primary production; improving the understanding of current, potential and future availability and demand of biomass (including agricultural and forestry residues and waste) across sectors, taking into account added value, sustainability, soil fertility and climate mitigation potential; supporting the	CEC (2012c)

Policy initiative (Communications)	Description of the policy and the use of LCT/LCA	Reference
	future development of an agreed methodology for the calculation of environmental footprints, e.g. using LCA.	
Building the single market for green products (COM(2013)196) Commission recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental (Recommendation 2013/179/EU)	The initiative Building the Single Market for Green Products intends to address 4 key points: i) the lack of a common definition of what green products/organizations are, ii) the unnecessary costs for businesses arising from the proliferation, from both private and public, of several footprint methods and the consequent need to use more than one method and to comply with different requirements for different countries/retailers, iii) the remove of obstacle to free trade within EU, iv) the lack of trust in green claims by consumers. In this initiative, the Commission, among all: • invites Member States (MS) to use of the harmonized LCA methodology (PEF and OEF, as defined in the Recommendation 2013/179/EU) in national policies/initiatives concerning the assessment and communication of the environmental performances of products and organizations respectively, committing itself in the gradual integration of the methodologies in EMAS, GPP and Ecolabel. • establishes principles for communicating LC environmental performances • launches a three year testing phase, to make easier the application of the harmonized LCA methodology and to further specify its application/communication aspects. The harmonized LCA methodology for products and organizations is specified in the Recommendation 2013/179/EU (which is adopted in parallel to this initiative) and builds on the Commission's previous work (ILCD Handbook) and existing LCA approach and standards.	CEC (2013a), CEC (2013b)
Resource efficiency opportunities in the building sector (COM(2014)445)	This initiative intends to promote a more efficient use of resources consumed by new and renovated commercial, residential and public buildings and to reduce their overall environmental impacts throughout the full life cycle. The LCT has been used to target the problem. Energy consumption during manufacturing stage (manufacture of products and building construction process) has been compared to energy consumption during the building operation stage, highlighting the important weight of the former too. The direct link between the design for reducing life-cycle environmental impacts and consequent economic benefits in operation/maintenance stage are also at the base of this communication. In consistency with the objective declared in the Roadmap	CEC (2014)

Policy initiative (Communications)	Description of the policy and the use of LCT/LCA	Reference
	to resources efficient Europe and with the sector challenges/needs as defined in the Strategy for Sustainable Competitiveness of the Construction Sector and its Enterprises (resources efficiency and mutual recognition/harmonization of various existing assessment methods), the Communication explicitly refers to the LCA (harmonized, COM(2013)179) as method to produce reliable, transparent and comparable data enabling professional, decision makers and investors to use life-cycle aspects throughout EU. These data will have to be based on a common (and flexible) framework of indicators relevant for this specific sector and able to allow for a common approach in the assessment of Environmental Performance of buildings. Key investigation areas to set the framework are for example energy use (operational energy and embodied energy of products/construction process), material use and embodied environmental impacts, etc.	
Closing the loop – An EU Action Plan for the Circular Economy (COM(2015)614)	The action plan focusses on action at EU level with high added value for the transition to a more circular economy, i.e. where the value of products, materials and resources is maintained in the economy for as long as possible and the generation of waste is minimised. The set of proposed actions builds on a life cycle perspective. The resource efficiency is tackled considering production, consumption, waste management and recycling (waste to resources), key areas are identified (e.g. plastics, food waste, critical raw material, etc) and research & innovation are stressed as new technologies, processes, services and business models will be necessary to speed the transition. LCA (in particular the PEF, currently under testing) is mentioned as a methodology whose use will be explored for the measurement/communication of environmental information. LC based scheme and label (namely, Ecolabel and EMAS) are explicitly mentioned as implementation measures to promote production and consumption.	CEC (2015a)
Better Regulation for better results – An EU Agenda (COM(2015)215)	The Better Regulation communication define a precise way of working to ensure that political decisions are prepared in an open, transparent manner, informed by the best available evidence and backed by the comprehensive involvement of stakeholders. Better Regulation covers the whole policy cycle – policy design and preparation, adoption; implementation (transposition, complementary non-regulatory actions), application (including enforcement), evaluation and revision. The package includes the Better Regulation Toolbox including LCT/LCA as a tool for implementing the Better Regulation (through environmental data and indicators, or through economic/social and sustainability assessment/analysis	CEC (2015b)

Policy initiative (Communications)	Description of the policy and the use of LCT/LCA	Reference
	based on LCT).	

4.2 Directives

This section includes 8 EU Directives released from 2000 to 2014. It includes Directives concerning the procurement (public procurement, award of concession of contracts, and procurement in special sector such as water, energy, etc) and Directives concerning the key themes such as Waste, with the so called Waste Framework Directive and the End-of-Life Directive, and Energy, with Directives related to renewable energy, biofuels and energy related products.

Table 5: Main EU environmental Directives integrating LCT/LCA

Policy initiative (Directives)	Description	Reference
End of Life Vehicle Directive (2000/53/EC)	The Directive lays down measures which aim, as a first priority, at the prevention of waste from vehicles and, in addition, at the reuse, recycling and other forms of recovery of end-of life vehicles and their components so as to reduce the disposal of waste, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles and especially the operators directly involved in the treatment of end-of life vehicles. Priorities, obligations and minimum technical requirements are provided relevant to manufacturing, collection, treatment and reuse and recovery stages. An ex-post Evaluation of this directive was performed in 2014, in the frame of a wider fitness check study including overall 5 Waste stream Directives. In this study, the LCA is mentioned to assess composite materials and complex electronic systems used in modern vehicles and, in turn, to evaluate the review of recycling and recovery targets. In fact, the use of these technologies pose challenges in maintaining the overall reuse, recycling and recovery rates of ELVs.	EC (2000)
Promotion of the Biofuels and other renewable fuels for transport (2003/30/EC)	This Directive aims at promoting the use of biofuels or other renewable fuels to replace diesel or petrol for transport purposes in each Member State, with a view to contributing to objectives such as meeting climate change commitments, environmentally friendly security of supply and promoting renewable energy sources. The Directive asks to MS to make available on their market a minimum proportion of biofuels and other renewable fuels, in different forms (pure, blended, etc), to monitor certain aspects of their use and, in general, to adopt measures considering the overall climate and environmental	EC (2003)

Policy initiative (Directives)	Description	Reference
	balance of the different biofuels. A life cycle perspective is mentioned for use in the report that the Commission has to draw up every two years (since 2006) to evaluate the progress in the use of biofuels and other renewable fuels.	
Waste and repealing certain directive (Waste framework Directive - WFD) (2008/98/EC)	The WFD revises previous Directive 2006/12/EC aiming at: clarifying key concepts like the waste hierarchy; strengthening the measures that must be taken in regard to waste prevention; introducing an approach that takes into account the whole life-cycle of products and materials and not only the waste phase; and focusing on reducing the environmental impacts of waste generation and waste management, thereby strengthening the economic value of waste. In Article 4(2) it opens to potential deviations from the waste hierarchy for specific waste streams "where this is justified by life cycle thinking on the overall impacts of the generation and management of such waste". Moreover, the introduction of extended producer responsibility in this Directive is one of the means to support the design and production of goods which take into full account and facilitate the efficient use of resources during their whole life-cycle including their repair, re-use, disassembly and recycling without compromising the free circulation of goods on the internal market.	(EC, 2008)
Promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (2009/28/EC)	This Directive establishes a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. It lays down rules relating to statistical transfers between Member States, joint projects between Member States and with third countries, guarantees of origin, administrative procedures, information and training, and access to the electricity grid for energy from renewable sources. Finally, the Directive establishes sustainability criteria for biofuels and bioliquids. They concern the minimum GHG emission saving potential and origin of biofuels/bioliquids. The methodology used to account for GHG emission saving is based on Life Cycle approach as it takes into account all phases from extraction/cultivation to use.	EC (2009a)
Establishing a framework for the setting of ecodesign requirements for energy-related products (2009/125/EC)	The Ecodesign Directive provides with consistent EU-wide rules for improving the environmental performance of energy related products (ERPs) through Ecodesign. In the directive is stated that action should be taken during the design phase of energy-related products, since it appears that the pollution caused during a product's life cycle is determined at that stage, and most of the costs involved are committed then. Moreover, the exchange of information on environmental life cycle performance and on the achievements of design solutions should be facilitated.	EC (2009b)
Indication by	In the directive text is stated that when the Commission	(EC, 2010b)

Policy initiative (Directives)	Description	Reference
labelling and standard product information of the consumption of energy and other resources by energy-related products (2010/30/EC)	reviews progress and reports on the implementation of the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan in 2012, it will, in particular, analyse whether further action to improve the energy and environmental performance of products is needed, including, inter alia the possibility to provide consumers with information on the carbon footprint of products or the products' environmental impact during their life cycle.	
Award of concession of contracts Directive (2014/23/EC)	The Directive establishes rules on the procedures for procurement by contracting authorities and contracting entities by means of a concession, whose value is estimated to be not less than 5.186.000 Euro (threshold). The Directive, with the aim of better integrating environmental and social considerations in the awarding procedures, says that "contracting authorities or contracting entities should be allowed to use award criteria or concession performance conditions relating to the works or services to be provided under the concession contract in any respect and at any stage of their life cycles from extraction of raw materials for the product to the stage of disposal of the product, including factors involved in the specific process of production, provision or trading of those works or services or a specific process during a later stage of their life cycle, even where such factors do not form part of their material substance".	(EC, 2014a)
Public procurement and repealing Directive 2004/18/EC (2014/24/EC)	This Directive establishes rules on the procedures for procurement by contracting authorities with respect to public contracts as well as design contests, whose value is estimated to be not less than specific thresholds (differentiated in function of contracting authorities/entity and for object – supplies, works, services). Pursuing the main aim of open competition as well as sustainability objectives, the Directive refers to LCT namely, specifies that technical specifications should be drawn up to make possible the submission of tenders reflecting the diversity of technical solutions standards and technical specifications in the marketplace including those drawn up on the basis of performance criteria linked to the life cycle and the sustainability of the production process (of the works, supplies and services) are explicitly mentioned. The Life Cycle Costing (LCC) is mentioned as a methodology that contracting authorities can use to identify the most economically advantageous tender.	(EC, 2014b)
Procurement by entities operating in the water, energy, transport and postal services sector	This Directive establishes rules on the procedures for procurement by contracting entities with respect to contracts as well as design contests, whose value is estimated to be not less than specific thresholds (differentiated for object – supplies and services contracts as well as design context), works contracts, service contracts for social and other specific	(EC, 2014c)

Policy initiative (Directives)	Description	Reference
(2014/25/EC)	service. As the Directive 2014/24/EC, also this Directive state that performance criteria linked to the life cycle and the sustainability of production process should be included in the technical specification with the final aim of pursuing open competition and sustainability objectives. In the same way, the Directive refers to the LCC as a possible methodology for the identification of the most economically advantageous tender.	

4.3 Regulations

In this section 4 main Regulations are included relating to the period from 2006 to 2014. They concern two key sectors, namely Construction and Chemicals, the scheme for setting/reporting organization environmental management, the schemes for the qualification of reduced environmental impact products.

Table 6: Main EU environmental Regulations integrating LCT/LCA

Policy initiative (Regulations)	Description	Reference
REACh Regulation on Chemicals (Regulation No 1907/2006)	Risk assessment and management of chemicals has been set integrating life cycle thinking. In fact, in the regulation, risk management measures should be applied to ensure, when substances are manufactured, placed on the market and used, that exposure to these substances including discharges, emissions and losses, throughout the whole life-cycle is below the threshold level beyond which adverse effects may occur. The chemical safety assessment shall consider the use of the substance on its own (including any major impurities and additives), in a preparation and in an article, as defined by the identified uses. The assessment shall consider all stages of the life-cycle of the substance resulting from the manufacture and identified uses. While LCA or LCT are not explicitly mentioned in REACh, this can be seen as introducing aspects of life cycle thinking to the regulation of chemicals.	EC(2006)
EMAS - Community eco-management and audit scheme (Regulation No 1221/2009)	The EMAS III regulation prescribes that for non-industrial organisations, such as local authorities or financial institutions, it is essential that they also consider the environmental aspects associated with their core business. These include, amongst others, product life cycle related issues (design, development, packaging, transportation, use and waste recovery/disposal).	EC (2009b)
EU Ecolabel (Regulation No 66/2010)	Since Regulation (EC) No 880/1992 and subsequently Regulation No 1980/2000 on a revised Community eco-label award scheme, the EU aims at establishing a voluntary ecolabel award scheme intended to promote products with a reduced environmental impact during their entire life cycle and to provide consumers with accurate, non-deceptive, science-based information on the environmental impact of products. This Regulation lays down rules for the establishment and application of the voluntary EU Ecolabel scheme. Among all, the Regulation states that EU Ecolabel criteria shall be determined on a scientific basis considering the whole life cycle of products.	(EC, 2010a)

Harmonized condition for the marketing of construction products and repealing Council Directive 89/106/EEC (Regulation No 305/2011)	This Regulation lays down conditions for the placing or making available on the market of construction products by establishing harmonized rules on how to express the performance of construction products in relation to their essential characteristics and on the use of CE marking on those products. One of the basic requirements for construction works set in EU regulation (EC, 2011) states that the construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition.	EC (2011)

4.4 Decisions

Finally, this section includes the landmark documents in 2012-2013, concerning the general European Environment Action Programme, i.e. the proposal and the final programme.

Table 7: Main EU Decisions integrating LCT/LCA

Policy initiative (Decisions)	**Description**	**Reference**
Proposal for Decision of the EU Parliament and of the EU Council on a General Union Environmental Action programme to 2020 "Living well, within the limits of our planet (COM(2012)710) General Union Environment Action Programme to 2020 "Living well, within the limits of our planet" (1386/2013/EU)	The Communication propose the adoption of a General Union Environment program to 2020 in order to step up the contribution of environment policy to the transition towards a resource-efficient, low-carbon economy in which natural capital is protected and enhanced, and the health and well-being of citizens is safeguarded. In the following Decision (No. 1386/2013/EU) a life cycle perspective is used and policies addressing life cycle aspects/impacts of products are announced to be reviewed. In particular, it is stated that measures will be taken to further improve the environmental performance of goods and services on the EU market over their whole life cycle through measures to increase the supply of environmentally sustainable products and stimulate a significant shift in consumer demand for these products. This will be achieved using a balanced mix of incentives for consumers and businesses, including SMEs, market based instruments and regulations to reduce the environmental impacts of their operations and products. Moreover, existing product legislation such as the Ecodesign and Energy Label Directives and the Ecolabel Regulation will be reviewed with a view to improving the environmental performance and resource efficiency of products throughout their lifecycle, thus ensuring a more coherent framework for sustainable production and consumption in the EU.	CEC (2012b), CEC (2013c)

5 LCA for the impact assessment of policies

LCA may be implemented to support the comparison of options in the impact assessment of policies. This section intends to provide further analysis on the use of LCA at impact assessment level, being a crucial step in preparing evidence and providing transparency on the benefits and costs of policy choices. To this aim, in the following sub-chapters the procedure for the impact assessment of policies and the added value of LCA use at this step are explained.

5.1 The impact assessment of policies and the related steps

The Better regulation guidelines establishes key requirements for the conduction of IA of policies among which: i) IAs must set out the logical reasoning that links the problem (including subsidiarity issues), its underlying drivers, the objectives and a range of policy options to tackle the problem (presenting the likely impacts of these options, who will be affected by them and how); ii) Stakeholders must be able to provide feedback on the basis of an Inception Impact Assessment which describes the problem, subsidiarity related issues, objectives, policy options and an initial consideration of relevant impacts of these policy options; iii) IAs must compare the policy options on the basis of their economic, social and environmental impacts (quantified as far as possible) and present these in the IA Report.

In the policy impact assessment different policy options are evaluated and compared in order for the policy makers to have better information for the political decision and implementation. The impact assessments of policies are presented in the Staff Working Document (SWD) on the base of a homogenous structure including the following sections:

- **Procedural issues and consultation of interested parties**. It includes the background and the previous work done on the topic trying to solve the question: what is the problem and why is it a problem?
- **Problem definition**. Herein the nature and extent of the problem are explained, including the baseline scenario and the subsidiarity. Why should the EU act?
- **Policy objectives**. General and specific objectives must be clearly identified as well as the criteria to assess all policy options. What should be achieved?
- **Policy options**. What are the various options to achieve the objectives? Available options are identified and explained with a view to selecting the most relevant ones. These options include the no further action, "do nothing" or no change option (also called the business as usual, baseline or *status quo* option).
- **Analysis of impacts**. What are the impacts of the different policy options and who will be affected? This section should include the methodology, scenarios and limitations. Some options can be a combination of previous options. At the end of the analysis, all potential impacts – positive and negative – should be mapped including the economic, social and environmental dimensions and who will be affected. The result of this analysis should give a solid understanding of the extent to which option achieves the objectives, with what benefits and at what costs, with what implications for different stakeholders and at what risk of unintended consequences.
- **Comparison of policy options**. How do the options compare? Based on the results and evidences shown in the previous section the different options are compared with regard to their effectiveness, efficiency and coherence, as well as their compliance with the proportionality principle. Then some of will be discarded and some others will be proposed as the most preferable solutions. The IA result can indicate that no (further) EU policy response is needed or that no single preferred option is put forward (because trade-offs exist between different impacts).
- **Future monitoring and evaluation**. How would actual impacts be monitored and evaluated? This section should identify monitoring and ex-post evaluation

arrangements to track whether the policy measure actually delivers the intended results and to inform any future revisions of the policy.

The draft of the IAs or the SWD summarising major evaluation must be submitted to the Regulatory Scrutiny Board for the Quality check.

5.2 LCA added value when applied for the impact assessment of policies

The LCA plays a major role in the IAs of policies when multiple dimensions of impacts should be addressed (integrated assessment). Some LCA elements are particularly relevant for addressing sustainability problems:

1. the life cycle perspective: all phases ("from the cradle to the grave") of the life cycle of a product (good or service) are assessed with regard to all relevant material and energy flows, from the extraction and processing of the resources, production and further processing, distribution and transport, use and consumption to recycling and disposal and, this may be done covering complex supply chains (figure 6);
2. identification of the most important burdens and most relevant life cycle stages contributing to environmental and social impacts (material extraction, manufacturing, use phase etc.) and, identification of environmental (and social) "hot spots" of goods/ services/ systems/ technologies/ innovations/ infrastructures (e.g. material, component, process) (figure 7);
3. identification of unintended burdens shifting between environmental impacts (reducing one impact while increasing another) and over life cycle stages (e.g. reducing impact in the end of life while increasing the impact in the use phase) (figure 8); this also applies for social aspects, if Social Life Cycle Assessment (SLCA) is used;
4. cross-media environmental approach in which relevant environmental impacts are taken into account, i.e., both on the input side (use of resources) and on the output side (emissions into air, water and soil, including waste and physical impacts);
5. running scenarios under specific assumptions in terms of production and consumption patterns to estimate impacts associated with current and possible future scenarios;
6. ensuring consistency and a systemic approach in the evaluation of impacts.

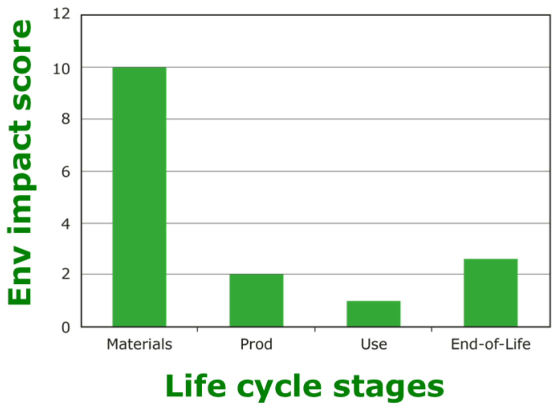


Figure 7: Example of LCA results. Impacts can be presented with different disaggregation level (for single material/component/ and/or for single impact categories)

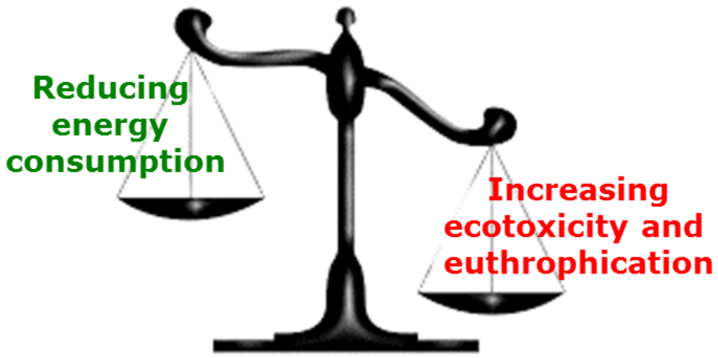


Figure 8: Example of burden shifting related to an intervention: it is possible that while reducing impacts associated to energy consumption (e.g. in a more energy efficient product) unintended additional burdens on the environment are caused (e.g. using substance in the product, which may lead to ecotoxicity or eutrophication)

In order to better understand the benefits arising from the use of LCT/LCA in the IA, an analysis of SWD has been performed (table 8), including mainly SWDs from the Energy, Climate action and Environment topics in the last 5 years.

These documents have been analysed in order to understand if the LCT/LCA has been used to address environmental issues. Moreover, the contexts where LCA could play a role or, its use could be enhanced have been highlighted in the last column.

Several situations exist. Sometimes LCT and LCA are neither used nor mentioned, as in the IAs concerning the Climate Change topic. Few cases present the application of LCT limited to the LCC. In few SWDs the LCA is mentioned as potential implementation measure whereas in other cases LCA studies are used to set and assess options.

Table 8: Main SWDs from the Energy, Climate action and Environment topics in the last 5 years

Year	Topic	IA reference	Commission Proposal	Use of LCA[4]	Comments and Potential role of LCA
2016	Climate action	SWD (2016) 249	Proposal for a Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry into the 2030 climate and energy framework and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change	NO	The inclusion of advanced A-LCA and in particular the use of dynamic CO_2 emission profiles might change the "accounted" emissions and removal in LULUCF. While reporting concerns an inventory of all emissions and removals, accounting aims to identify those which are human induced and the result of additional action.
		SWD (2016) 247	Proposal for a Regulation on binding annual greenhouse gas emission reductions by	NO	

[4] Explicit mention/use of LCT applied to environmental pillar and/or LCA

Year	Topic	IA reference	Commission Proposal	Use of LCA[4]	Comments and Potential role of LCA
			Member States from 2021 to 2030 for a resilient Energy Union and to meet commitments under the Paris Agreement and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change.		
2015	Climate action / energy	SWD (2015) 135	Proposal for a Directive amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments.	NO	Concerning the allocation modalities for carbon leakage, some stakeholders claim that additional criteria should be introduced being the carbon footprint along the whole LCA one of them since they have an overall positive carbon footprint saving more energy and GHG emissions than used in the manufacturing phase. The inclusion of LCA criteria may move those industries or sectors from a lower to a higher free allocation (%) group.
	Energy	SWD (2015) 139	Proposal for a Regulation setting a framework for energy efficiency labelling and repealing Directive 2010/30/EU	NO	In all the IA concerning Ecodesign or energy efficiency, LCC is always used since the Ecodesign Directive requires minimum requirements on product energy efficiency to be established at the level of Least LCC (LLCC) from the point of view of the end-user, meaning the level at which the combined purchase and running costs (energy, maintenance, disposal, etc.) of a product are the lowest.
		SWD (2015) 90	Commission Regulation implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for local space heaters (LSH)	YES	Since this IA concerns Ecodesign, LCC appears as the Least LCC for the minimum requirements of the products. This IA tries to promote market take-up of energy –efficient LSH with low PM, OGC (organic gaseous carbon) and CO emissions. Annex 9 includes environmental impacts of LSH

Year	Topic	IA reference	Commission Proposal	Use of LCA[4]	Comments and Potential role of LCA
					over product life cycle, including 15 impact categories divided in 5 phases including end-of-life. A more extended analysis of those LCA (with total quantities instead of relative) could be relevant for promoting one of the products or highlight hotspots.
2014	Agriculture and Rural Development	SWD (2014) 28	Proposal for a Regulation amending Regulation (EU) No 1308/2013 and Regulation (EU) No 1306/2013 as regards the aid scheme for the supply of fruit and vegetables, bananas and milk in the educational establishments	YES	Under one of the options, MSs continue to be encouraged to take into account environmental considerations when choosing the list of products to be distributed (such as seasonal or organic products). And this goes beyond giving stronger orientation towards the distribution of products coming from local purchasing, short supply chains and local markets that may have positive environmental impacts. In order to know which supply chain present better environmental impacts, LCA studies could be definitive.
2014	Climate Action	SWD (2014) 296	Proposal on a Directive on laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels.	YES	This IA tries to establish a methodology for fuel suppliers to report as accurately as possible the life-cycle greenhouse gas emissions, covering all relevant stages including extraction, land-use changes, transport and distribution, processing and combustion, irrespective of where those emissions occur, of the fuel and energy other than biofuels that they supply. The choice of methodology is critical in determining the accuracy of the reported carbon intensity of the fuels being supplied. Environmental impacts of fossil fuels must refer to the LCA or to Well-to-wheels (WTW) which is a LC-based methodology.

Year	Topic	IA reference	Commission Proposal	Use of LCA[4]	Comments and Potential role of LCA
2014	Climate Action	SWD (2014) 160	Communication - Strategy for reducing Heavy-Duty Vehicles' fuel consumption and CO_2 emissions.	YES	WTW and tank-to-wheel (TTW) emissions are calculated. An LCA considering other impact categories might show possible burden shifts.
2014	Climate Action	SWD (2014) 15	Communication: A policy framework for climate and energy in the period from 2020 to 2030	NO	LCA could help enlarging the analysis done in the scenarios assessed far beyond GHG emissions and energy efficiency. In this way possible burden shifts could be detected.
2014	Environment	SWD (2014) 289	Proposal for a Directive of the European Parliament and of the Council amending Directives 2008/98/EC on waste, 94/62/EC on packaging and packaging waste, 1999/31/EC on the landfill of waste, 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment	YES	In the Annex 12: An overview of the European reference model on waste, the life cycle approach used in the model considers only the climate change impacts through the Global Warming Potential (GWP) of each treatment method. Then, when setting the EU targets for food waste prevention, the calculated savings over the business as usual are presented as tons of food waste, km^2 of land and tons of CO_2 eq. This could be clearly enlarged with other impact categories really relevant when talking about food waste.
2014	Environment	SWD (2014) 21	Communication: Exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing in the EU	YES	In this IA, different hypothetical LCA studies are used to show the potential risks of air pollution and Greenhouse gas (GHG) emissions achieving the conclusion that "Unless properly mitigated, the GHG emissions per unit of electricity generated from shale gas would be around 4% to 8% higher than for electricity generated by conventional pipeline gas from within Europe" .
2014	Industry and entrepreneurship	SWD (2014) 222	Commission Regulation implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign	YES	Since this IA concerns Ecodesign, LCC appears as the Least LCC for the minimum requirements of the products. This IA tries to develop a policy

Year	Topic	IA reference	Commission Proposal	Use of LCA[4]	Comments and Potential role of LCA
			requirements for ventilation units		to reduce energy consumption and related CO_2 and pollutant emissions due to ventilation units. LCA is used to highlight the environmental impact of the use phase of ventilation units including 14 impact categories. It is shown that the use phase has a relative significant impact on almost all impact categories being highlighted by the IA heavy metals emissions, eutrophication and persistent organic pollutants, albeit it is said that the absolute impacts for these impact categories is low. Absolute values may help to see the real hotspots in the life cycle of ventilation units.
2013	Environment	SWD (2013) 444	Proposal for a Directive amending Directive 94/62/EC on packaging and packaging waste to reduce the consumption of lightweight plastic carrier bags	YES	LCA is used as evidence for selecting the options to put forward. In section 3: description of policy option, it says: "In light of the environmental impacts of single-use plastic carrier bags referred to in the problem definition and the LCA evidence reviewed, the options put forward will focus on prevention measures targeting single-use plastic carrier bags (both non-biodegradable and biodegradable)"
2013	Environment	SWD (2013) 111	Communication from the Commission to the European Parliament and the Council - Building the Single Market for Green Products: Facilitating better information on the environmental performance of products and organisations	YES	LCA appears in the background section of the problem definition. The problem is that there is a proliferation of methodologies that hampers the functioning of the market of green products. The objective of the EU action is to improve the availability of reliable information on the environmental performance of products and organizations. Options try to include LCA and PEF
2012	Energy	SWD (2012) 419	Commission Regulation implementing Directive 2009/125/EC of the European	YES	Since this IA concerns Ecodesign, LCC appears as the Least LCC for the minimum

Year	Topic	IA reference	Commission Proposal	Use of LCA[4]	Comments and Potential role of LCA
			Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment		requirements of the products. This IA tries to develop a policy to reduce energy consumption and related CO_2 and pollutant emissions due to DLS. LCA is used to highlight the environmental impact of the use phase of DLS including 14 impact categories. It is shown that for dust and eutrophication, the impact in the end-of-life phase is comparable to that in the use phase. Absolute values may help to see the real hotspots in the life cycle of DLS.
2012	Energy/Climate action	SWD (2012) 343	Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.	YES	The LCT is the base of all policy options aiming to simultaneously ensure sustainability of biofuels and reduce life cycle greenhouse gas emissions (up to 10 %) per unit of energy from fuel and energy supplied. An LCA study (covering more impact categories) could allow the identification of possible burden shifts.

5.2.1 Example of LCA applied to energy policies

To better understand what benefit the LCA could provide, if used in the IAs (and its potential), an example is here provided. The Directive 2009/28/EC on the promotion of the use of energy from renewable sources (the "Renewable Energy Directive" - RED) and the Directive 98/70/EC (the "Fuel Quality Directive" – FQD) are analysed more in detail. These directives impose diverse targets towards which the contributions from biofuels are supposed to be significant: the RED established mandatory targets to be achieved by 2020 for a 20% overall share of renewable energy in the EU and a 10% share for renewable energy in the transport sector. In the same line, the FQD introduced a mandatory target to achieve by 2020 a 6% reduction in the greenhouse gas intensity of fuels used in road transport.

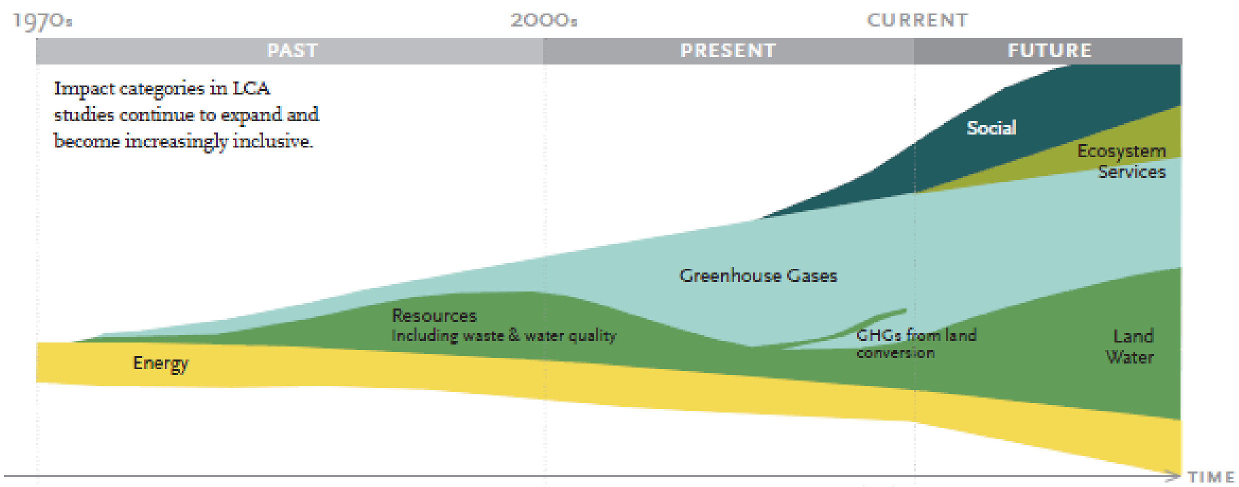
These directives require biofuels to achieve minimum greenhouse gas emissions savings of 35% compared to fossil fuels (progressive increasing to 50% in 2017 and 60% in 2018 for new installations). Moreover, they impose a number of sustainability criteria aimed at preventing the conversion of land characterized by high carbon stock and high biodiversity for biofuel production.

LCT is present in those directives since the required reductions can be achieved along the whole life cycle of the fuel or energy produced (including all relevant stages, from extraction or cultivation, including land-use changes, transport and distribution, processing and combustion, irrespective where those emissions occur). An LCT-based methodology is specified (ANNEX V, EC 2009) to estimate alternative energy production systems' reductions in GHG emissions. Default values of LC-GHG emission saving are provided for biofuels and bio-liquids. Moreover, a formula is provided to account for GHG emission in the transport sector. These methodologies are the base to define the National Renewable Energy Action Plan, in particular, to: (i) assess and compare the different set of measures (e.g. support schemes) proposed by the plan, and (ii) verify the extent to which the proposed measures achieve the targets established by the Directives.

The analysed policy-framework focuses on Climate Change and attempts to standardize the accounting of GHG emission. However, transposition of the RED into national legislation might still result in diverse application of allocation methods due to differences in interpretations, and so different results will be obtained for the same value chain (Wardenaar et al. 2012). In Europe, a lot of effort has been done to harmonize the calculation of GHG emission related to bioenergy, including the set of voluntary international schemes[5] to help in the calculation.

There have been several policy proposals and IAs always focused on the specific requirement related to GHG emissions (e.g. the Directive UE/2015/1513 and the analytical work behind, SWD (2012) 344, based on a consequential LCA and considering impacts from Indirect Land Use Change; the proposal for a regulation on the inclusion of emissions/removals from Land Use, Land Use Change and Forestry in the 2030 climate and energy framework and amending Regulation No 525/2013, supported by the SWD(2016)249; the proposal for a Regulation on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 for a resilient Energy Union and to meet commitments under the Paris Agreement and amending Regulation No 525/2013, supported by SWD (2016) 249) but not considering any wider environmental and social impact associated with the promotion of biofuels.

All potential impacts should be considered (several environmental impact categories) as far as possible in a holistic and integrated manner for a complete impact assessment. The inclusion of LCA studies of different bioenergy value chains which integrate a high number of impact categories (as shown in figure 9, the number and range of impact categories considered in LCA studies is expanding) could highlight possible burden shifts between impacts, parts of the life cycle and even in terms of spatial and temporal resolution. These studies could be useful to detect certain warnings that will need to be considered in case a policy is designed to promote the use of any bioenergy value chain that fulfil the actual sustainability requirements (mainly focused on the GHG emission reduction).



5 There is an official list of recognized voluntary schemes approved by DG Energy (http://www.biograce.net/content/ghgcalculationtools/recognisedtool/)

Figure 9: Evolution of impact categories number and range in LCA studies (Simplified starting from the figure in McManus and Taylor 2015, The briefing [6]).

To further clarify the example, a JRC study is extracted from Giuntoli et al. (2015). In this study three pathways to produce 1 MJ of useful thermal energy are studied: loose residues burned in a log-stove, a district heating plant utilizing forest chips and a domestic stove fuelled with wood pellets. Those bioenergy systems are analysed, following the approach applied in the RED for GHG emissions, focusing on the impacts of the whole value chain and comparing them to a fossil reference value chain system using natural gas (NG). The environmental impact categories analysed are global warming (figure 10), acidification, particulate matter and photochemical ozone formation (figure 11). As shown in figure 10, all three bioenergy pathways using forest logging residues comply with the 60% GHG savings threshold (comparing to NG pathway) established in the RED directive and with the 70% threshold proposed by the SWD(2014)259 concerning the sustainability criteria of solid and gaseous biomass and supporting the updating of the RED Directive.

Nevertheless, when looking a figure 11, these same three bioenergy systems have higher environmental impacts associated with local pollution than the natural gas (NG) alternative. Furthermore, several additional environmental risks are known to be associated with the removal and use of forest logging residues for bioenergy concerning mostly biodiversity loss and, mainly for stumps removal, physical damage to forest soils.

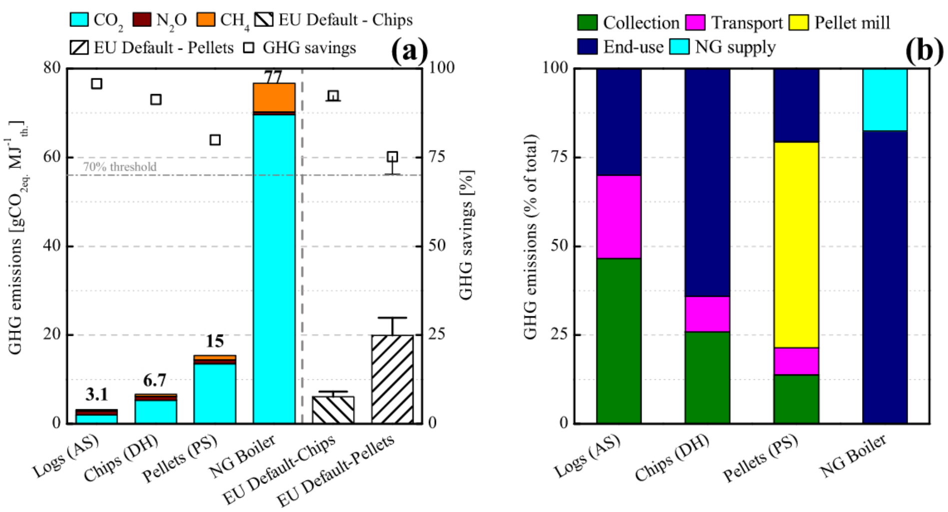


Figure 10: GHG emissions of the three bioenergy pathways. Comparison in terms of GHG emissions with NG, Default chips and pellets are shown as well as compliance with minimum threshold imposed by the Directive (Source: Giuntoli et al. 2015).

[6] http://www.bioenergyconnection.org/article/life-cycle-analysis-bioenergy-policy (access done on December 2016)

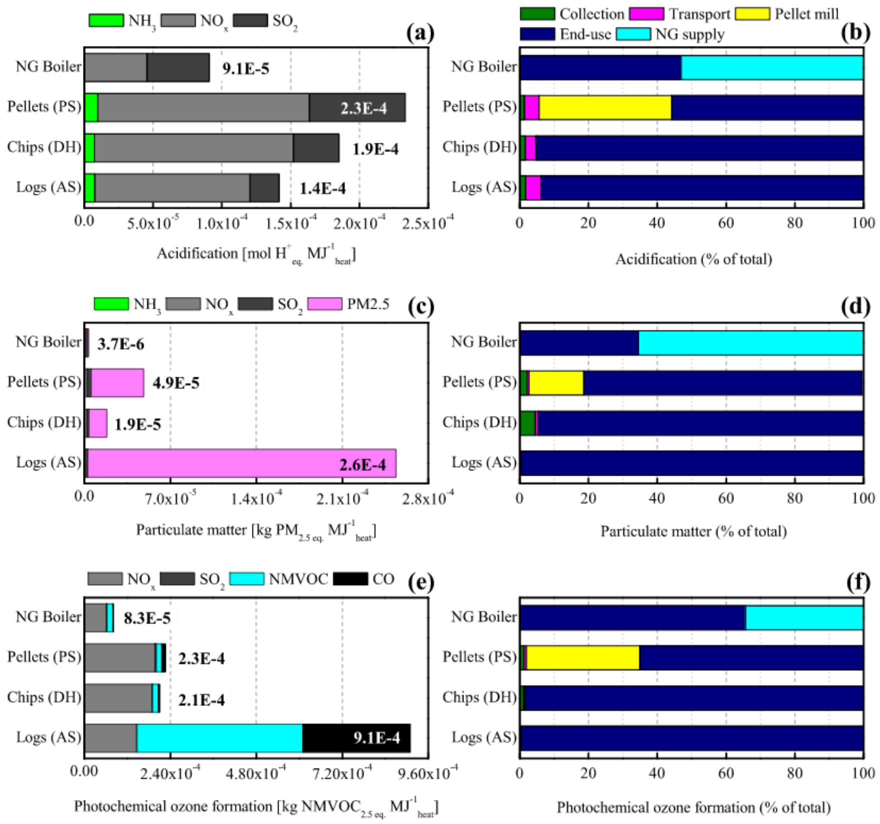


Figure 11: Performance comparison of the considered energy pathways in relationship to several environmental impact categories (Source: Giuntoli et al. 2015).

Additional considerations concern the use of LCA to assess climate change mitigation potential and the LCA modelling approach in the context of policy support

GHG emissions saving from bioenergy systems (compared to a reference fossil system) calculated through an LCA (or through the LC-based methodology proposed by the EU legislations) should not be interpreted as a direct and accurate measure of the climate change mitigation effects of a policy (Giuntoli et al., 2015). In fact, studies according to the above-mentioned methodologies usually track just CO_2, N_2O and CH_4 (Plevin et al. 2014) and do not address other forcers, e.g. indirect GHGs or albedo change. Moreover, if the studied system includes transient emission profiles (as in the case of LCA bioenergy studies including the change in forest carbon pool) obtained results can change significantly based on the time horizon chosen for the accounting of annual average carbon stock change (Giuntoli et al., 2015. This happens because LCA uses simplified, normalized metrics which are not able to properly consider the timing of biogenic carbon fluxes.

As far as the LCA modelling approach is concerned, recent studies claim that ALCA presents certain deficiencies when applied to policies that could be overcome by using CLCA (Brander et al. 2009). In fact, while the ALCA is designed to accounts for impacts of a product systems at the present time, the CLCA aims to estimate the future effects of a decision/action and as a such consider market mechanisms generated by the decision/action. For example, in a CLCA, effects of a decision in the context of biofuels is assessed in relationship to the energy market as well as to the other impacted market (food, feed). As better explained in the following chapter, a change in the demand of crops from the energy market affects, through price-mechanisms, the yields and the extension of crop area.

Several discussion elements have been raised concerning on one hand the actual applicability of CLCA in the light of currently available LCA tools and databases, on the other hand the reliability of economic models used in consequential modelling.

5.3 Use of LCA in bioenergy policies

Different LCA tools have been frequently used in legislation in the last years for informing about environmental impacts of bioenergy. The history of bioenergy sustainability criteria is closely linked to the development of LCA methodology. ALCA was applied to biofuels in the Well-to-Wheels (WtW) study (Edwards et al. 2007) already in 2007. Immediately afterwards, the Renewable Energy Directive (RED) (EC 2009a) adopted ALCA as the most convenient form of LCA for legislation, whilst recognising that the substitution method for considering by-products was the appropriate method for policy analysis. The RED calculated GHG savings per unit of fossil fuel replaced, not considering carbon dioxide emissions from burning biofuels on the basis that the biogenic carbon had been sequestered from the atmosphere shortly before by crops (EC 2008a). The same carbon neutrality assumption was then adopted for solid biomass.

However, bioenergy systems can influence directly and indirectly local and global climate through a complex interaction of perturbations, including: CO_2 and other long and short-lived climate forcers from biomass combustion, alteration of biophysical properties of the land surface, influence on land use and management and substitution of fossil fuels and other commodities such as food and wood products. ALCA studies of bioenergy systems in the past have been unable to properly capture these complexities and, consequently, have often been misinterpreted, providing decision-makers with incomplete information.

The GHG savings metrics used in the RED for biofuels, and in SWD(2014)259 for solid and gaseous biomass is often considered as a proxy for biofuels and bioenergy climate mitigation potential. However, it can only provide limited information. It is merely a modelling construct to benchmark different pathways on a common scale, useful to identify the pathways, which are inefficient, or with highest impacts, to improve the supply chain without overlooking potential trade-offs between different processing steps.

This type of analysis cannot thus be used alone to support policy analysis and planning work as carried out for example for an Impact Assessment, because it does not account for market-mediated effects of increasing demand of biomass for bioenergy, which are instead significant. In the case of bioenergy, ALCA may also lead to incorrect conclusions because it neglects crucial phenomena linked for example to the temporal imbalance between emissions and removals of biogenic CO_2, to the land-use etc. More complex tools, different metrics, additional climate forcers and several other environmental impacts must be instead taken into account for a more complete impact assessment in support to a proper policy design.

This has become evident in recent years. Because of the attributional nature of the tool prescribed by the RED to calculate GHG savings of biofuels pathways, market-mediated effects have been overlooked and the potential dangers linked to an increased demand of land/commodities for energy (Indirect Land Use Change) were masked (Searchinger et al. 2008 and 2015). The static nature of the tool and the acquired practice of neglecting biogenic-C cycle has led to overlooking the potential climate worsening caused by the use of slow-growing forest biomass as bioenergy (Agostini et al. 2014). Focus on Well Mixed GHG and GWP metrics has not considered potential bio-geophysical forcers, Near Term Climate Forcers (NTCFs) and the difference between long-lived and short-lived GHG on various aspects of the climate (Levasseur et al. 2016).

Therefore, when the goal of the impact assessment is to assess the consequences of a policy, then impacts caused by various policy choices against one (or multiple) baselines (biomass alternative uses to bioenergy) should be investigated through consequential LCA. This assessment usually involves the use of Integrated Assessment Models (IAM) and , ideally, it should:

- assess impacts at a global geographic scale;

- assess impacts on all market sectors of the economy;
- assess impacts on all relevant carbon pools, including biogenic carbon emissions and removals;

Recent scientific studies based on IAM have shed light on many of these mechanisms and largely clarified the potential impacts of many biofuels and bioenergy pathways (Matthews et al. 2015; Forsell et al. 2016; Valin et al. 2015).

In the case of biofuels, one of the main open issue is related to the additionality of impacts. This was due to the assessment of impacts only in the energy sector, without including impacts on other markets of the economy (food and feed). An increase in the demand of crops in the energy sector impacts on the other markets through price-mechanisms, which both raise yields and increase crop area (indirect land use change: ILUC). The magnitude of ILUC can only be determined by complex global econometric models (Laborde 2011, Valin et al. 2015), which seeks to look at the global land use change response to increased biofuel demand. This is done by comparing an economic scenario with the biofuels, against a baseline scenario where the biofuel demand is absent. The results of the CLCA and IAM carried out in the above mentioned studies have brought the EC in 2015 to amend the RED by including ILUC emissions values for biofuels in the reporting requirements for Member States and economic operators (Directive 2015/1513).

The IA for the preparation of the new Proposal for a Directive on the Promotion of the Use of Renewable Energy Sources (RED-2) (CEC 2016) refers to the results of such studies to conclude that ILUC emissions can be significant and need to be reduced by implementing mitigating options, for example with the introduction of a cap of 7% on the contribution of food-based biofuels towards transport energy consumption, and a gradual phase out until 2030, or by the promotion of "low indirect land-use change-risk biofuels and bioliquids" (including advanced biofuels from wastes and residues).

Regarding bioenergy from forest feedstock, the impact assessment on the Sustainability of Bioenergy carried out in 2016 also made use of several complementary IAM exercises, in order to understand the impacts associated to the baseline scenario as well as of the policy options, as for example:

- a modelling exercise with GLOBIOM (global economic land use model) and G4M (forestry sector model) – RECEBIO project (Forsell et al. 2016)
- a modelling exercise with Green-X (EU renewable energy model), combined with ArcGIS Network (geospatial model for biomass transport chains) and MULTIREG (input-output model) – BIOSUSTAIN project
- a modelling exercise with VTT-TIAM (energy model), MITERRA (agriculture model), and CARBINE (Forests/forestry model) – BioImpact project (Matthews et al. 2015)

These analyses largely improved the understanding of the climate mitigation potentials of bioenergy in general (and of forest bioenergy in particular); in particular, they raised the attention to the fact that biogenic CO_2 emissions associated with an increased demand for forest-based biomass may lead to minimal or even negative greenhouse gas savings compared with fossil fuels (and can lead to adverse environmental impacts on biodiversity, soil and air quality).

It is now evident that, when considering forest biomass used for bioenergy, supply-chain emissions as calculated according to the indications in the relevant directives following an ALCA methodology are less relevant (except in a few cases of cultivated woody feedstock) to assess which pathways may provide actual climate change mitigation. The largest component of the impact is linked to C-stock changes in the forest. Applying attributional LCA to bioenergy (or any biomass product) without considering a baseline use for the biomass or land and without considering explicitly the biogenic-C cycle, provides a limited view of the impacts and gives incomplete information to policy makers in the phase of policy design. However, these impacts change quite dramatically depending on type of feedstock, geographical origin, current and forecasted practices etc. Data gaps still need to be filled and currently there is no consensus on a proper methodology to assess this baseline. Some studies (e.g. BioImpact Project) in fact point out that this is almost impossible, and they rather propose a decision tree to assess the potential additionality of each bioenergy project.

However, the large debate made clear that bioenergy may not always contribute to climate change mitigation strategies within the necessary timescales required by the Paris Agreement. It is also possible that bioenergy strategies will temporarily increase climate change magnitude and rate, even when residual biomass is considered (Giuntoli et al. 2016).

The discussions above highlight how bioenergy and biofuels policies in the last years followed the evolution of LCA analysis. The use and availability of more complex and sophisticated tools as the Integrated Assessment Modelling frameworks, allowed the identification (and in several cases also the quantification) of additional effects (e.g. ILUC, biogenic CO_2 emissions etc.) that were not properly taken into consideration (or couldn't be estimated and quantified) in the previous versions of the related policies.

The lesson learnt indicates that simplified methodologies (like the GHG-savings metrics) can be useful tools for policy implementation, but awareness on their limitations is necessary. More complex tools, as large modelling studies, must be instead taken into account for a proper policy design and impact assessments.

5.4 LCA supporting policy impact assessment: development needs

Key areas of development for improving the implementation of LCA in the impact assessment of policies can be identified.

The interpretation of results clearly plays a relevant role as it supports the evaluation of the extent to which a specific policy option complies with the overall objective (defined in the Policy Anticipation and Problem definition step). A sound interpretation of LCA results requires on one hand a clear and complete goal and scope definition, on the other hand a deep knowledge of the LCIA methods used in the study, with particular reference to the specific perspective underpinned by the models behind the environmental indicators. Meta-analyses of existing studies, with reference to specific sector, can provide valuable information to be used in policy impact assessment step and, at the same time, can point out the need of LCA studies and/or the need for improving the application of LCA to the specific sector. It is the case, for example, of the meta-analysis conducted by Nordelof et al. (2015) in the electrified vehicle sector, which highlighted the often missing identification of the time scope in the scope definition.

An important issue that LCA can deal with is the (environmental) rebound effect associated to the eco-innovation and thus, its proper consideration in the context of eco-innovation policy assessment. The rebound effect has been defined as "an increase in consumption due to environmental efficiency interventions that can occur through a price reduction (i.e. an efficient product being cheaper and hence more is consumed) or other behavioural responses" (De Camillis et al. 2013). Other authors (Font Vivanco et al. 2014a) defined the rebound effect in a more comprehensive way as "the change in overall consumption and production due to the behavioral or other systemic response to changes in economic variables (income, price and financial gains or costs of product and material substitution) induced by a change in the technical efficiency of providing an energy service"; they also identified four type of rebound effect that could be summarized as follow:

- **direct effect**: change in the consumption or production of a product as a behavioral response to a change in economic variables induced by a change in the provision of <u>the same product</u>

- **indirect effect**: change in the consumption or production of other products as a behavioral response to a change in economic variables induced by a change in the provision of a product
- **economy-wide/structural effect**: change in the overall consumption and production as a systemic market in response to changes in aggregated total demand induced by a change in the provision of a product/service (e.g. by linking the LCA process tree to a CGE model)
- **transformational effect**: change in the overall consumption and production as a systemic societal response to changes in consumers' preferences, social institutions or the organization of production induced by a change in the provision of a product/service

The concept of rebound effect is particularly relevant when assessing diffusion of innovation, the analysis of the adoption of new innovations, and emerging technologies trough LCA. With reference to the emerging technologies, Sharp et al. (2016) identified a potential for integrating the diffusion modelling techniques and LCA in order to providing estimates for the extent of market penetration, the displacement of existing systems, and the rate of adoption. Diffusion modelling techniques can be conducted with a macro-level perspective, based on a time-function to represent the adoption, and with a micro-level perspective, considering interaction among individuals to simulate the adoption. The use of LCA to deal with the rebound effect provides a more comprehensive evaluation of the effect itself, which is significant in the context of policy making (Font Vivanco et al. 2014a), however the need for a common framework supporting a consistent integration in LCA modelling has been recognized (Font Vivanco et al. 2014a). In fact, the size of the rebound effect is affected by methodological choices in modelling demand change (Font Vivanco et al. 2016 and 2014b; Murray 2013, Chitnis et al. 2014). Moreover, recent studies highlighted that environmental burden modelling is also a source of bias, with specific relation to incomplete background system, technology assumptions and sectorial aggregation (Font Vivanco et al. 2016). This claims for further research on demand change modelling and LCA quality data on one hand, for sensitivity analysis of choices related to environmental modelling in rebound effect assessment (Font Vivanco et al. 2016) on the other hand. An evident need for LCA in support of policy impact assessment arises in the context of product-oriented policies. Product oriented policies (e.g. labels, financial incentives, emission standard for buildings, etc.) address the most relevant impact categories or most impacting LC stages of a specific product. Product-oriented policies are linked to territorial policies and play a major role in the achievement of their goals. Thus, the benefits associated to the product-oriented policy implementation requires for an LCA under proper scenario, able to accommodate all elements of the micro-macro scale framework, namely those relating to production, consumption, infrastructure and local context (this also includes the hot topic attributional versus consequential). An example are the climate policies targeting emissions from vehicles which are relevant in the achievement of Air Quality Directive goals. These policies cannot be evaluated in isolation. On the production side, industrial policies addressing the emission from production plants as well as plant's presence in EU/Extra EU (e.g. sector that are delocalised) are relevant for the achievement of the air quality goal. On the consumption side citizen' choice (e.g. SUV or city car) and their behaviour (e.g. frequency of usage and driving style) also affect the expected impact of the policies. On the infrastructure area the availability and quality of transport alternatives (e.g. railways) needs to be taken into account and, finally, in relationship to the local context the current environmental status (e.g. the concentration of local pollutant from other drivers, pressures) allows to evaluate the significance of the results achievable through the policies being assessed.

Finally, as a general consideration the use of complex and articulated methodologies could not matching the need to simplify and streamline the policy impact assessment process, with particular reference to the results communication and their use. Thus, beyond the above-mentioned inputs to develop/integrate the LCA further in order to perform comprehensive assessment, it is important to stress the relevance of guidance in LCA use and integration with other tools, as well as major research in the context of aggregation of multiple criteria assessment. This also includes normalization and weighting factors development and application.

6 Conclusion and outlooks

Among the main challenges posed by sustainability, policy makers are increasingly expressing specific needs, namely: i) ensuring consistency in the assessment of different environmental and socio-economic burdens, avoiding burden shifting (amongst impact categories, in space and in time); ii) better consistency between product policies and territorial policies at macro scale (e.g. a product policy at micro scale for a detergent and the freshwater environmental quality requirements of a macro-scale policy such as the Water Framework Directive); iii) the identification of the relative contribution of production and consumption patterns in the achievement of macro-scale goals. This will also affect the possibility of ensuring not only a relative decoupling of welfare from environmental impacts but also the absolute decoupling, towards "living well within the limits of our planet". In the context of challenges posed by sustainability, the LCA play a key role as it can provide support to policy-makers to take transparent and evidence-based decisions towards the needs above reported, as recognized by the Better regulation.

The previous chapters show that, so far, i) LCT/LCA have been integrated in main EU environmental policies and ii) LCA is mostly mentioned as implementation measure. However, the LCA can provide support all along the policy cycle, especially at impact assessment step where, the analysis conducted in relation to the Energy, Climate action and Environment report a major room for LCT/LCA enhancing. In fact, LCT/LCA is significant to catch and assess the effects that policies produce on the supply chains (complex too) and to explore future consequences associated to different policy options.

A broad and international discussion on the need of a guidance for the application of LCA in the policy is ongoing. Several elements may affect the LCA results and, consequently, the decision support, including: data quality, modelling choice (e.g. Plevin et al. 2014a discussing attributional versus consequential approaches), methodological choices (e.g. Wardenaar et al. 2012 discussing the differences of LCA for analysis and for policy, focusing on the allocation methods), uncertainty analysis etc. Hence, further guidance tailoring LCA for policy needs are of upmost important, especially when the application of LCA with different assumptions lead to conflicting advice (e.g. Lazarevic et al. 2012). In this respect, methodologies for capitalising existing knowledge are extremely important, e.g. further development of the meta-analysis of existing studies, as well as the integration of LCA with methodology for robust and systematic sensitivity analysis.

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List of abbreviations and definitions

Abbreviations:

ALCA – Attributional Life Cycle Assessment
CEC – Communication of the European Commission
CLCA – Consequential Life Cycle Assessment
EC – European Commission
ELV – End-of Life Vehicles
EMAS – Eco-Management and Audit Scheme
EPLCA – European Platform on Life Cycle Assessment
EU – European Union
GPP – Green Public Procurement
ILCD – International Reference Life Cycle Data System
IPP – Integrated Product Policy
ISO – International Organization for Standardization
JRC – Joint Research Center
LCC – Life Cycle Costing
LCA – Life Cycle Assessment
LCI – Life cycle inventory
LCIA –Life cycle impact assessment
LCSA – Life Cycle Sustainability Assessment*
LCT – Life Cycle Thinking
MS – Member States
OECD – Organization for Economic Co-operation and Development
OEF – Organization Environmental Footprint
PEF - Product Environmental Footprint
RA – Risk Assessment
REACh - Registration, Evaluation, Authorisation and Restriction of Chemicals
SCP – Sustainable Consumption and Production
SDGs – Sustainable Development Goals
SETAC – Society for Environmental Toxicology and Chemistry
SLCA – Social Life Cycle Assessment
SMM – Sustainable Material Management
SWD – Staff Working Document
UNEP – United Nation Environment Programme
* The acronym LCSA also stands for Life Cycle Sustainability Analysis

Definitions:

Allocation: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems

Attributional Life Cycle Assessment: LCA modelling approach that trucks energy and material flows along a product's supply chain and during use and disposal or recycling. All flows are considered, regardless of their relevance to a change in the modelled system

Background process. Processes of the product life cycle for which a direct access to information is not available

Consequential Life Cycle Assessment: LCA modelling approach that estimates how flows to and from the environment would be affected by different potential decisions. Only flows affected by a decision are considered.

Elementary flow: Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation

Foreground process: Processes of the product life cycle for which a direct access to information is available

Functional unit: Quantified performance of a product system for use as a reference unit

Life cycle impact assessment: Stage of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

Multi-functionality: Character of a product when it fulfils more than one function and/or deliver more than one product.

System boundary: Set of criteria specifying which unit processes are part of a specific product system under study

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