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TransBarriers

Guideline for assessing barriers to Low Carbon Technologies in Buildings

Carmenza Robledo, Susann Görlinger, Christof Knoeri, Gregoire Meylan, Roman Seidl, and Michael Stauffacher

USYS TdLab
Department of Environmental Systems Science
Transdisciplinarity Lab · Science-Society Interface

eit Climate-KIC

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Climate-KIC Climate-KIC is the EU's largest public private partnership addressing climate change through innovation to build a zero carbon economy. It addresses climate change across four priority themes: urban areas, land use, production systems, climate metrics and finance. Education is at the heart of these themes to inspire and empower the next generation of climate leaders. Climate-KIC run programmes for students, start-ups and innovators across Europe via centres in major cities, convening a community of the best people and organisations. Its approach starts with improving the way people live in cities. Its focus on industry creates the products required for a better living environment, and it looks to optimise land use to produce the food people need. Climate-KIC is supported by the European Institute of Innovation and Technology (EIT), a body of the European Union.

USYS TdLab The USYS TdLab develops new educational and research approaches to solve complex problems at the interface between academia and society. The TdLab works with teachers and researchers to plan and execute projects involving multiple disciplines and stakeholders. Through its teaching programmes, the TdLab trains students to apply their scientific expertise to tackle complex societal problems that advance sustainable development. The TdLab provides a forum in which researchers discuss issues related to sustainability with stakeholders from civil society, politics, and the private and public sectors. The TdLab promotes intra- and interdepartmental dialogue and provides a platform to identify emerging issues related to society and the environment.

TransBarriers Many low carbon building technologies (LCT) have been developed in the last 15 years, but the absorption of these technologies is still moderate. This indicates that existing barriers prevent their full deployment. TransBarriers was a research project co-funded by Climate KIC and the ETH Zurich. The project was aimed at improving understanding barriers to low carbon technologies through a transdisciplinary approach. The project developed the current guideline under collaboration with the project Berlin TXL – The Urban Republic in Germany and two technology providers in Switzerland, LafargeHolcim and GLASSX AG.

Disclaimer The guideline and its recommendations do not reflect an official position from Climate KIC or the ETH Zurich and are full responsibility of the authors.

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Acronyms and Abbreviations

CoP	Community of Practice
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
LCT	Low carbon technology
ISCU	International Council for Science
ISSC	International Council for Social Science
KM	Knowledge management
LCA	Life Cycle Assessment
UNFCCC	United Nations Framework Convention on Climate Change

Preface

Over 40% percent of per capita greenhouse gas emissions in the European Union originate from activities related to buildings, namely electricity production and use, heating, manufacturing and construction. This figure highlights the remarkable potential that the built environment offers for greenhouse gas emissions reduction.

Despite the achievement of great progress in the development of low carbon technologies for buildings, the rate of adoption and the total market penetration of these technologies remains low. Research shows that there are significant barriers and market distortions that hinder the deployment of low carbon technologies in the built environment in Europe. A proper understanding of these barriers is a necessary first step towards reducing greenhouse gas emissions in the building sector.

Climate-KIC's mission is to bring sustainable innovation to market using a systemic approach, which is a recognition that we not only need new technologies but also new business models, legal frameworks, social practices and cross-sectorial thinking. Key to our systemic innovation approach is our partner community, which is comprised of a diverse group of first-rate knowledge institutions, leading corporations and SMEs, as well as ambitious actors from the public sector.

The TdLab of the Department of Environmental Systems at ETH Zurich and Climate-KIC joined forces in 2015 to embark on a co-funded research initiative which resulted in the TransBarriers project. The interdisciplinary team at TdLab works in close collaboration with the private sector and has developed a methodology for fostering a better understanding of the existing barriers for the implementation of low carbon technologies in the built environment and how those barriers can be overcome.

I am confident that the use of this publication will support policy makers, project developers and technology providers in deploying low carbon building technologies at a greater rate in order to realize some of the tremendous climate change mitigation potential in the European built environment.

Dominic Hofstetter
Director, Climate-KIC Switzerland

1 Introduction

The built environment is a major contributor to the man-made emissions of climate relevant greenhouse gases, thus there is a strategic interest in considering this sector when discussing climate change mitigation. The Fifth Assessment Report of the IPCC differentiates four mitigation options for buildings: i) carbon efficiency; ii) energy efficiency of technology; iii) system/(infrastructure) efficiency; and iv) service demand reduction[1]. These options include both technological innovation and deployment of technologies, being the latter a process that includes selection, installation and use (adoption) of technologies. Thus all options largely depend on human decisions, responses, actions and the availability of technologies itself is not enough to secure neither innovation nor deployment.

This dependence on human behaviour is clear when analysing why the potential for GHG emission reduction from buildings has not yet been realised, even if many LCTs exist and seem to be already cost-effective in the short term. Reasons explaining what hinders technological innovation or deployment of existing technologies are discussed in the IPCC Assessment Report under the term "barriers". The identification of barriers to a broader adoption of LCTs has been in the focus from a range of perspectives. For instance, in their studies in the 90s Jaffe and colleagues[2,3,4] identified several rational causes for this "efficiency gap" including lack of information, actor relationships and roles, uncertainty about future prices or qualitative attributes of technologies beyond efficiency performance.

The term "barrier" spans a wide spectrum of factors, stakeholders and interactions from local, individual, small scale to global scale or structural. More specific to the building design and construction industry, Hoffmann and Henn[5] argued that environmental progress would continue to stall if the remaining social and psychological barriers are not addressed. This has been reiterated by a number of studies for different LCTs, analysing construc-

1 Lucon O., D. Ürge-Vorsatz, A. Zain Ahmed, H. Akbari, P. Bertoldi, L.F. Cabeza, N. Eyre, A. Gadgil, L.D.D. Harvey, Y. Jiang, E. Liphoto, S. Mirasgedis, S. Murakami, J. Parikh, C. Pyke, and M.V. Vilariño (2014). Buildings. In: Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* []. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

2 Jaffe, A. B., & Stavins, R. N. (1994). The energy-efficiency gap: what does it mean? *Energy Policy, 22*(10), 804-810.

3 Jaffe, A. B., Newell, R. G., & Stavins, R. N. (1999). *Energy-efficient technologies and climate change policies: issues and evidence*. Washington, DC: Resources for the Future.

4 Murtishaw, S., & Sathaye, J. (2006). *Quantifying the effect of the Principal-Agent Problem on US residential energy use*. Berkeley: California, USA: University of California.

5 Hoffman, A. J., & Henn, R. (2008). Overcoming the Social and Psychological Barriers to Green Building. *Organization & Environment, 21*(4), 390-419.

tion stakeholder decisions[6,7] or different policies and various approaches to close the efficiency gap[8,9]. The literature on barriers to the adoption of LCTs in buildings agrees that the lag in adoption can not be attributed to a single barrier, as barriers are distributed to multiple stakeholder and change from technology to technology and over time. However, some general hindering factors to a broad adoption of LCTs are repeatedly mentioned as i.a. knowledge gap and misconceptions, split interests across stakeholders, lack of a green market incentives and non-economic drivers as peer effects, personal commitment or emotions. Such general hindering factors are multiplied by contextual factors such as the specific natural environment, cultural values of given social groups or distinct rules and regulations. Consequently, we argue that identifying generalizable, "one-size" and one-dimensional obstacles (e.g. lack of price competitiveness is "the barrier") is neither realistic nor useful for overcoming barriers to innovation or deployment of LCTs in buildings.

A broad range of expertise from research and practice is necessary for identifying and assessing the context specific variety of barriers to LCTs. Such collaboration across different scientific disciplines and of science and practitioners is denoted as transdisciplinarity[10]. The reason for this collaboration is substantive ("valuing knowledge of practitioners") as well as procedural ("engage them intensely in the process of knowledge co-generation so that mutual learning becomes possible and "implementation" is not a follow-up but rather a parallel process by which industry representatives directly use the gained knowledge/experience in their daily life). Transdisciplinarity has become in the last decades a dominant scientific approach informing concrete action for sustainable development generally or transition to a low carbon society more specifically. A major handbook[11], guide-

6 Friege, J., & Chappin, E. (2014). Modelling decisions on energy-efficient renovations: A review. *Renewable and Sustainable Energy Reviews, 39*(0), 196-208.

7 Knoeri, C., Binder, C. R., & Althaus, H. J. (2011). Decisions on recycling: Construction stakeholders' decisions regarding recycled mineral construction materials. *Resources, Conservation and Recycling, 55*(11), 1039-1050.

8 Brown, M. (2015). Innovative energy-efficiency policies: an international review. *Wiley Interdisciplinary Reviews-Energy and Environment, 4*(1), 1-25.

9 Zuo, J., & Zhao, Z. Y. (2014). Green building research-current status and future agenda: A review. *Renewable & Sustainable Energy Reviews*, 30, 271-281

10 Klein, J. T. (2001). *Transdisciplinarity: Joint problem solving among science, technology, and society: An effective way for managing complexity*: Springer.

11 Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., . . . Zemp, E. (2008). *Handbook of transdisciplinary research*: Springer.

lines[12], method books[13] and several special issues of scientific journals have been produced presenting numerous successfully conducted case studies and reviews of the state-of-art[14]. Transdisciplinarity got increased traction through the establishment of the Future Earth Programme in 2013[15] by the International Councils for Science (ISCU) and Social Science (ISSC). This global research platform promotes actively the co-design of research projects and the co-production of knowledge in research, that is, transdisciplinarity.

The present guideline is based on this specific expertise of transdisciplinarity, giving guidance on how to assess barriers to LCT in buildings considering technical, environmental, social and institutional components. The interaction of these components using a systemic approach stays at the conceptual basis of the guideline. In contrast to existing reviews and analyses of barriers, we emphasize the need of capturing the deeply contextualized character of barriers: barriers need to be identified for specific technologies and/or projects within a specific socio-institutional-cultural-economic setting and promoted and steered by key stakeholders. This may be from a technology perspective (e.g. by LCT companies) or from a project perspective (i.e. a specific building project). Both perspectives will be explicitly addressed in this guideline document. The approach formulated in this guideline goes beyond understanding a problem by bringing together various stakeholders, inducing a learning process among them and thus motivating action and facilitating the identification of concrete solutions to barriers to LCT in buildings. In this guideline the term "stakeholder" means any identifiable individual or group who can meaningfully affect or be affected by the achievement of an organization's or project's objectives (see glossary).

The guideline is structured in two parts: theoretical framework and practical steps. The theoretical framework introduces the overall rationale of the systemic approach used in the guideline and answers to the question of "why" to proceed this way. The practical steps, built up as a cook recipe, gives advice on "how" to identify, assess and quantify specific barriers at the technology or at the project level.

12 Pohl, C., & Hadorn, G. H. (2007). *Principles for designing transdisciplinary research*: oekom Munich.

13 Bergmann, M., Jahn, T., Knobloch, T., Krohn, W., Pohl, C., & Schramm, E. (2013). *Methods for transdisciplinary research: A primer for practice*: Campus Verlag. See as well the selection of tools by the Swiss based td-net: http://www.naturalsciences.ch/topics/co-producing_knowledge

14 See e.g. *Futures* in 2004 and 2015, *GAIA* in 2007, *Interdisciplinary Science Reviews* in 2014

15 http://www.futureearth.org

Part I Theoretical framework

2 Scope

2.1 Objectives

This guideline aims to facilitate consistent and comparable assessment of barriers to the development and deployment of low carbon technologies in buildings[16], so that clear action for overcoming these barriers can be taken.

Why it is necessary to pursue consistent and comparable assessment of barriers? Because these two attributes, being comparable and being consistent are necessary to build up a knowledge basis beyond independent, unique or specific cases and towards a comprehensive understanding of hindering factors to low carbon pathways in buildings and this knowledge is essential for designing adequate solutions.

The guideline uses a systemic approach for increasing the understanding of barriers to a) the innovative process towards low carbon technologies in the supply chain; and b) the deployment of low carbon technologies (LCT) in projects.

Why is necessary to use a systemic approach? The main assumption here is that barriers to low carbon technologies are not generic but **context dependent**, i.e. a result of the specific interactions of the technical, social, economic and environmental components within a given system. Details on the systemic approach are discussed in section 3.0.

16 In the following text of this guideline we use „barriers to low carbon technologies" and refer to „barriers to development and deployment of low carbon technologies".

2.2 Target population and beneficiaries

The primary users of this guideline are researchers and/or consultants who are asked to assess barriers to low carbon technologies in buildings. These include the assessment of barrier to specific technologies and/or of barriers within a specific project. The use of the guideline requires an understanding of transdisciplinary research and of analysis of complex systems. It is important to recognise that this guideline does not propose a desk study but rather a multi-stakeholder process whereby the researchers and/or consultants facilitate a process of mutual exchange and learning among the stakeholders guided by a set of systematic, analytical steps (see Figure 1).

The results obtained by using this guideline increases knowledge on what are barriers to the development and deployment of low carbon technologies, what

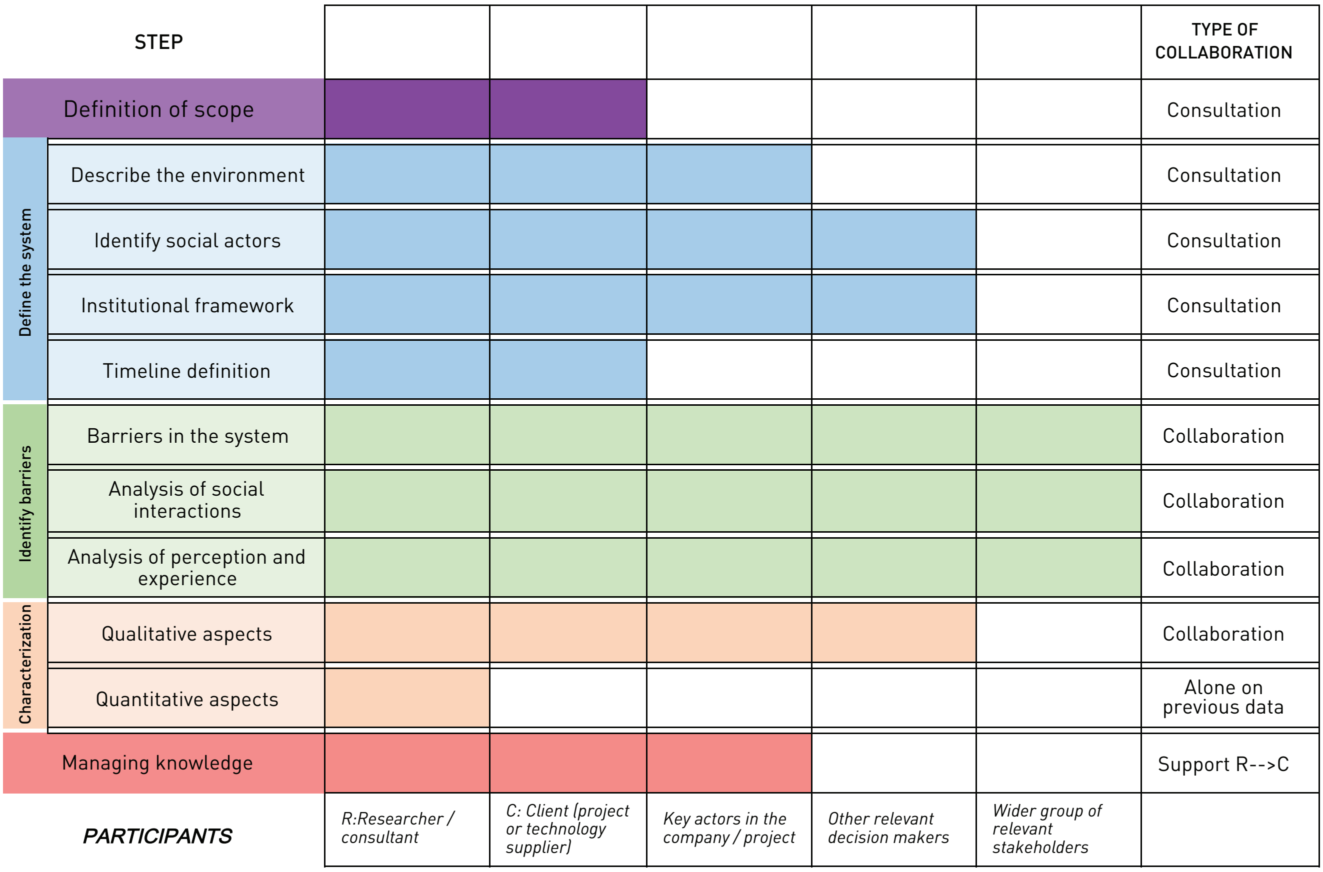


Figure 1
Possible stakeholders participating in the assessment of barriers to LCTs.
Note to the Figure: The purpose of the figure is to highlight the participatory approach needed for the assessment of barriers following this guideline. Each step will be clarified in Part II

are their drivers and how big these barriers. Thus these results are the first step towards concrete options for reducing or overcoming these barriers and are important for:

- **Policy makers** responsible for creating enabling conditions for low carbon pathways in buildings at the national and sub-national levels. This includes policy makers looking at the building, urban development and energy sectors.
- **Technology developers**, producers and sellers who want to increase the deployment of low carbon technology in the markets.
- **Project developers** (including architects, engineers, consultants or investors), who need to reduce the GHG emissions over the life cycle of a project.
- **Marketing experts** in the building sector, who need to promote low carbon buildings as part of their portfolio.

2.3 Areas of use

The guideline can be used either for assessing barriers that a given low carbon technology faces or for assessing barriers to maximizing the use of low carbon technologies in a specific project (building or group of buildings). In both cases, the involvement of a broad set of stakeholders is key for the success.

The guideline proposes a process in three main steps: defining the system, identifying barriers and characterizing barriers. The third step – characterization – covers qualitative and quantitative characterization of barriers. These three steps are interactive and, depending on the specific requests, the user can undertake the first step alone, the two first or all steps, i.e. the user does not need to undertake all steps for getting relevant results.

2.4 Main concepts

We introduce here five concepts that are at the very base of this guideline:

Low carbon technology: The term "low carbon technology" (LCT) refers to technologies that reduce GHG emissions during their production and/or use phases. In order to define if a given technology is "low carbon" the technology provider needs to set a reference scenario to compare with other available technologies. This guideline doesn't provide methods for setting the reference scenario; furthermore the guideline builds up on the existing experience by technology providers about the "low carbon" character of a given technology. For the purpose of this guideline the term "low carbon technology" can refer to a single specific technology and/or to a group of technologies that are connected and that achieve a GHG emission reduction through its application together.

System: refers to a set of interacting or interdependent components forming a complex whole. Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning.

Systemic approach: the term systemic approach is used in multiple disciplines as psychology, medicine, policy or ecology. In a wider sense "systemic approach" highlights the need to understand the system in which an actor or phenomenon is embedded and its dynamics. Using a systemic approach includes the identification of the system components and the analysis of the multiple interactions between the system components over time. Chapter 3 presents the systemic approach for this guideline in detail.

Transdisciplinarity: A collaboration across different scientific disciplines and of science and other sectors of the society including policy-makers, civil society and private sector.

Transdisciplinary approach: A transdisciplinary approach seeks for co-generation of knowledge beyond specific disciplines and integrating knowledge, experience and perceptions from different stakeholders through interaction.

3 Systemic approach

The guideline differentiates between four types of buildings by their function: single-family house, apartment building, commercial or public building and industrial building. Several aspects in the system determine the use of LCT in any of these buildings, including i.a. legislation, price, existing infrastructure, public preferences, expected performance, etc. These aspects can be structured in the four system components: institutional[17], socio-economic, natural environment and technical environment; creating a so called complex system[18]. These components interact with each other over time and, if the interaction is not appropriate, then barriers to innovation or deployment of LCTs appear and burden the realisation of the full (market) potential of LCTs (see Figure 2).

17 In this guideline "institution" is defined as humanly devised agreements that structure human interaction. They are made up of formal constructs (rules, laws, constitutions), informal constructs (norms of behavior, conventions and self-imposed codes of conduct) and their enforcement characteristics. See glossary.

18 Complex system consist of diverse and autonomous but interrelated and interdependent components or parts linked through many (dense) interconnections or relationships. Complex systems cannot be described by a single rule and their characteristics are not reducible to one level of description. They exhibit properties that emerge from the interaction of their components and which cannot be predicted from the properties of the single components. Some general features of complex systems are emergence, self-organization, collective behavior and the capacity to evolve and adapt.

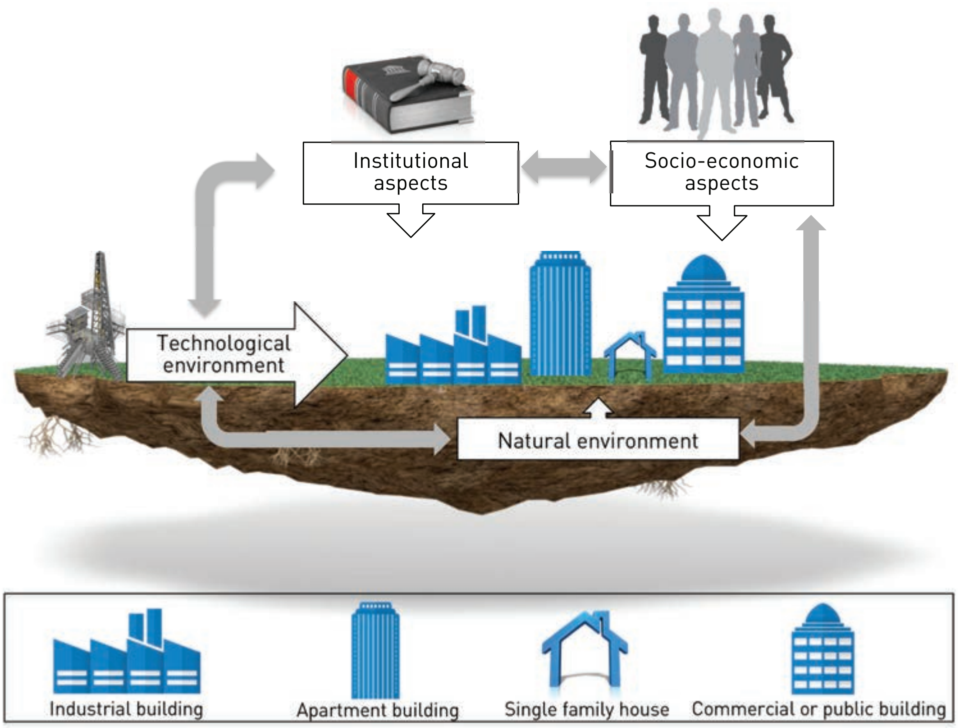


Figure 2
Systemic interactions in the building system.

Barriers depend upon the specific system where they occur, thus for analysing potential or existing barriers you need to understand the four components of the system under consideration as well their interrelations over time. The first step for defining your system boundaries is to clarify if you are looking at barriers to a specific technology and/or at barriers to a maximise the use of low carbon technologies in a specific project. The differentiation if you are interested in barriers to technologies or barriers within a project determines what is called "entry point" in this guideline.

3.1 Entry point

This guideline differentiates between two possible entry points: technology or project. In both cases you deal with a complex system, but the characteristics of complexity are different (see 3.1.1. and 3.1.2 for detail).

3.1.1 Technology entry point

The technology entry point is useful when you are interested in understanding barriers to a specific LCT or a group of technologies, e.g. low carbon cement vs. conventional cement or heat-pump vs. oil boilers. Using the technology entry point allows to answer questions such as:

- What are the (most important) barriers for realising the market potential of my technology?
- What are the causes of these barriers?
- What attributes of a barrier can be quantified and how? (e.g. in monetary terms, in number of people affected)
- What are the impacts of these barriers (e.g. in terms of non-reduced GHG emissions or environmental damage)?

Typically, a given LCT can be used in different types of projects (e.g. one can use low carbon cement in public buildings as well as in single-family houses or apartment buildings). Each of these projects will have specific environmental and technical environments, different groups of stakeholders and different types of regulations. Thus the level of complexity increases with the increasing number of project types, because each project type includes its own stakeholder groups, decision-makers and institutional agreements (see Figure 3).

3.1.2 Project entry point

If your interest is in understanding barriers at the project level (e.g. barriers to LCT in single-family houses or to use of LCTs in a urban restoration project) then you should use the project entry point.

Using the project entry point allows to answer questions such as:

- What LCTs are available for my project and what is their impact on my project?

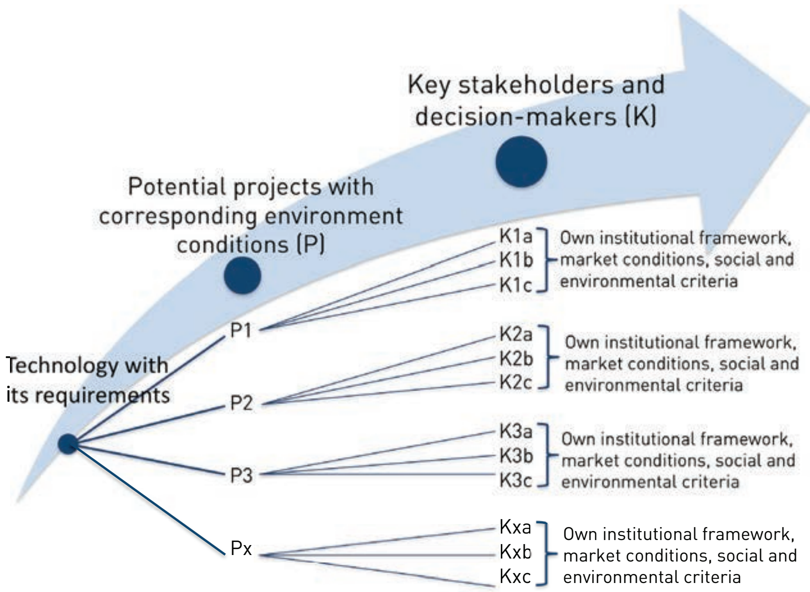


Figure 3
Technology entry point.

- What are the (most important) barriers for promoting the use of LCT in my project?
- What are the causes of these barriers?
- What attributes of a barrier can be quantified and how? (e.g. in increasing project costs)
- What are the impacts of these barriers (e.g. in non-reduced GHG emissions or in reducing the selling potential of my project)?

When referring to a project the guideline considers the design, construction, selling and use phase of a building or group of buildings. As stated before the guideline differentiates four types of buildings by its function: single-family house, apartment building, commercial or government building and industrial building The first two types, single-family house and apartment building, serve the same function as residential buildings, but have different structures and sizes and are therefore separated into two types. In addition, subtypes of projects are possible including new building, restoration, renovation or retrofit. Thus a characterization of your projects considering, type of building (defined by its function) and project sub-type is necessary before starting the analysis of potential barriers (see Section 5.1.2 for the practical steps of the characterization).

Using the project entry point implies that you focus on a specific project with one set of stakeholders and decision-makers, institutional aspects, market conditions and decision criteria, but multiple technologies. The more key stakeholders and decision-makers you have in a project the more complex your system can become. The existence of several stakeholders and decision makers can be related to the size of the project. For instance, if you combine public, commercial and residential buildings in one project it is possible that representatives of all final users are to be considered as decision makers during the design and construction phases. If that is the case, each of these social actors can have its own preferences, prejudices and priorities with regard to the multiple LCTs options that could be used in your project. Thus answering how specific stakeholders and decision-makers have an impact on the selection of several technologies becomes your major challenge. In addition, you will need to understand the interactions between technologies and how this knowledge affects the decision-making (see Figure 4).

When using the project entry point, the results are useful for project managers and policy makers at the city level. Further, using this entry point contributes to understand barriers to policies aimed at reducing GHG emissions in buildings either in mixed areas, areas in transition or in urban and rural areas.

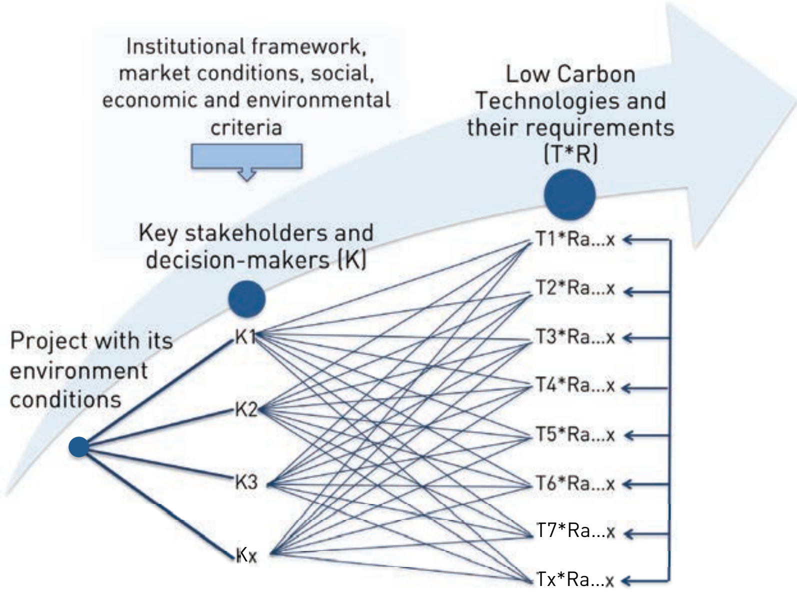


Figure 4
Project entry point.

3.2 Environment

This guideline differentiates between *natural* and *technical* environment.

Natural environment refers to natural conditions including climate and weather, topography, type of soil, water bodies, vegetation or existing fauna. Technologies can be more or less suitable according to the specific natural conditions and can create natural limitations for using a specific LCT (e.g. Phase-change Material windows are not suitable for areas with high temperatures during day and night).

Buildings (project entry point) are embedded in a specific natural environment which has a direct impact through seasons (solar potential), outside temperature, wind exposition, sun exposition, soil support capacity or exposition to extreme events like hurricanes or earthquakes. In a sense the natural environment provides both opportunities and requirements to buildings. Thus it is important to explore the opportunities and potential constraints provided by the natural environment to the deployment of LCTs.

Technical environment refers mainly to (urban) infrastructure and technology available or needed for deploying LCTs (either specific or generic). It includes existing or planned infrastructure, energy sources and energy systems and other elements in the built environment (e.g. other buildings, roads or parks). The lack of appropriate technical environment can be a barrier for a given LCT, which is considered here under "lack of technical suitability" (see section 3.7).

3.3 Social component

This refers to the stakeholders involved in your system. As stated before the term "stakeholder" includes any identifiable individual or group who can meaningfully affect or be affected by the achievement of an organization's or project's objectives (see glossary). Stakeholders are relevant because they affect the success of an organization or a project i.e. because they affect the deployment of LCTs.

For the purpose of this guideline we propose a role-based classification of stakeholders that distinguishes between the following potential roles:

- **Regulator:** is the stakeholder responsible for providing and enforcing norms relevant for the deployment of LCTs. It includes laws as well as lower level of regulations. Regulators are typically part of the public sector and include i.a. city authorities or environmental authorities. Regulators can be at the national, sub-national or local level. They play a very important role in creating enabling conditions for LCTs' deployment.
- **Investor:** is the stakeholder that provides the financing means. It can be from the private or the public sector and very often several investors provide means either for a project or for the development of a specific LCT. The investor can become or not the final owner of a project.
- **Owner:** Refers to the final owner of a building or parts of a buildings (e.g. apartment or an office). Final owners are not always included in deciding upon the deployment of LCTs and you need to assess if final owners are relevant or not for assessing barriers to LCTs in your specific case.
- **Manager/Developer:** is the stakeholder responsible for running the project or the stakeholder responsible for developing a LCT that succeeds in the market. The manager/developer is in direct or indirect relation with all other stakeholders and plays a key role both in communication and decision-making.
- **Planner:** When you use the technology entry point the planner is the one who designs the technology, whereas when you use the project entry point, the planner is the one who designs the project. Planners analyse the feasibility of a project or a LCT and undertake or supervise all design steps from the idea to the detailed planning.
- **Constructor:** Constructors are either the stakeholders in charge of producing a LCT in series (technology entry point) or the stakeholders responsible for the actual activity of constructing a building (project entry point).
- **Technology provider:** when using the technology entry point; the technology provider refers to the unit(s) within a company that provides inputs for developing and/or producing a LCT. When using the project entry point; it refers to those stakeholders that provide either LCTs to a project or technologies that are in competition with LCTs. In this case it includes industries producing LCTs (technology producers) as well as retailers (which are intermediaries between the technology

producer and the technology consumer/user). Technology producers and technology retailers can have different interests and motivations for promoting LCTs. Thus if you have both in your project we recommend to distinguish them into two different roles.

- Marketing managers: when using the technology entry point the marketing role includes mainly two activities: sales and marketing. These two roles are often but not always combined in one single department or company unit. When using the project entry point the marketing role refers to the stakeholder responsible for selling the building units (e.g. apartments, offices or shops). An extensive use of LCTs can become an attractive marketing/selling argument especially if these technologies generate monetary savings over the use phase.
- User: refers to the final user / occupier of a building and the included LCTs . Most climate mitigation strategies related to "service demand reduction" depend upon the behaviour of the LCT's users (e.g. proper use of ventilation technologies for reducing energy consumption).
- General public and public opinion's representatives: refers to those segments of the civil society that are relevant for the deployment of LCTs either at the level of technology development (technology entry point) and /or within a specific project (project entry point). A consumer representative often represents the public opinion and is in charge of securing the consumer's interests. Consumer representatives can have a high influence on the acceptance of a LCT or of a project (using LCTs) especially when considering large projects i.e. projects of multiple buildings (with multiple functions).

Not all roles are relevant for the assessment of barriers in all cases and for both entry points. Thus you will need to clarify which of these stakeholders are relevant in your case (see section 6.3 for the corresponding steps). Further, you need to be aware that stakeholders here are both objects of research (we want to analyse their decisions) but as well part of the assessment process. In a transdisciplinary research process, you want thereby to induce dialogue, i.e. mutual exchange and learning among the stakeholders involved. Not in all assessments, it will, however, be possible to include all stakeholders in the process but still as many as possible should play an active role by bringing their knowledge in and learning from the results.

3.4 Institutional component

It refers to the institutional framework that applies for your system. Institutional framework includes the set of formal laws, regulations and procedures as well as the informal conventions, customs, and norms that shape socioeconomic activity and behaviour. In this guideline we focus on the formal elements from the institutional framework and their impact on deployment of LCTs in buildings. For instance, the institutional framework can create enabling conditions that promote the deployment of LCTs through legislation (reducing the use of non-LCTs or providing credit for LCTs' development) or through incentives (e.g. subsidies for LCTs).

3.5 Timeline

Timeline refers to the different phases that need to be considered when assessing barriers to LCTs. The timeline for projects is defined differently according to the context (see Table 1).

The example shows that even though some generic project phases can be derived, their exact goals and order highly depend on the country context. In the German performance phases for example the

Table 1
Project phases .

Construction project phases

Generic project phases		Swiss model according to SIA 112 (2015)		German performance phases accordting to HOAI (DE S.139)
Main phase	sub phase	Phase	Selection	Performance phase
Planning phase	Strategic planning	Strategic planning	Clarification of needs and altenatives	LS1, Clarification of the basic information
	Feasibility studies	Pre-studies	Project definition and feasibility studies	LS2, Pre-planning
			Auswahlverfahren	
	Design	Design	Pre-project	LS3, Design planning
			Building project	LS4, Permits planning
			Permits and requirements	
Construction phase	Bidding / Tendering	Bidding/Tendering	Tendering, comparison and assignment	LS6, Preparation of the specifications LS7, Tendering
	Detail planning	Realisation/Building	Building planning	LS5, Building planning
	Building / Construction		Building	LS8, Monitoring
			Inbetriebsetzung, Abschluss	
Use phase	Operation	Use phase	Service	LS9 Monitoring and documentation
	Maintenance		Maintanance	

detailed planning (e.g. LS5 Building planning) is clearly placed before (see numbering) the bidding and tendering phase, while in the Swiss model these two phases seem to run in parallel or even in reversed order. Nevertheless, the planning phase ending with the construction permit and the construction phase with the handover of the property seems to be a more universal feature found in both countries analysed. However the exact processes and stakeholders involved throughout the process will in addition depend extensively on the type of project[19]. The process complexity in large development projects - like the redevelopment of the airport Berlin TXL used as a case study in this guideline – is an order of magnitude higher than in a small refurbishment project like the replacement of a heating system for example.

When using the technology entry point the timeline corresponds to the R&D phases in the specific industry. If you use the technology entry point and there are no clearly defined phases in your industry consider the following phases for the technology entry point: innovation stimulus, research and development, market adoption and market diffusion[20].

19 Girmscheid, G., & Selberherr, J. (2011). Projektabwicklung in der Bauwirtschaft - Projektprozesse. *Modulor*, 04.

20 Pleschak, F., & Sabisch, H. (1996). *Innovationsmanagement*. Stuttgart: Schäffer-Poeschel, Vahs, D., & Burmester, R. (2005). *Innovationsmanagement von der Produktidee zur erfolgreichen Vermarktung*. Stuttgart: Schäffer-Poeschel.

3.6 Interactions

All components of a system interact with each other over the life span of a technology innovation or project (see Figure 5). There are plenty of examples of such interactions: daily sun exposure (natural environment) has an impact on the feasibility of solar panels (technical environment), preferences for close/open windows (social component) has an impact on heating and air conditioning systems (technical environment), social preferences and aesthetic values (social component) have an impact on regulations (institutional component).

Similarly, a new regulation (institutional framework) can become the stimuli for a technological innovation (technological environment) and/or can promote the use of a given LCT (social component).

All these interactions are important for the deployment of LCTs, however the decisions made by stakeholders over time play the key role on which technologies are developed and applied and on how several LCTs are used.

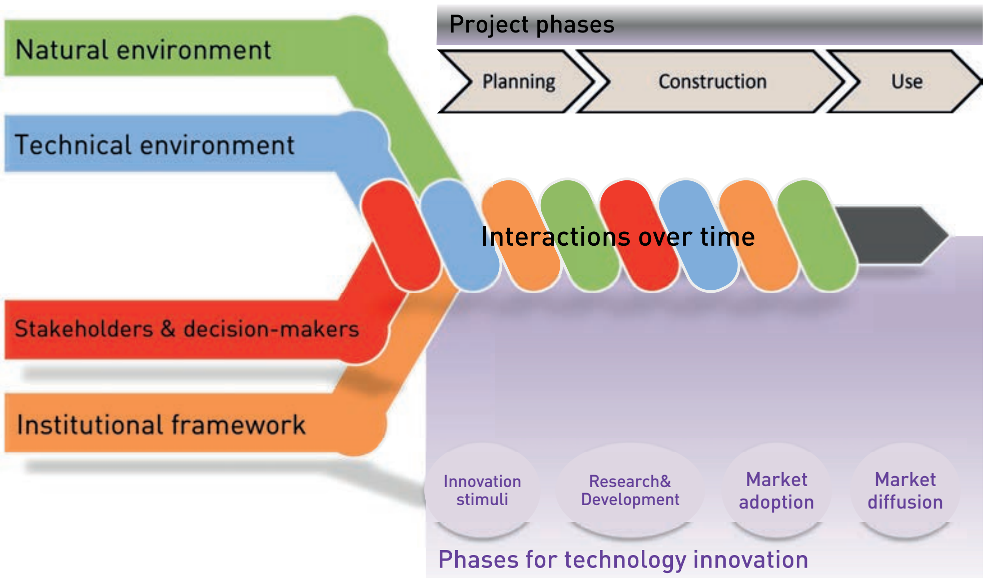


Figure 5
Interactions between system components over time.

Thus the deployment of LCT depends strongly upon decisions of several stakeholders over the timeline and these decisions can become an enabling or hindering factor. Thus it is important to understand the roles of different stakeholders *over time* and to identify the main decision-makers in each phase, their level of influence of each stakeholder over the different phases. The analysis of the social interactions is necessary for understanding who makes relevant decisions on deployment of LCTs, when and based on which criteria (see section 7.2 for concrete steps for analysing roles and social interaction over time).

3.7 Typology of barriers to LCTs

The deployment of LCT in buildings depends upon several factors beyond the availability of the given technology, i.e. the level of deployment is system dependant. In this guideline we include 6 main factors, which result from the inter-relations between the system components. These factors are awareness, acceptance, financial feasibility and competitiveness, policy and regulation, workforce capacity and technical capacity (see Figure 6).

Lack of awareness, acceptance, of a supporting regulatory framework, of workforce capacity can create a barrier to deployment of a given technology or in general to deployment of LCT in buildings. Lack of financial incentives i.e. lack of financial competitiveness in the short and medium terms or upfront costs that are too high compared to other technology can also hinder the deployment of LCTs.

Awareness implies that decision-makers, users and any other relevant stakeholder are aware of the existence and benefits of a given LCT and about the possibility to combine LCTs in order to increase co-benefits.

Acceptance means that decision makers, users and any other relevant stakeholder are willing and prepared to use LCTs in an efficient manner. Acceptance has to do with values and perceptions as well as with information.

Financial feasibility covers all financial aspects related costs and investments required for developing, producing, buying, installing and/or using a LCT. Cost efficiency is a major objective for most stakeholders, however cost efficiency for the producer of an LCT can be in contradiction with cost efficiency for the user of a LCT.

Policy/regulation, as clarified in section 3.4 it is key to have policies and regulations that enable and whenever possible even promote the design, production and use of LCTs.

Workforce capacity refers to the capacity and competences of mainly developers, planners and constructors to plan, design with and install LCTs.

Technical suitability refers to the fulfilment of technical requirements that some LCTs have on the existing infrastructure so that the technology can be used. Technical requirements are different across LCTs and according to the technical and natural environment in which LCTs are applied.

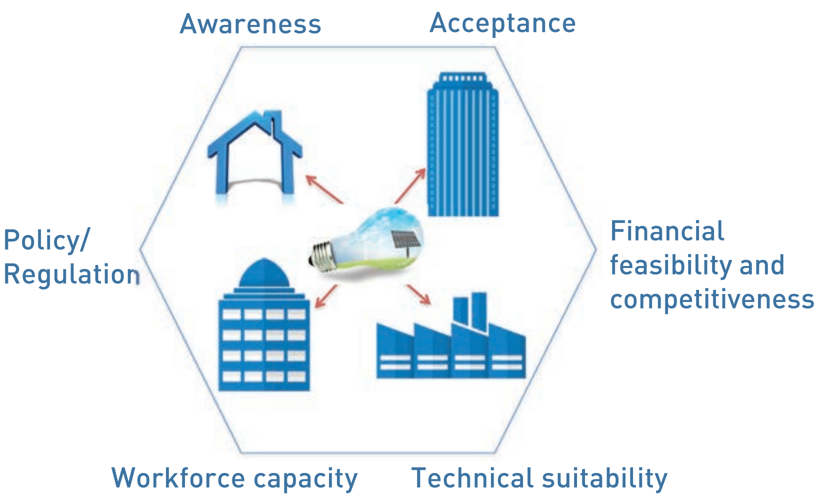


Figure 6
Factors affecting deployment of LCTs.

4 The role of Knowledge Management

The main purpose of this guideline is to provide a consistent approach for assessing barriers to LCTs according to the specific system where these occur. Such an assessment shall incentivize and facilitate measurements for overcoming these barriers. The implementation of the guideline builds on a multi-stakeholder process, facilitated by researcher/s and/or consultant/s. Thus the assessment process asks for a well organised form how knowledge is collected, exchanged and stored. Knowledge Management (KM) is one option and presents an overarching approach to facilitate this. Further, KM can serve as well to overcome the identified barriers, besides many other options. On the one hand, avoid the creation of new barriers and, on the other hand, mitigate existing ones. In fact, KM is relevant in all kind of collaborations, be they short to medium term, in the form of projects or programmes, or continuous in an organisational or cross-organisational context as well as for the innovation process aimed at creating LCTs. KM is important from the very beginning of all these processes, i.e., when setting up a project or collaboration and remains important over all phases.

Due to its wide potential as a tool in the assessment and for overcoming barriers to LCT's deployment we have included a specific section on KM. This section elucidates how the lack of KM can become a barrier to the deployment of LCTs and, in contrary, how professional KM can help overcome these barriers.

4.1 What is KM and how can it help reduce barriers to the deployment of LCTs?

KM is **defined** here as "the deliberate and systematic coordination of an organization's people, technology, processes, and organizational structure in order to add value through reuse and innovation. This is achieved through the promotion of creating, sharing, and applying knowledge as well as through the feeding of valuable lessons learned and best practices into corporate memory in order to foster continued organizational learning"[21]. This definition includes the creation of new knowledge and the collection, storing and distributing of existing knowledge. KM should enable all relevant stakeholders (from individuals to organisations) to share knowledge and facilitate learning.

KM should be **established** by encouraging people to (i) **share** knowledge, (ii) establish processes that capture, locate, collect and distribute knowledge, and (iii) set up an IT infrastructure that easily stores, organizes and retrieves knowledge. These aspects are also influenced by informal conventions, customs and norms in and between organizations.

21 Dalkir, K. (2011). *Knowledge Management in Theory and Practice* (second ed.). Cambridge MA: MIT Press. p 4.

KM is usually **applied** within an organisational structure. Here, KM is looked at on the single organisational level and on a larger scale, i.e., beyond single organizations, because the deployment of LCT can also be decided on a level that involves multiple organisations (see project entry point). However, it is an additional challenge to look at KM across organisations, because of the lack of organisational structures that can be used for KM (focusing on people, processes and infrastructure is easier within a single organisation than across organisations). Furthermore, laws and regulations concerning intellectual property rights might render knowledge exchange more difficult and in the case of confidential industrial knowledge even undesirable.

The following sections address barrier types that can be influenced and overcome by KM (especially lack of awareness, of acceptance or of workforce capacity; see Figure 6). These types of barriers typically emerge from an information asymmetry or gap, which refers to situations where there is no awareness or acceptance of relevant information and/or the information is not available where it is needed. There can be several information asymmetries relevant for the deployment of LCTs, such as:

- A project starts with a (technology) solution instead of a stakeholder problem; an approach that risks to ignore stakeholder needs
- Multidisciplinary teams work in silos with insufficient exchange of information
- No identification of knowledge gaps, knowledge providers and receivers (who knows what and who needs to know what from whom) is performed
- Lack of awareness of, access to and exchange of previous knowledge
- Lack of knowledge about stakeholders and market needs
- Lack of stakeholder knowledge on (new) LCTs

The role of KM is first to raise awareness of information asymmetries as potential barriers, and then to provide people, processes and IT infrastructure to overcome them.

4.2 Technology Entry Point – lack of KM as a barrier to deployment of LCT

Technologies can be deployed within or for a company (e.g., by universities or service contractors), which results in different potential deployment barriers. Furthermore, large and small companies face similar but also very specific KM challenges, which are considered below.

Technological development in companies is mainly solution and not problem driven. Often, new inventions result from research questions and a market need is created afterwards (personal communication, D. Hofstetter). In such a situation KM can help to improve communication between various departments in a LCT supplier enterprise, to overcome the information gap between users and producers or to increase awareness of existing technologies. Indeed KM can play an essential role in the outreach approach, i.e., distributing and sharing information on LCT, and informing different stakeholders so they can make informed decisions concerning LCT. This can even include sensitizing the general public through media presence, publications, lobbying and informing policy and regulation makers. Thus KM needs to (i) identify relevant knowledge gaps, (ii) analyse who are the relevant knowledge providers and users, and (iii) provide processes and an (IT) infrastructure to connect them. Technology is often developed within multidisciplinary teams. To avoid silos and foster exchange of knowledge, early and regular interaction and exchange of knowledge between design, production and application is needed. Knowledge can be obtained from inside and outside the organisation through formal and informal networks such as informal, e.g., personal network, formalized networks like Communities of Practice (CoP) or specific collaboration projects.

Knowledge **transfer and learning** within the organisation can be based on previous experience in similar fields or by transferring this knowledge into new areas.

4.3 Project Entry Point – lack of KM as a barrier to deployment of LCT

KM is traditionally applied within a specific organisational context such as a company. Projects tend to have a different and less stable organisational structure, which can be a hurdle to the steering and managing of knowledge. Below are listed a number of barriers for the deployment of LCT in projects if KM is lacking and potential steps to overcome them:

Lack of KM can be a barrier to deployment in projects that involve multiple (external) stakeholders from different fields (project developer, constructors, architects, etc.). It requires careful management in order to transfer knowledge between independent projects and independent project developers and also for sharing knowledge between them. Again, people, processes and IT infrastructure are the building blocks for KM. Analysing the knowledge gaps and identifying and connecting knowledge providers and knowledge receivers are important steps.

KM can help overcome barriers by distributing knowledge and connecting the different stakeholders through platforms, networks, CoPs etc. Their specific needs and expectations (e.g., recognize the ownership of knowledge) should be taken into account. For example, the developer of a typical building project often has no expert knowledge on specific technologies such as LCT, but relies on (external) experts to suggest and decide on certain technologies. To enable knowledge exchange and learning, the project lead should promote a culture of knowledge sharing and prevent „not invented here" reaction by providing the right incentives. There are indeed key lessons learned over time and in different sectors, that might be of interest in the context of overcoming barriers to LCTs in buildings (s. Box1).

Box 1 – Lessons learned from interviews with KM experts from representatives from the private and public sectors, the civil society and academia

- All interviewees pointed out the importance of KM as a top leadership task.
- KM should be seen as an investment, not a cost factor.
- KM needs to be aligned with the overall organisational strategy and embedded in organisational processes supported by project and quality management.
- Cultural change to stimulate knowledge sharing is key. Knowledge sharing is stimulated if the organisation acts credibly, so people have trust, keep ownership of their knowledge assets and benefit themselves from knowledge exchange.
- Tangible outputs such as videos and success stories support learning and involve people by making KM a hands on experience
- Easy to use IT tools are important for knowledge storing and distribution but only a means to reach the KM objectives.

5 Transferability

In the context of this guideline transferability refers to the degree to which results from the assessment of barriers to deployment of LCTs from an explicit context (technology, project, city, country/region) can be generalized or transferred to other contexts or settings[22]. Here we differentiate between two options: a) when transfer is possible and b) the possibility to learn through comparative analysis of several studies using this guideline.

As we have clarified in the previous sections of this theoretical framework barriers to deployment of LCTs are highly dependent of the system where they occur, thus transferring results of the analysis of barriers in one system to another can be misleading. A certain level of transferability exists if the specific systems are clearly comparable. However, even in those cases transfer of results shall not be done one to one and it is necessary to analyse the potential impacts on barriers due to those elements in the system that are not similar or comparable.

Far more appropriate is to build up knowledge through comparative analysis of results obtained using this guideline in several (comparable) systems and in a consistent manner[23]. The primary reason for undertaking such comparative analysis is the possibility to gain a better understanding of causalities behind the creation of barriers as well as learning from experiences on overcoming these. A key requirement for comparative analysis is transparency and reliability of the data, assessment method and thus results from both cases, which is achieved through the consistent use this guideline as an overarching methodology for assessing barriers. By doing so it becomes possible to attribute similarities or differences in the results either to the system or to the specific barriers. Comparative analysis of several studies can also facilitate the scaling up results. For example, common results across the analysis of barriers to deployment of LCTs in several sub-national entities (e.g. states or departments) can be used to generate conclusions and recommendations for reducing barriers at the national level. More detailed advice on comparative analysis and transferability of results can be proposed once the present guideline has been more widely used and will become thus a next step.

22 Lincoln Y., Guba E. (2002). The only generalization is: There is no generalization. In Gomm R., Hammersley M., Foster P. (Eds.), *Case study method* (pp. 27–44). London: Sage.

23 Multiple case study design, see Yin, R. K. (2013). *Case study research: Design and methods*. Sage publications. Qualitative comparative analysis (QCA), see Ragin, C. C. (2014). *The comparative method: Moving beyond qualitative and quantitative strategies*. Univ of California Press.

Part II Practical steps

This second part of the guideline explains the concrete steps required for assessing barriers to the development and deployment of LCTs. It includes four major steps: 1) defining the system, 2) identifying main barriers,3) characterizing barriers and 4) reducing barriers through improved knowledge management (s. Figure 7). Each of the major steps include its own "small" steps, which are described in detailed in the following sections.

The first major step is to define the specific system where your assessment takes place. It covers the clarification of the entry point (technology or project) and the description of all components of the system, including natural environment, technical environment, stakeholders and decision makers as well as the set of institutional agreements (laws, policies, etc.) that affect your technology or project. Further, the description of the system includes the

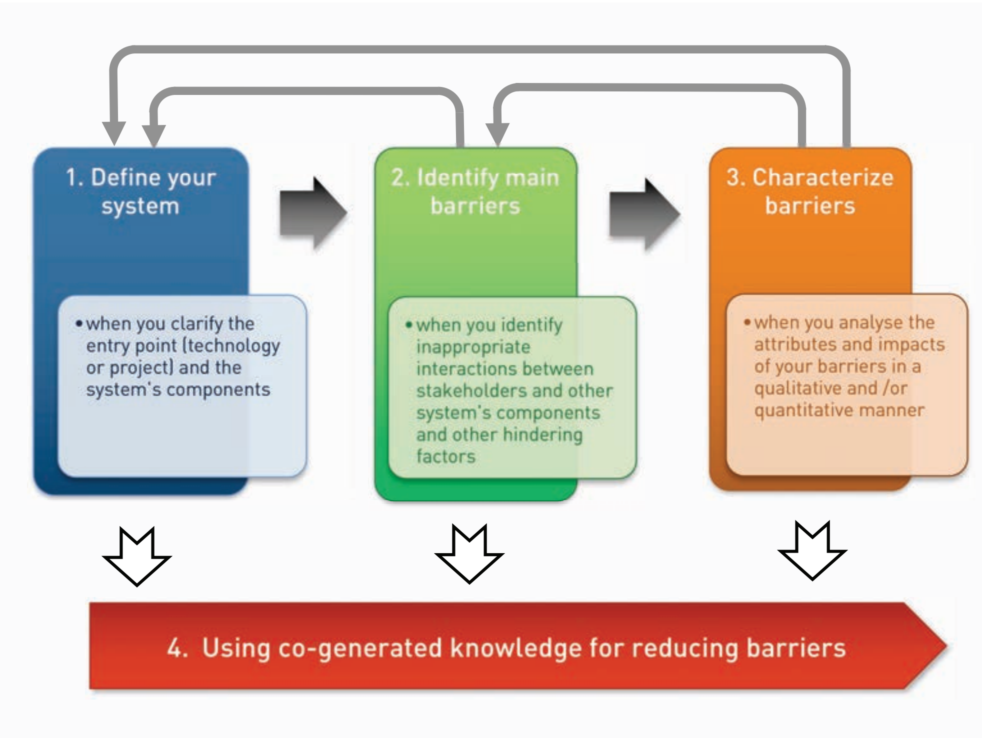


Figure 7
Steps for assessing barriers to the development and deployment of LCTs in buildings.

clarification of the specific phases in the system's timeline. The theoretical background for this first step of defining your system is explained in sections 3.1–3.5 and the practical steps are explained in sections 6.1–6.5.

The second major step in Figure 7 refers to the need to identify the barriers that are relevant for your system. In section 3.7 of the theoretical framework we have presented a typology of barriers including lack of awareness, lack of acceptance, inappropriate policies and regulations, lack of financial feasibility and competitiveness, lack of workforce capacity and lack of or reduced technical suitability. However, as not all barriers are present or important in all cases, you need to identify which of these barriers are relevant in your specific case. Furthermore, you need to identify the stakeholders and decision makers that are involved in the barrier and those who can help to overcome it. The practical steps for identifying the main barriers relevant to your system are explained in sections 7.1 to 7.3.

The third major step of the assessment as presented in Figure7 deals with how to characterize the specific barriers that are relevant for your system. You can characterize either attributes of the most relevant barriers (e.g. if the barrier is lack of awareness of a given LCT by architects you might want to know how many architects do not know your product) and/or the impacts of these barriers (e.g. if the barrier is lack of awareness you might have to know the impact on reduce selling units or the impact on GHG emissions that have not been reduced due to this specific barrier). Attributes and impacts can be characterized in a qualitative or in a quantitative manner. Sections 8.1 and 8.2 explain how to undertake the characterization of barriers in your system.

Undertaking steps 2 and 3 can have an impact on the previous steps. For instance, when you analyse the interactions in your system for identifying key barriers you can find new relevant stakeholders. The grey lines in Figure 7 indicate the possibility that after undertaking steps 2 or 3 you might need to review or complete the previous steps. You should take as much iterations as necessary until completing your assessment and as far as possible with the resources available.

The last major step as shown in Figure 7 builds up on the knowledge gained from undertaking steps 1-3, where you have gained a good understanding of the problem. Managing this knowledge and combining it with the existing knowledge from the relevant stakeholders and decision-makers *shall promote concrete actions that help to minimize or overcome a set of barriers in a given system*. Co-generated knowledge is not a solution per se but an essential initial step towards reducing barriers to the deployment of LCTs in buildings. As explained in section 4.0 Knowledge Management is system dependent. In sections 9.1 and 9.2 the guideline presents some initial steps for improving the management of knowledge related to barriers at the level of technologies or projects.

Before you start with the assessment of barriers in any system you need to clarify the scope of your assessment. It means that jointly with your client (e.g. a project manager or the selling department of a company producing LCTs) you have to clarify the entry point (technology or project), what are the specific objectives of the assessment, the relevant questions and how far your client wants to go i.e. what resources the client wants to invest in terms of time and money. This will have an impact on both, which of the three major steps you undertake and which methods you use for each step. In section 9.1 and 9.2 you find a check list and a set of methods suitable for the different steps. You can use these section for selecting appropriate methods according to your resources and for checking your analysis for completeness.

6 Defining the system

At this stage you should have already clarified with your client if your assessment has a technology or a project entry point (see Section 3.1 for clarification). In general terms it can be said that if your client is a producer of a specific LCT or a group of LCTs the "technology entry point" is most certainly the one pertinent for your study. If your client is a project manager, then you will most likely use the "project entry point". However, if your client is a policy maker, a person responsible for urban development, or a trader of LCTs then you need to clarify with your client which entry point is more appropriated.

Once you have clarified the entry point you can proceed to define the system by describing its key components (see Sections 3.1 to 3.6 for the theoretical background on the systemic approach). Figure 8 presents the process for defining these components, including the description of the entry point, the clarification of the natural and technical environment, the identification of the key social actors (stakeholders and decision-makers) and relevant institutional framework as well as the clarification of the timeline.

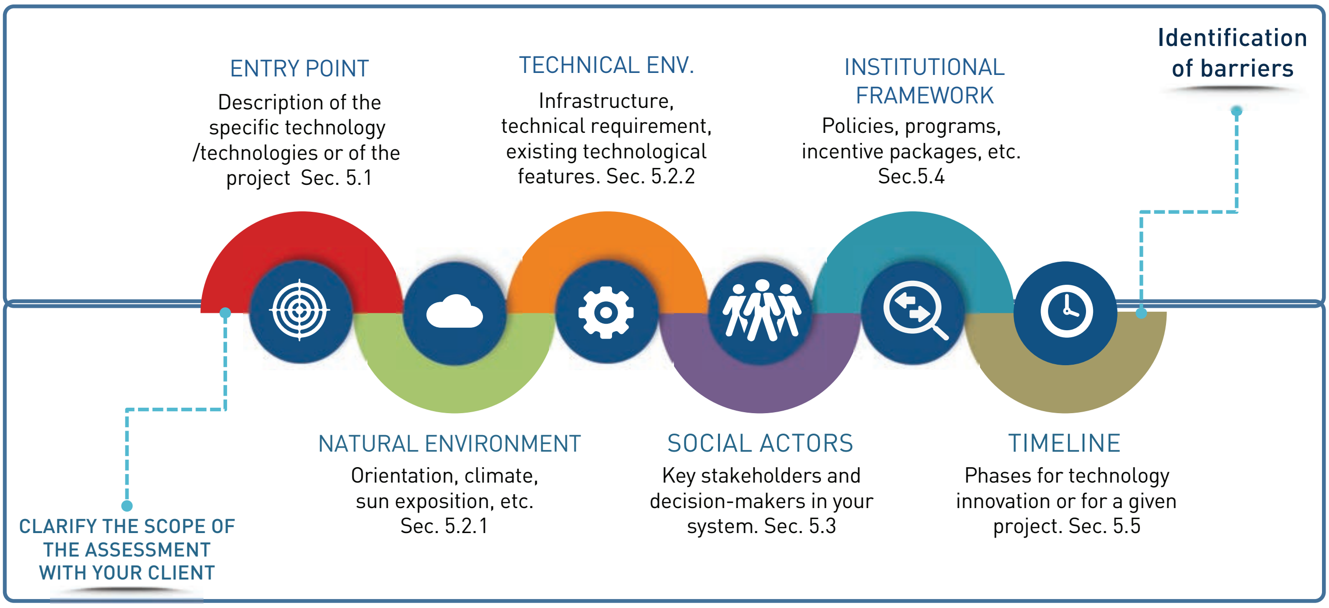


Figure 8
Process for defining the system.

The steps in this process are interdependent, meaning that what you consider in one step can affect others (e.g. what you identify as relevant institutional framework can have an impact on who is consider a key stakeholder or decision-maker). Thus the process of defining the system is not completely linear and it can be necessary to check previous steps after finalising each step. According to the resources on your disposal you can take as many iterations as necessary. If the resources are not enough for getting a complete understanding of the system components, then you need to document what component you consider incomplete and why.

6.1 Entry point

6.1.1 Technology entry point

If you are using the technology entry point the first step is to describe the specific LCT or the group of LCTs included in your assessment (see Figure 8). You can describe the LCTs using Table 2. Box 2 provides a real case example, that can facilitate your use of Table 2.

Table 2
Technology Description.

Name of the Low Carbon Technology	
Basic principle	Shortly explains what is the technical principle used for the given technology.
Status	It can be that a technology is rather in development, new in the market (n≤3 years) or present in the market for a medium to long period (n>3 years).It refers to the "market readiness".
Types of building where your technology can be used	State in which types of buildings your technology can be used: a) single family house, apartment buildings, commercial/government buildings and/or industrial buildings or any combination. b) new construction and/or renovation (can the LCT be used in renovations or it needs to be installed from the beginning).
Applied in the following building components	Select for which components your LCT can be applied to, e.g. roof, structure, façade, internal technology, windows, etc. If your technology is not standing alone but depends upon a more systemic approach in the whole building, e.g. ventilation system) please stay it so and explain the specific system and the role the LCT plays in it.
Minimum requirements	These are the requirements without which your LCT can not be used or it becomes redundant. It can include i.a. technical or legal requirements or conditions required from the natural environment and technical environment (see Section 3.2 for clarification on environment).
Facilitating requirements	These are requirements that increase or improve the performance of your LCT.
Mitigation option	Explain why you consider that this technology is a "low carbon" option. Whenever available provide baseline information
	Explain what other technologies that are used in the baseline are substituted and to which extent
	Explain why your technology should be considered as LCT and state the potential GHG emission reductions. Whenever possible document how this information was produced

Box 2 – Example of a technology description

Phase-change Material (PCM) Windows:

Source:	Interview 05.10.2015, CEO GlassX AG, Zurich
Basic principle:	The PCM-Material stores the solar (and internal heat) energy during the day and releases the energy into the building during the night working as a thermal storage. The specific system considered had in addition an exterior prism glass pane attached reflecting solar radiation from steep angles (in summer) and letting low-angled sunlight passing through in winter month (a feature not exclusive for PCM windows).
Status:	Present in the market since 2000 (Swiss Solar Price 2001)
Type of building:	The technology is primarily applied in new residential multi-family buildings due to historic reasons, besides having a large potential for retrofitting over-heated office buildings.
Building components:	PCM windows replace normal windows or façade elements.
Minimum requirements:	PCM windows are slightly heavier than comparable windows or façade elements. This additional weight has to be carried by the structure. In addition, they require lower temperatures at night to release the stored energy from the day, climatic conditions with an average annual temperature below 20°C are therefore a must.
Facilitating requirements:	Building design: Sunny location and large south facing façade
	Structure: Modular instead of massive construction as with the latter the additional thermal mass storage of the PCM windows is negligible.
	Technical building equipment: Consideration in the energy concept is a key aspect. This allows reducing the size of heating and cooling systems, in favour of the PCM windows.
Mitigation option:	PCM windows is one puzzle piece of passive solar use in buildings. Well-designed buildings can save up to 30% energy, although figures from reference buildings are lower at still considerable 15-20%, compared to conventional buildings.
Baseline:	Measuring the effect of PCM windows on its own is however difficult as they are always integrated in entire building energy concepts. Therefore, the baseline are conventional buildings without specific passive solar technology. Then of course the question rises what passive solar technology is? That could be any normal window or just highly insulated panes with a device for sunlight angle specific shading. The baseline therefore has to be specific to the project considered, as it is design and location specific.

6.1.2 Project as entry point

If you are using the project entry point the first step is to describe the project under assessment (see Figure 8). Table 3 guides you to the main points that you need to consider for characterizing a project.

Follow these steps for defining the system boundaries when using the project entry point. Box 3 presents a preliminary description of the project on the Berlin TXL – The Urban Republic[24].

24 See further information about the Berlin TXL – The Urban Republic under http://www.berlintxl.de

Table 3
Characterization of project.

Name of the project	
Place	Including a description of the location and its natural conditions (see 3.2)
Current phase	According to the phases included in section 3.5 timeline
Management organization	Breve description of the management structure responsible for the project. A detailed analysis of the key stakeholders and decision-makers will be done when analysing the social component (Section 6.3)
New building or renovation?	
Project's function(s) and number of objects	Make a short description using the rational of the matrix in Table 3
Size	In area and volume
Partners	
Is there any specific requirements about building materials?	Either in general for the whole building or group of buildings and/or for specific building components e.g. roof, structure, façade, internal technology, windows, etc. Such requirements can be defined e.g. by the investors who prefer one material of by the local authorities (e.g. if your project is located in an historical site).
Technical requirements	E.g. expected fire resistance, expected water consumption, expected energy consumption, expected inside temperature during day and night, etc.
Available technical environment (currently)	See section 3.2
Expected technical environment by construction phase (if different than above)	See section 3.2

If you have more than one building type in your project, then you should complete Table 4 describing the different types of buildings. Thus the four types mentioned before should just serve as guide for characterizing the buildings considered in a specific case (see Table 3).

Several LCTs can be used in one project. Thus potentially useful LCTs need to be identified. The more functions and the more building types your project has, the wider the set of LCTs that can be used. Identifying potential LCTs in a rather simple project (e.g. one single-house) can be done directly in consultation with the architect and building engineers (if different), however if you are assessing barriers for LCTs in a project with several building types and/or combined functions then the system is more complex and consequently more potentially useful LCT need to be considered. In this case you will need to include specialists and consultants as well. A selection of methods for identifying the barriers is presented in section 10.2.

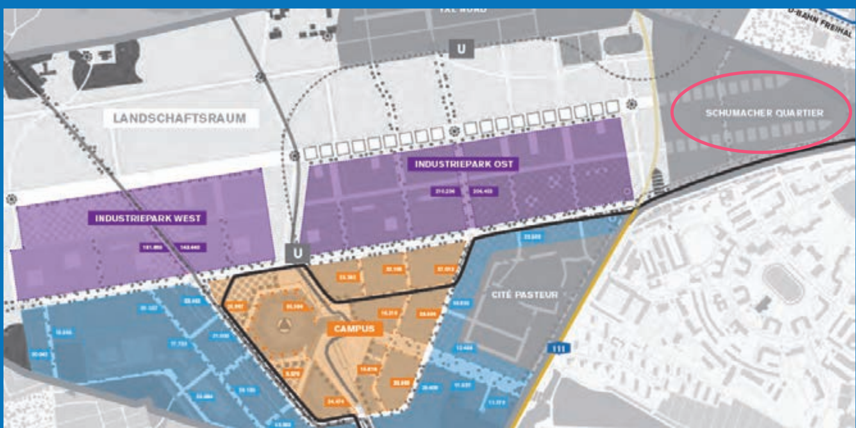
Table 4
Matrix for characterizing building function and number of objects.

Function / Number of objects	Single-family house	Apartment building	Commercial or government building	Industrial building
Single-object				A
Single object with multiple functions		B	B	
Multiple objects with one function	C			
Multiple objects with multiple functions	D	D	D	

Note: the matrix presents four examples: A is a project for a single industrial building i.e. a factory; B is a project of one single building with a commercial area in the first two floors and apartments in all others; C is a project where several single-family houses will be built and D is a urban development project where several single family- houses (one function) are combined with buildings that include commercial/government and residential functions. When using the matrix you need to differentiate between new buildings and restoration/rehabilitation projects

Box 3 – Example of a project description and how we jointly identified LCTs in the project on Berlin TXL "The Urban Tech Republic"

This Schumacher quarter at the former Tegel Airport will be home to approximately 5,000 apartments for the growing city of Berlin. The urban technologies that are developed and produced in the "Urban Tech Republic" will be used in the new residential quarter. Technologies that save energy and reduce costs, for example. And there will be apartments, day care, schools, and shopping options for people who work, conduct research, and study here. This neighbourhood will help make the Schumacher quarter a "city of the future[25].



One element of this housing area was selected as a first case study from Berlin TXL: a student housing project. First inspiration comes from the Danish "Tietgen Residence Hall". A type of residence that supports and develops an attractive housing and student area[26].

A second case identified was the renovation of the current airport terminal. This building should be modified as office and shopping building.

25 Source: http://www.berlintxl.de/en/about-berlin-txl/development.html

26 Source: http://tietgenkollegiet.dk/en/home/

6.2 Environment

Figure 8 shows that after describing your entry point you continue with the description of the natural and technical environment. Section 3.2 contains the theoretical framework explaining why it is important to clarify both types of environment. The two sections below explain how to proceed.

6.2.1 Natural environment

When you use the *technology entry point*, you need to clarify under which natural conditions your LCT behaves best and if there are natural conditions under which your technology cannot or should not be used (see Box 4 for an example).

If you use the *project entry point*, the natural environment will provide specific conditions to which your building needs to respond. This includes local climate, sun exposition, weather, wind, type of soil and rain patterns. For example, buildings located in places with a long winter period characterized by very low temperatures provide a better opportunity for LCT in the

Box 4 – Example of requirements due to technical or natural environment on low carbon concrete

Low carbon concrete:	
Source:	Interview 22.10.2015, Head of Advanced Concrete, LafargeHolcim, Holderbank, Switzerland
Baseline:	Carbon emissions depend from the type of cement but according to the interviewee 250 $kgCO_2/m^3$ structural concrete can be considered as an average value.
Mitigation options:	Technically it is possible to reduce this value to $100kgCO_2/m^3$ concrete. This would however require by jointly applying the following five steps: 1. use of low footprint mineral additions: (clinker substitution), 2. use of mineral activator such as high strength class cement, 3. use the mix design concept of high performance concrete, 4. optimize the use of water reducers (additives), and 5. not only focus on strength but mainly on durability for sustainability performing concrete.
Technical requirement:	Unlike other LCT, with LCC, not the specific application type or exposition class of the building element are the technically limiting factors but the line of concrete production. Steps 2–5 on the way to LCC are all in the concrete production process and cannot or only partially be influenced by the cement supplier. Furthermore, they require a ready-mix system (i.e. lorries with constantly mixing the concrete up to the construction site, to control all variables). However 50% of the world cement market is bag market, mainly used in developing countries where concrete is mixed by hand on site. This procedure requires approximately 20% more cement than the ready-mix system, which creates a perverse incentive for cement suppliers with a low carbon goal.
Natural requirement:	Number one priority of the five steps mentioned above is the reduction of CO_2 in cement through clinker substitution as most CO_2 in concrete comes from clinker. This requires however the presence of suitable substitution material (e.g. fly ash, slag, pozzolan, limestone). These are for example rare in Switzerland which could lead to comparably high CO_2 impacts of Swiss cement mixtures.

heating system, whereas buildings located in areas with long sunny periods can offer better opportunities for LCT aimed at using solar energy. Thus when using the project entry point, you need to describe the requirements and opportunities related to the natural environment and analyse which LCTs fit better to the specific natural conditions.

6.2.2 Technical environment

If you use the technology entry point, then you need to specify the minimum and the facilitating requirements that your technology has on the technical environment (see Box 4). This information complements the technology description (Table 1).

6.3 Social component: stakeholders and decision-makers

When using the project entry point the technical environment is one factor that co-determines which LCTs can be used in the specific project. As the technical environment varies from project to project you need to understand which are the opportunities and constrains that a given technical environment provides to your project as a whole and to the most promising LCTs (as identified following section 3.1.2). This information should be included in the characterization of the project (Table 2).

You need to identify and characterize the most important stakeholders in your system and understand the relationships between them. If there is an existing and agreed stakeholder classification in your context (e.g. WBCSD or SIA) please use this classification for identifying the stakeholders relevant to your system and their specific roles over time.

If there is no stakeholder classification or if you don't feel confident with the existing ones, then use the classification included in Section 3.3. Your system can include only some or all of these roles; small projects tend to have several roles within one organisation or even by a single person. When analysing barriers to LCTs in big industries and /or in big projects there can be several individuals and/or organisations in each of these roles and you need to identify the most relevant for your case using the format presented in Table 5.

When using the technology entry point several of these stakeholders are part of the same organization and have some level of (at least formal) communication with each other. When you use the project entry project it is possible that some stakeholders know each other previously but one can expect that several stakeholders don't know and even don't notice each other. Further, different stakeholders have different priorities, perceptions requirements and preferences with regard to LCT. Thus the stakeholders and policy-makers that you identify here are a key input for analysing the social interactions (Section 7.2).

Table 5
Matrix for stakeholder identification.

Role / Name of the stakeholder	Regulator	Investor	Manager /Developer	Planner	Constructor	Technology provider	Marketing	User	Public opinion	Consumer representative

6.4 Institutional framework

You need to undertake the following steps for analysing the impact of the institutional framework:

- Identify the key legislation regulating the development and use of LCTs in the building sector. Legislation includes laws, directives, regulations or other acts provided by the legislative. Consider legislation at local, national and regional level including taxes, subsidies and any other incentive scheme or mechanism. Keep in mind that in regions like the European Union there is legislation at the regional level (e.g. the 2010 Energy Performance of Buildings Directive) and that this legislative framework can be in contradiction with national or sub-national legislation.
- Identify legislation from other sectors, especially energy sector and settlements (i.e. urban law) that can have an impact on the deployment of LCTs. Consider legislation at local, national and regional levels. In regions like the European Union there is legislation at the regional level (e.g. the 2012 Energy Efficiency Directive).
- Analyse the institutional framework in two steps; the specific regulation alone and the interface with other regulations. Be aware that the interface with other regulations can include regulations at different levels (e.g. the interface between an European directive and a national law). Use the following guiding questions for your analysis:
  A) specific regulation
    a. Does the regulation facilitate or make it difficult to develop, install or use LCTs?
    b. Does the regulation include incentives for LCTs? If yes, who profits from the incentives and who is excluded? (i.e. is your company/your project a potential beneficiary from an incentive?)
    c. Is the regulation already enforced or will it be enforced during the time period relevant for

your technology development/ for your project development?
B) looking at the interface between regulations
a. Do the regulations foster the development, installation and/or use of LCTs? If yes, how? (e.g. through increasing incentives)
b. Do the regulations hinder the development, installation or use of LCTs?

It is possible that you find clear barriers to deployment of LCTs through the analysis of the institutional framework, especially when looking at the interface between regulations. If that is the case, please document the barrier(s) and include these in your results from Section 7.1 "Barriers identified through the analysis of the system".

6.5 Timeline

When using the project entry point you need to clarify the phases during the lifetime of your project using the following steps:

- Clarify if there are pre-defined phases in your country (see Table 1 for examples from Switzerland and Germany).
- If there are no pre-defined phases by the project developers or in the specific country or region, then use the generic phases as included in Table 1.
- Give real (expected) time for each of these phases in your project. In reality phases overlap, thus include overlapping in your analysis.
- Identify if and how roles change over the project phases (see example from Berlin TXL – The Urban Tech Republic in Table 6).

When using the technology entry point you should produce a similar characterization of stakeholders over the phases in the development and commercialization of your LCTs. The steps are thus the same as above, but you need to adjust using the phases as foreseen in the specific industry. If you use the technology entry point and there are no clearly defined phases in your industry consider the following phases for the technology entry point: innovation stimulus, research and development, market adoption and market diffusion[27]. When using the technology entry point you should produce a characterization of stakeholders over the phases, similar as

27 Pleschak, F., & Sabisch, H. (1996). *Innovationsmanagement*. Stuttgart: Schäffer-Poeschel, Vahs, D., & Burmester, R. (2005). *Innovationsmanagement von der Produktidee zur erfolgreichen Vermarktung*. Stuttgart: Schäffer-Poeschel.

Table 6
Stakeholder identification over the project phases and characterization according to their roles for Berlin TXL (R: Regulatory role I: Investing or commissioning role; D: Design and engineering role; C: Constructing role including material supply; U: Use or occupational role) indicated through colour.

Stakeholder identification & characterization										
Main construction phase:		Planning phase			Construction phase			Use phase		
Sub-phases:		Strategic planning	Feasibility studies	Design	Detail planning	Bidding/Tendering	Building/Construction	Operation		Maintenance
Stakeholder group WBCSD (2008)	Name (s) real or generic if not yet known	Stakeholder involvement and role R: Regulation, I: Investment/comissioning, D: Design, C: Construction, U: Use								
Public Opinion / News	Pressure of public opinion	I	I	I	I/D	I	I	U		I
	Political influence	I	I	I	I/D	I	I			
Local authorities (Behörden)	House of Representatives Berlin	I	I	I	I	I	I	I		I
	Senate Berlin: Finance	I	R	R	R					
	Senate Berlin: City development & Environment	R								
	Senate Berlin: Economics, Technology and Science	R	R	R						
	Bezirk Reinickendorf	R	R	R						
Developers (Projektentwickler / Bauträger)	Tegel Projekt GmbH	D	D	D	D	D	D	D/U		D/U
	Senate Berlin: City development & Environment	D	D	D	D	D	D	D/U		D/U
	Housing co-operatives (just residential)	D	D	D	D	D	D	D/U		D/U
Capital providers (Investoren) & Owners (Eigentümer)	Senate Berlin: Finances	I	I	I	I	I	I			
	National buro for buildings	I	I	I	I	I	I			
	Housing co-operatives (just residential)				I	I	I	I/U	I/U	U
Users (Nutzer)	General lessor for StartUp KMU (Terminal D, offices)							I/U	I/U	U
	General lessor for Students (just residential)							I/U	I/U	U
Designers (Gestalter)	Feasibility study architect	D								
	Architect	D	D	D	D	D	D			
Engineers (Ingenieure)	Technical Services	D	D	D	D	D	D			
	Construction engineer	D	D	D	D	D	D			
	Innovation consultant	D	D	D	D	D	D			
	Smart concept engineer	D	D	D	D	D	D			
Contractors (Bauunternehmer)	Building contractors					C	C			
Suppliers (Baumaterial-Lieferanten)	Facade elements suppplier					C	C			
	Windows supplier					C	C			
	Technical biulding equipment supplier					C	C			
Consultants (Berater)	Project management consultens	D	D	D	D	D	D			
	Infrastructure consutant	D	D	D	D	D	D			
	Economic consultant	D								

R: Regulator; I: Investor; D: Developer and Planner; C: Constructor; U: User the characterization presented in Table 6 for the project entry point. Recall in your analysis that adoption and diffusion of a new LCT can be increased by means of appropriate communication both within the company (internal innovation communication) and towards potential customers (external innovation communication)[28].

Table 6 shows the involved stakeholder groups and their roles throughout the project phases of the Berlin Tegel TXL project. Based on the project phases three distinct groups of stakeholders can be derived. (i) The first group is the one involved throughout the process like the House of Representatives, the developers and the public opinion. (ii) A second group are the ones involved only in the planning and construction phase (i.e. Capital providers, engineers and most consultants). (iii) The third group would be the ones only involved in one specific phase for example economic consultant and feasibility study architect in the planning phase, contractors and suppliers in the construction phase and users in the use phase. Most stakeholders do not change their role throughout the process and could be assigned a fairly clear function in the process

28 Vahs, D., & Burmester, R. (2005). *Innovationsmanagement von der Produktidee zur erfolgreichen Vermarktung*. Stuttgart: Schäffer-Poeschel.

7 Identifying (main) barriers

Once you have clarity about your specific system, you can proceed with the identification of the main barriers for the development and/or deployment of LCTs (Figure 7). In this guideline we present three possible ways for getting this identification: through the analysis of the system's components (Section 7.1), through the analysis of social interactions (Section 7.2) or through analysis of the perception and experience of stakeholders and decision-makers (Section 7.3). These three ways are not exclusive and can serve either as each other's validation (i.e. when you identify the same barriers by using different ways) or as a complement (i.e. when you identify different barriers through different methods). According to the scope and resources for your assessment you can use one or more ways for identifying barriers.

7.1 Barriers identified through definition of the system

The analysis of the system components can show existing barriers to LCT. Some examples are when you find regulations that create obstacles to deploying LCTs, when the technical environment does not support a given LCTs, when the environmental conditions do not fulfil the minimum requirements by a given LCT, when the available working capacity (social component) does not know how to install a given LCT, etc. These barriers should have appeared and been documented when you undertook steps 6.1 to 6.5. Thus the only additional step here is to list these already documented barriers and whenever possible consider to verify these through by using any of the two other ways for identification of barriers presented below.

7.2 Analysis of social interactions

As explained in Section 3.6 decisions made by stakeholders and policy makers play a central role either in promoting or hindering the development and deployment of LCTs. Thus understanding who decides on what and based on which criteria is extremely important for identifying potential barriers to LCTs.

The analysis of social interactions is useful for understanding the type of relationships among the key stakeholders (and decision-makers) relevant for your system. The method presented here is based on the Actor Impact Analysis (AIA)[29]. This

29 Actor Impact Analysis (AIA) is a method for identification of relevant agents or actors in social system (Knoeri et all, 2011) based and adapted from qualitative cross-impact analysis (e.g. Scholz RW, Tietje O (2002) *Embedded case study methods: integrating quantitative and qualitative knowledge*. Sage, Thousand Oaks). For a detailed explanation of the method consult Knoeri, Ch; Binder, C; and Althaus, HJ. 2011 "An agent operationalization approach for context specific agent-based modelling" under http://jasss.soc.surrey.ac.uk/14/2/4.html) or U. Asan, C. E. Bozdag, S. Polat (2004). A fuzzy approach to qualitative cross impact analysis, *Omega 32*(6), 443-458.

method allows characterizing the interactions between stakeholders and with the institutional framework according to their capacity to influence the selection and use of LCTs as well as to the extent of their dependence (influence and dependency values). It further allows differentiating between four types of actors or stakeholders[30].

- *Steering actors or stakeholders:* are actors with a high level of influence (i.e. influence on many other actors), but with a very low dependency.

30 We use the term „actor" as a more general term denoting both stakeholders and elements of the institutional framework, that is, all entities representing acting or decision making power.

- *Key connected actors or stakeholders:* are actors that have both a high level of influence on others, but also a high level of dependence from other actors.
- *Buffering actors or stakeholders:* are actors with a reduced influence but also with a reduced dependency.
- *Reactive actors or stakeholders:* are actors that are highly dependent, but have a low influence value.

Actors with a high level of influence (steering and key connected actors) are highly relevant for securing deployment of LCTs. Thus it is important that these actors are aware of the benefits of LCTs. See Box 5 presenting a concrete example.

Box 5 – Example of how to undertake the analysis of social interactions in a real case

In the following we present the procedure and results from the Berlin TXL Project based on the working session in Berlin on Jan 19th 2016 with two members of the project management.

One of the key points of the Actor Impact Analysis is its' specificity to a certain issue and consequently the requirement for a clear problem specification. In the case at hand, this was the use of LCTs in the Berlin Tegel project. Regarding this specific issue the two members of the project management were asked to rank the direct impact of stakeholder group A (e.g. public opinion & news) on stakeholder group B (e.g. local authorities) on a scale from 0 (no influence), 1 (medium influence) to 2 (strong influence). This has been done on the aggregated stakeholder group level based on the stakeholder identification presented above. This aggregation was necessary as an impact assessment with the entire list would have required 650 assessments while the aggregated version only required 90 assessments (Table 7).

The row (i.e. activity) and column (i.e. passivity) sums of Table 8 can then be displayed in a system grid divided by the mean impact sums into the four actor classes outlined above (Figure 9). Similar to previous studies[31], developers, engineers and designer were found to be key connected actors, not surprisingly suppliers, contractors and users were rated reacting actors, while public opinion/news, local authorities, and investors and owners were buffering actors. Especially the latter two groups have surprisingly low activity sums, which might be a sign that most of their impact already has been transferred to the developer. It is important to mention that this analysis is specific to the planning phase and might change in the construction phase. However, most barriers towards the use of LCTs seems to origin in this phase and the strictly regulated construction processes in the actual construction phase leave very little room for changes regarding particular technologies.

31 Knoeri, C., Binder, C. R., & Althaus, H.-J. (2011). An Agent Operationalization Approach for Context Specific Agent-Based Modeling. *Journal of Artificial Societies and Social Simulation, 14*(2), 4.

Table 7
Actor cross-impact matrix in the Berlin TXL .

		Public Opinion / News	Local authorities (Behörden)	Capital providers (Investoren) and owners (Eigentümer)	Developers (Projektentwickler / Bauträger)	Users (Nutzer)	Designers (Gestalter)	Engineers (Ingenieure)	Contractors (Bauunternehmer)	Suppliers (Baumaterial-Lieferanten)	Consultants (Berater)	Activity sum
generic names	includes in Tegel Project	General Public & Media	Parl. , SenStadtUm, SenWTF, Reinickendorf	SenFin, BIMA, ResHousingCoop	SenStadtUm Hochbau, Tegel Projekt GmbH, ResHousingCoop	Landlords office & residential buildings	architect feasibility and planning and construction	Technical services, construction, innovation and smart concept engineer	contractors	Facade, windows and technical building equipment suppliers	Drees & Summer, Lahmeyer Berlin GmbH, E&Y	
Public Opinion / News	General Public & Media		1	0	1	0	0	0	0	0	0	2
Local authorities (Behörden)	Parl. , SenStadtUm, SenWTF, Reinickendorf	1		1	1	1	0	0	0	0	0	4
Capital providers (Investoren) and owners (Eigentümer)	SenFin, BIMA, ResHousingCoop	0	1		1	0	0	0	0	0	0	2
Developers (Projektentwickler / Bauträger)	SenStadtUm Hochbau, Tegel Projekt GmbH, ResHousingCoop	2	1	1		2	2	2	2	2	2	16
Users (Nutzer)	Landlords office & residential buildings	1	0	0	0		0	0	0	0	0	1
Designers (Gestalter)	architect feasibility and planning and construction	0	0	0	1	1		2	2	2	2	10
Engineers (Ingenieure)	Technical services, construction, innovation and smart concept engineer	0	0	0	2	2	2		2	2	2	12
Contractors (Bauunternehmer)	contractors	0	0	0	0	0	0	1		2	0	3
Suppliers (Baumaterial-Lieferanten)	Facade, windows and technical building equipment suppliers	0	0	0	0	0	1	1	1		0	3
Consultants (Berater)	Drees & Summer, Lahmeyer Berlin GmbH, E&Y	0	0	0	1	0	1	2	2	0		6
Passivity sum		4	3	2	7	6	6	8	9	8	6	

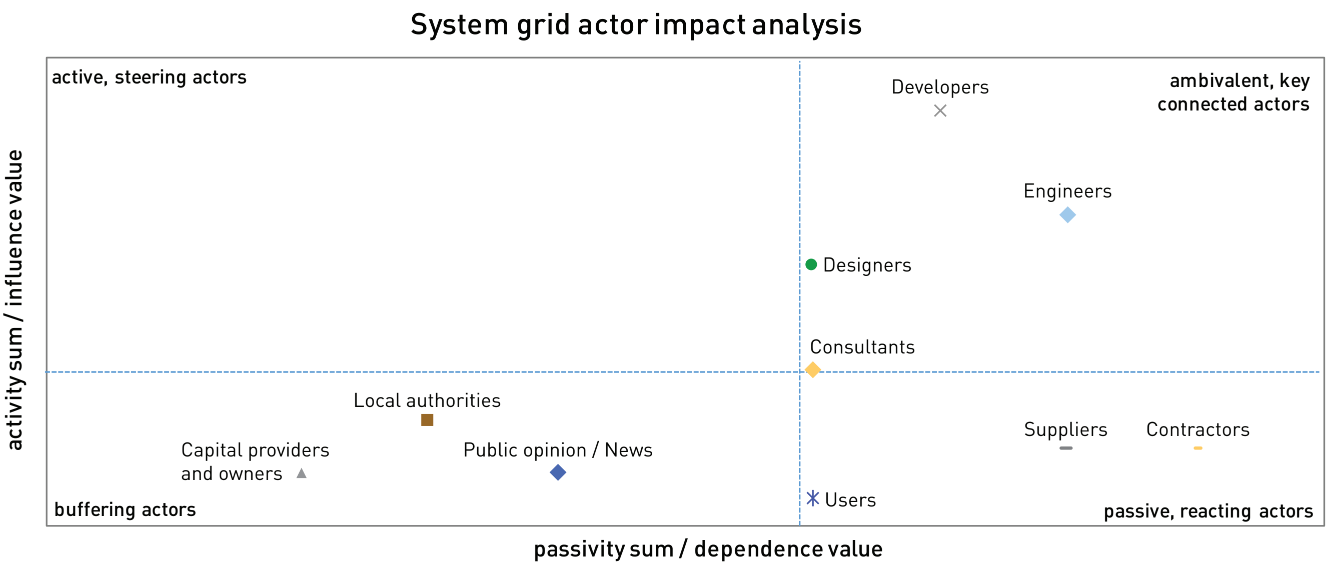


Figure 9
System grid actor impact analysis for the planning phase in the Berlin Tegel TXL project.

7.3 Perception and experience by stakeholders and decision-makers

A third way for identifying barriers is to use the expertise and experience from the key stakeholders and decision-makers. Most of them have been in touch with barriers to LCTs in the past and this knowledge can be extremely important for both identifying and addressing the specific barriers for your case.

There are two modalities for identifying barriers through the analysis of perception and experience by key stakeholders and decision-makers: (i) direct identification and (ii) indirect identification. Both modalities offer advantages and disadvantages that you need to consult with your client. For instance, the direct identification is an easy and straight forward method that easily increases willingness to act, because stakeholders are active in identifying the difficulties. However the direct identification might have problems of correct recall (false memory effects[32]), unconscious biases or even occasions of manipulation and deliberative incorrect information. Conversely, the indirect identification requires more resources (in terms of time and skills from the one conducting the assessment), but has less bias than the direct system (i.e. it might be more accurate).

The clearer the system is defined the more efficient is the identification of barriers. You can of course undertake enquiries about not clear-defined systems, however doing so allows only a very general identification of barriers. If you are interested in proposing ways for overcoming barriers you need to identify the system dependencies because these will provide information about the size and the drivers of a barrier.

Direct identification of barriers

You can identify barriers to LCTs asking the stakeholders directly about their experience facing hindrances either to a specific technology or to the use of LCTs in a specific project. The main advantage of using the direct enquiry is that you easily get the information. Further, if conduct direct identification using a participative method (e.g. Delphi workshop) you will have a summative knowledge process and you will get a certain level of agreement among your stakeholders. In this case, in addition to the need of securing balanced participation, you need to facilitate the discussion whenever there is disagreement among workshop participants either on specific barriers or on determining values (e.g. environmental performance vs. cost effectiveness). Cross-validation may be one way to check for the soundness of responses: ask other experts for their opinion on the answers given. Box 6 presents an example of direct identification as done for the Berlin TXL project.

32 Brainerd, C. J., & Reyna, V. F. (2005). *The science of false memory*. Oxford University Press.

Box 6 – Direct identification of barriers – An example from Berlin TXL

In June 2015 a multi-stakeholder workshop was conducted with stakeholders and decision-makers from the Berlin TXL project, with the participation of 27 representatives from industry, research, consultants and members of the Berlin TXL management team. One of the workshop's objective was to jointly identify the three most important potential barriers for using LCTs in two types of buildings in Berlin Tegel TXL, residential (new building) and offices (as a renovation of the current airport's terminal B). Using the experience of the workshop's participants an exercise on two steps was conducted: first identifying as much potential barriers as possible end then jointly prioritizing the three most important. The exercise was conducted in two groups, one for residential and one for office with participation of all stakeholder types in each group (see photos below).

For the residential building the group selected the following potential main barriers:

- Contradiction in legislation and regulation across EU, national and local levels, that hinder the use of LCTs
- Lack of priority across stakeholders in the built environment to adopt LCTs
- Different budget strategies/cost calculations across sub-projects and across stakeholders

For the renovation to offices in terminal B the group selected the following potential main barriers:

- Technology providers don't know who makes decision relevant to their LCTs, when and based on which criteria
- Berlin TXL does not find answers to their requests for LCTs (e.g. "smart window")
- Technology suppliers do not know about requests or ideas from Berlin TXL

However, the direct identification can be biased because stakeholders not necessarily decide consistently and because leading individuals can have an overproportioned impact on the process. If you consider that this is your case, then you should use indirect identification.

Indirect identification of barriers

In this case your enquiry focuses on the decisions made by key stakeholders and on their impact on LCTs. Instead of asking for barriers directly, the indirect identification of barriers starts with asking key stakeholders and decision-makers about past selection of technologies for specific cases. Decisions supporting both, LCTs and baseline-technologies should be included. Then the facilitator should guide the group through the analysis of the impact of these decisions on LCTs development or deployment (according to the entry point) as well as through the rationalisation of the values and criteria on which the decisions were made.

The indirect way also offers strategies to overcome conscious deception attempts, for instance trying to hide the real aim of an intervention or inquiry or seemingly make attempts to deceive pointless (bogus pipeline"[33]). An important element here is that the facilitator will need to deal with issues of legitimisation and trust. Although this is certain for all steps in the assessment it is special relevant when using indirect methods because lack of trust or legitimacy can evolve to a deep bias in the whole process what will reduce credibility of the results.

There are several methods for conducting an indirect identification of barriers (more on methods for each step in Section 10.2).

33 Jones, E. E., & Sigall, H. (1971). The bogus pipeline: a new paradigm for measuring affect and attitude. *Psychological Bulletin, 76*(5), 349.

8 Characterizing barriers

After identifying the main barriers in your system you need to get a better understanding of the characteristics of these barriers. This will serve as basis for developing concrete action towards overcoming these. You can characterize either attributes or impacts of each barrier. "Attributes" refer to intrinsic characteristics of the barrier (e.g. the difference in price to a baseline technology) while "impacts" refer to the how (much) a barrier affect other components of the system (e.g. the amount of no-reduced GHG emissions because baseline technologies continue being used). Attributes and impacts can be characterized in a qualitative (Section 8.1) or in a quantitative manner (section 8.2) and according to a temporal axe, selecting if the characterization should consider attributes and impacts as in the past and/or current situation or if preferred, developing scenarios about the evolution of attributes and impacts in a future moment.

There are plenty of attributes and potential impacts that can be characterized by any barrier to development and deployment of LCTs. Before you start the characterization of those barriers identified in your system you need to clarify with your client, which are the most relevant attributes and impacts to be covered.

8.1 Qualitative aspects

In this guideline we recommend to consider the characterization of at least three attributes:

- Type of barrier
- Carriers of the barrier
- Driver(s) of the barrier

Table 8 provides a format for characterizing barriers and in Section 10.2 you find some recommended participatory methodologies that are useful for undertaking this characterization.

Type of barrier

You characterize your barrier using the typology as explained in section 3.7, which explain the following types lack of awareness, of acceptance, of financial feasibility or competitiveness, of technical suitability, of workforce capacity or inadequate policies or regulatory frameworks.

Carriers of the barrier

Carrier of a barrier is the stakeholder who doesn't promote or facilitate the development, production, installation or use of LCTs either with an active behaviour or due to lack of knowledge. See Table 12 for an example of carriers.

Driver of the barrier

Driver is the reason causing the lacking or inadequate conditions (see types or barriers before or in section 3.7) causing a barrier. The driver can be divers including e.g. the behaviour of a stakeholder or policy-maker, an element of the institutional framework or the technical environment.

Table 8
Characterization of barriers.

Name of the barrier	Type	Carrier	Driver
Potential users are not aware of a existing LCT (e.g. PMC)	• Lack of awareness • Lack of acceptance	• Architects • Engineers • Building officer	LCT including PMC are not included in the curricula of any of the relevant professions

Once you have done the characterization of barriers (filling in Table 19) *use the results of the analysis of interactions* (Section 3.6) for identifying if there are stakeholders or policy-makers in your system that have a high level of influence on the carriers and drivers of barriers or are considered either steering or key connected actors. These actors are key for overcoming the given barrier. Thus **at the end of the characterization of barriers you are already in a position to provide concrete recommendations considering the most relevant stakeholders for overcoming specific barriers** either to your LCT (when you use the technology entry point) or to the project.

8.2 Quantitative aspects

The next step is about quantification of the barrier. Quantification is understood here as an approximation of a subjective aspect (attribute or impact) of a barrier to LCT into numbers through an arbitrary scale. Every aspect can be quantified although the measurement might not be objective (e.g. when building users grade the usefulness of a given LCT). The arbitrary scale, as far as well-known and understood, allows comparisons between the impacts of different barriers on the whole system and/or between required efforts for overcoming the barriers. To compare between different barriers you can follow this stepwise approach with increasing level of information but as well required knowledge base[34]:

- Decide for each pair of two barriers if they are of equal or different magnitude (nominal scale)
- Bring the different barriers in ordinal ranking order (barrier x is more important than barrier y)
- Try ranking the difference between different barriers (the difference between barrier x and y is bigger than the difference between barrier z and q; likewise, you achieve an interval rating scale)

34 For different measurement scales, see e.g. http://www.socialresearchmethods.net/kb/measlevl.php

Quantified attributes in terms of impacts or required efforts are often required for promoting clear measures against barriers, however the efforts needed for getting these numbers can easily exceed the time and financial budgets of your client. Thus we recommend to follow the sufficiency principle: quantify as much as needed for your concrete purpose (e.g. if the barrier was characterized as lack of knowledge about LCT among architects involved in your project, this can be directly tackled without having to quantify how much additional CO_2 you will emit because of this; in contrast, if your barrier is higher cost of your LCT compared with other products on the market, your client might need to quantify the potential of COv reduction with your product and compare the long term costs of the different products under a scenario of CO_2 tax).

Consider the following steps when undertaking the quantification of barriers to deployment of LCTs

- Ask quantifiable questions of interest in your system.
- Select with your client the most relevant questions for your assessment (see Box 7 for an example).
- Select the quantification method.
- Get the data and apply the method (whenever necessary contact an expert on the specific methodology, do not try to do everything alone).
- Interpret the results considering assumptions, context, specificities of your case.

Section 10.2 presents some methods that can be useful for quantifying some relevant questions on barriers to LCTs.

Box 7 – Example on quantifiable questions

During the interviews with windows providers and construction experts the TransBarrier team found that lack of awareness by the architects/designers of the buildings is a potential barriers to deployment of Phase-change Material (PCM) windows in apartments buildings in Switzerland:

	Current	Future
Attributes	• What is the percentage of all architects active in Switzerland that don't know the technology? • How many apartment buildings per year do these architects/designers produce per year?	• How many architects do I need to sensitize before 2030 for increasing use of PCM in apartment buildings by 15%? • In how many educational institutes are these architects?
Impacts	• What is the average non-reduced GHG emissions per building that can be attributed to this barrier?	• What is the potential for reducing emissions by 2010? • How much needs to be invested to increase awareness on PCM by 20% by 2020?

9 Managing co-generated knowledge

Through the implementation of steps explained before you should have co-generated knowledge with your main stakeholders. Following the transdisciplinary approach this knowledge is build up on the experience, perception and values of the various stakeholders that participated in the process. The question now is how to use this co-generated knowledge for mitigating barriers to LCT. Following the outline of this guideline, the identification, qualification and quantification of barriers will be considered at the entry points of technology and project level and concrete KM steps will be suggested to overcome barriers.

9.1 Technology Entry Point

Steps to establish KM in order to overcome information barriers in large (supply) companies:

- Raise awareness that relevant knowledge might be already available within the organisation through experienced staff and previous experience of deploying new technologies.
- Identify relevant knowledge providers in the company and connect them with knowledge receivers through formal and informal networks, and an internal knowledge database as part of an IT infrastructure.
- Build up a culture of knowledge sharing (for both successes and failures).
- Provide incentives for knowledge providers and ensure that the ownership of knowledge is recognized.

Steps to establish KM in order to overcome information barriers in small companies and start-ups:

- Be aware that not much internal knowledge on barriers from previous deployments might be available.
- Access relevant knowledge from outside the organisation through formal and informal networks.
- Identify and maintain relationship with specific knowledge providers.
- Insource knowledge by hiring knowledge carriers.
- Each development phase needs a specific funding approach. In the early phases, public funding is frequent, whereas investors are more prominent towards market readiness of a new technology. The KM and outreach approach needs to be adapted according to the funding phase of the project.

If the technology has been fully or partly developed outside the company (either in collaboration with another company or by a research institution), there are additional hurdles for deployment. In this case special attention needs to be paid to questions such as knowledge transfer, access to knowledge providers, intellectual property rights, and confidentiality.

9.2 Project Entry Point

On the individual project level, KM might overcome barriers to the deployment of LCT by knowledge distribution activities:

- Convey a clear message to the different stakeholders and decision makers that LCT is a priority.
- Provide (project internal and cross-project) platforms where new LCTs can be presented to raise awareness and inform potential users.
- Provide networks, workshops and/or CoPs where experience on new technologies in general and on LCT in particular can be exchanged.
- Communicate incentives for LCT (e.g., organize technology challenges with clear LCT requirements).
- Highlight the importance of professional project management where success and failures from previous projects can be shared to enable learning.

Different project developers deploy similar project types (e.g., building hospitals, schools) with similar barriers to the deployment of LCT. This applies in particular for publicly funded projects. Knowledge on typical barriers for similar project types is valuable. Across projects, barriers can be overcome if policy makers set certain pre-conditions, which promote knowledge exchange. This can include:

- Setting up a database with best practice examples and lessons learned on the deployment of LCT (e.g., policy makers make contributions to such a DB mandatory for publicly funded projects on a local/national/EU-level).
- Transferring knowledge via platforms and informal and formal networks (CoP) to enable learning.
- Raising awareness and acceptance of LCT by:
- Inclusion of LCT related topics in the curricula of relevant stakeholders (engineers, architects etc.).
- Networks, workshops and/or CoPs where experience on new technologies in general and on LCT in particular can be exchanged.
- Enable lighthouse projects, where risk taking and openness towards new technologies as part of culture of learning is promoted.

10 Complementary information

10.1 Check list

This checklist gives you an overview of all the steps presented in this guideline.

☑ System is well defined

- ☐ *You have selected either the technology or the project entry point and described the technology or project*

  Technology entry point
  - ☐ *Technology is described*
  - ☐ *Type of projects where your technology can be used are clear*
  - ☐ *The ideal and the minimum requests that your technology has on the natural and technological are clear*

  Project entry point
  - ☐ *Project is characterized*
  - ☐ *Most promising LCT for your project are identified*
- ☐ *Relevant stakeholders and decision makers are identified and the relationships among these are mapped*
- ☐ *The institutional framework relevant to your technology or entry point has been analysed considering specific regulations as well as the interphase between regulations*
- ☐ *Timeline: Phases (technology or project phases) are described as well as the roles that the most relevant stakeholders play in each phase*

☑ Main barriers (to your technology or to use of LCTs in your project) are identified

- ☐ *The interactions between all actors are characterized and you have a clear understanding which are the steering, key connected, buffering and reactive actors by each phase*
- ☐ *You used one or more ways for identifying barriers: documenting the barriers as they were understood through the system's definition, through the analysis of social interactions, or using the experience by stakeholders and decision-makers (either directly or indirectly)*

☑ Main barriers (to your technology or to use of LCT in your project) are characterized in a qualitative manner

- ☐ *The barrier's types are clear (lack of awareness, of acceptance, of policy/regulation, lack of financing incentives or high costs, lack of workforce capacity lack of technical capacity*
- ☐ *The carriers of each barrier have been established*
- ☐ *The drivers of each barrier have been established*

☑ Main barriers have been characterized in a quantitative manner

- ☐ *Most relevant quantifiable questions are agreed upon*
- ☐ *Appropriated method selected*
- ☐ *Data has been gathered and the method(s) has (have) been applied*
- ☐ *Interpretation of results has been done in dialogue with an expert in the selected method(s)*

☑ Knowledge management steps that can support the process of overcoming specific barriers in your system have been identified

10.2 Roadmap and methods

Figure 10 presents a roadmap including all steps for the assessment of barriers to development and deployment of LCTs in buildings. At the left side of the roadmap you find each step and sub-steps. Colours in the boxes and arrows correspond to the colours as in Figure 7.

At the right side of the roadmap you find suitable methods for undertaking each step. A more detailed explanation of these methods is provided in Tables 11 and 12. As you might observe some methods can be used for more than one step. This is especially important for methods like stakeholder workshops and interviews, that can be used for undertaking several steps. The intention is not that you design one stakeholder workshop or interview process for each step. The contrary!

Stakeholder workshops and interviews are very flexible methods with multiple formats (see Tables 9 and 10) that allow you to undertake several steps together. If you want to do so, you need an in-depth planning of such workshops or interviews and each of the corresponding formats. See Box 8 for the example of the use of stakeholder workshops in the case of the Berlin TXL.

Box 8 – Use of stakeholder workshops in the case study Berlin TXL

For the case study in Berlin TXL the *TransBarriers* team undertook three stakeholder workshops.

The first workshop had the following objectives:

- To clarify the system
- To identify LCT suitable for the office and residential buildings in the Berlin TXL project
- To identify potential barriers for using these technologies
- To clarify what are the most relevant aspects to be further assessed about these barriers

Representatives from Berlin TXL project, LCT suppliers, private consultants, research and the *TransBarriers* team participated in this 1.5 day workshop.

The second workshop aimed at validating the stakeholder's matrix and conduct the Actor Impact Analysis for the system. This workshop counted with the participation of representatives of the Berlin TXL project and the *TransBarriers* team and took half a day.

The third workshop aimed at presenting the current guideline as well as at discussing the results obtained for the case study. Representatives from Berlin TXL project, private consultants and research as well as the *TransBarriers* team. The third workshop took half a day.

Each workshop was designed by the team considering both the objectives and the type of stakeholders participating in the workshop.

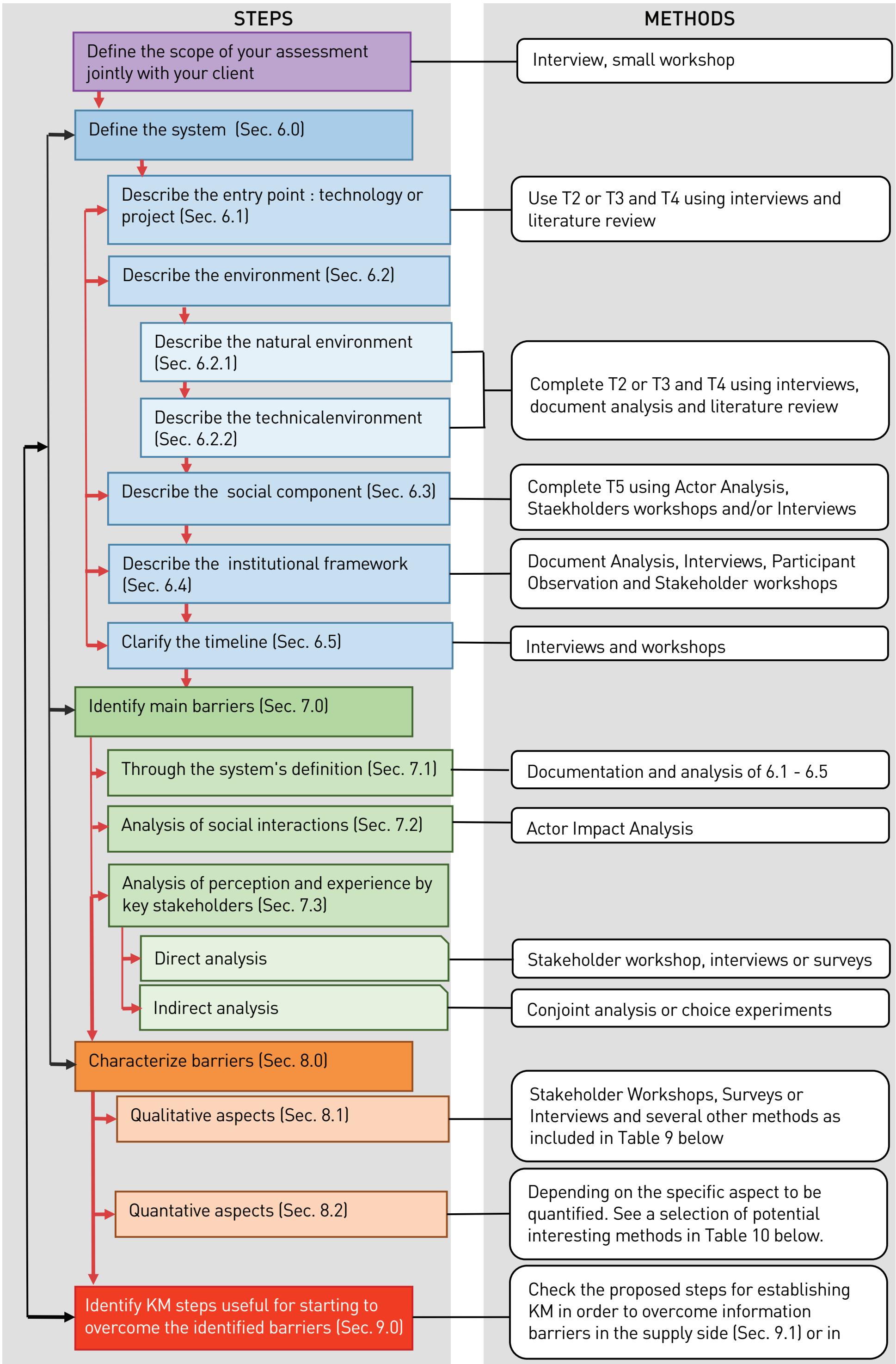


Figure 10
Roadmap for conducting the assessment of barriers to LCT in buildings.

Table 9
Selection of methods for undertaking steps as in sections 6.1.–8.1.

Name	Short explanation
Actor analysis	An actor or stakeholder analysis, first identifies actors, then differentiates between them and categorizes them (e.g. with respect to their power, interest); and lastly investigates relationships between stakeholders[35].
	Snowball sampling, chain referral, nomination technique: A first initial set of actors is identified and contacted and they are all asked for further actors they know are playing an important role in the process. This process is continued until no new actors are named[36].
	Media and document analysis: To help identifying important actors, a review of recent media articles[37] and other written documents[38] can be helpful.
Actor Impact Analysis	**Steps:** Step 1: Clear problem definitions (impact depends on the issue addressed) / Step 2: Identification of all potentially relevant actors / Step 3: Assessing direct impacts between the actors in a cross-impact matrix / Step 4: Visualization of the cross-impact matrix in a system grid and classification of the actors. **Required information:** Assessment of the direct impact of actor A on actor B regarding the particular issue. **Contributors (who should participate):** Preferably a broad coverage of relevant actors (Step 2) if this is not possible, system experts with different perspectives, interests and motives. Facilitator's tasks: Explaining the general task, highlighting the directness of the impact and the importance of the issue (not a general influence), reiterating the task after completing for re-evaluation. **Results:** Cross-impact matrix, system-grid and characterization of actors.
Document Analysis	Document analysis is a systematic procedure for reviewing or evaluating documents – both printed and electronic (computer-based and Internet-transmitted) material. http://www.emeraldinsight.com/doi/abs/10.3316/QRJ0902027?journalCode=qrj Analysing documents such as statistical data, protocols and minutes of meetings, planning documents, legislation texts. "planning charts, process data, documents that can be analyzed to understand the process of discussion/planning/deciding (i.e. decision heuristics of different actors); e.g. minutes of meetings, but also interview data."
Interviews	Personal interviews reveal in depth knowledge for instance about temporal dependencies in different phases may become clear by applying a phases-template. You can use structured or semi-structured interviews according to a) the objective and b) the assessment method that you want a use for the interviews. Personal interviews can be organized in person or as well by phone, skype or similar tools over distance. More information: http://www.socialresearchmethods.net/kb/intrview.php Schutt, R. K. (2011). Investigating the social world. The process and practice of research (7^{th} ed.). Thousand Oaks, CA: Pine Forge Press.

35 For a review of existing stakeholder analysis methods, see: Brugha, R., & Varvasovszky, Z. (2000). Stakeholder analysis: a review. *Health policy and planning, 15*(3), 239–246. Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., ... & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of environmental management, 90*(5), 1933–1949. For a good overview and concrete examples of some major techniques, see Bryson, J. M. (2004). What to do when stakeholders matter: stakeholder identification and analysis techniques. *Public management review, 6*(1), 21–53.

36 Biernacki, P., & Waldorf, D. (1981). Snowball sampling: Problems and techniques of chain referral sampling. *Sociological methods & research, 10*(2), 141–163.

37 Riff, D., Lacy, S., & Fico, F. (2014). *Analyzing media messages: Using quantitative content analysis in research*. Routledge.

38 Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative research journal, 9*(2), 27–40.

Table 9
(continued).

Name	Short explanation
Participant observation	Participation ("participant observation") in planning sessions for instance, may explicit the processes often implicit to the actors themselves. It may reveal standard thinking strategies or implicit assumptions about other actors' preferences. http://srmo.sagepub.com/view/participant-observation/n1.xml Severyn Bruyn (1963) The Methodology of Participant Observation. *Human Organization 22*(3), 224-235. doi: http://dx.doi.org/10.17730/humo.22.3.822753654496vwt4
Stakeholder workshops and expert meetings	Workshops with stakeholders may elicit new insight about different actors' views and values but also increase knowledge about the system at hand and respective other stakeholders. There are multiple formats and facilitation options for stakeholder workshops, thus it is necessary to have an in-depth planning that consider general and specific objectives and the corresponding didactic and modalities to be used. There are multiple facilitation methods for stakeholder workshops. You find some explained below. More information under see e.g. https://www.shareweb.ch/site/Learning-and-Networking/sdc_km_tools, http://ctb.ku.edu/en/table-of-contents/leadership/group-facilitation/main, http://infed.org/mobi/facilitating-learning-and-change-in-groups-and-group-sessions/. Specifically focussing on the transdisciplinary collaboration between science and practice, the toolbox of the td-net can be useful: http://www.naturwissenschaften.ch/topics/co-producing_
	Focus Group Discussions: In a focus group, a group of 6 to 10 participants meet to discuss on given topic (=focus), guided by the researcher[39]. Focus groups can be used to identify actors but as well to collect further information about them. A focus group can be considered a more structured way of organizing a workshop.
	Delphi Dialogue: Group of experts can be consulted in several consecutive rounds of interviews to elicit and contrast the knowledge and point of views[40].
Social field and online experiments	Online or field experiments can be used to test for specific effects of a restricted number of individual barriers by exposing randomized experimental groups and a control group with different set of manipulations[41].
Surveys	Surveys can help identifying important actors and give fast insights into their role in a building process. In contrast to personal interviews, postal or online surveys do not rely on direct interaction and thus are generally faster but less deep than interviews[42]. **Social network analysis:** A social network analysis helps specifically in understanding how different actors/stakeholders interact with each other, how they share information, who plays a central role, who has rather a bridging function in the network, etc. Such information is generally collected using postal (or online) survey; it can, however, as well be based on written documents and media products. In the latter case, it is referred to as discourse network analysis.

39 Kitzinger, J. (1995). Qualitative research. Introducing focus groups. *BMJ: British medical journal, 311*(7000), 299. Krueger, R. A., & Casey, M. A. (2014). *Focus groups: A practical guide for applied research*. Sage publications. Morgan, D. L. (1996). Focus groups. *Annual review of sociology*, 129-152.

40 Webler, T., Levine, D., Rakel, H., & Renn, O. (1991). A novel approach to reducing uncertainty: the group Delphi. *Technological forecasting and social change, 39*(3), 253-263.

41 Birnbaum, M. H. (Ed.). (2000). *Psychological experiments on the Internet*. Elsevier.

42 Scott, J. (2012). *Social network analysis*. Sage.

43 Leifeld, P. (2013). Reconceptualizing major policy change in the advocacy coalition framework: a discourse network analysis of German pension politics. *Policy Studies Journal, 41*(1), 169-198.

Table 10
Selection of methods useful for characterizing attributes or impacts of barriers to LCT.

Name	Short explanation
Agent-based modelling (ABM)	Allows identifying and studying group and social outcomes based on models of interactions (e.g., behaviour and decisions) between individuals (i.e., agents). A specific behaviour observed in a percentage of the population could lead to a social outcome that is unfavourable to an LCT. More information: Railsback, Steven F., and Volker Grimm. *Agent-based and Individual-based Modeling: A Practical Introduction*. Princeton University Press, 2011.
Carbon footprinting	Enables one to reduce the scope of an LCA to climate change. More information under http://www.carbonfootprint.com/
Cost-benefit analysis (CBA)	A method for summing up all costs and benefits of processes within system boundaries. The net cost of an LCT can act as barrier. More information under https://www.mindtools.com/pages/article/newTED_08.htm
Dense ranking	Items that compare equal receive the same ranking number, and the next item(s) receive the immediately following ranking number. More information under https://docs.tibco.com/pub/spotfire/7.0.1/doc/html/ncfe/ncfe_ranking_functions.htm
Energy consumption assessment	(Smart) meters are needed to measure the energy savings provided by LCTs. Low savings can become a barrier to an LCT See also http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf
Energy/material flow analysis (E/MFA)	Allows balancing stocks and flows of material or energy exchanged between processes of a system within its boundaries. The input of a problematic material upstream in the supply chain of an LCT can be a barrier. More information: Baccini, P., & Brunner, P. H. (2012). *Metabolism of the Anthroposphere: Analysis, Evaluation, Design* (2nd ed.). MIT Press
Environmentally extended Input-Output analysis (EEIOA)	EEIOA is a method for evaluating economic and environmental interdependencies on a large scale. It is an accounting procedure that documents all monetary and related environmental flows to and from discrete economic sectors, which together cover all traditional economic activity in an economy thereby accounting for all different stages during which a product has environmental impacts and measuring these impacts quantitatively. - Duchin, F., 1992. Industrial input-output-analysis e implications for industrial ecology. Proc. Natl. Acad. Sci. U. S. A. 89, 851-855. Minx, J.C., Wiedmann, T., Wood, R., Peters, G.P., Lenzen, M., Owen, A., Scott, K., Barrett, J., Hubacek, K., Baiocchi, G., Paul, A., Dawkins, E., Briggs, J., Guan, D., Suh, S., Ackerman, F., 2009. Input-output analysis and carbon footprinting: an overview of applications. Econ. Syst. Res. 21, 187-216.
Formative scenario analysis (FSA)	FSA is utilized to derive possible futures of any system (from a product to a country) by means of a structured process involving expert knowledge integration. Future barriers con be identified by means of FSA. More information: Scholz RW, Tietje O (2002) *Embedded case study methods: integrating quantitative and qualitative knowledge*. Sage, Thousand Oaks
Fractional ranking	Items that compare equal receive the same ranking number, which is the mean of what they would have under ordinal rankings.
Greenhouse gas emissions assessment	Monitoring GHG emissions over time by applying emission factors to the energy consumption assessment results Methodologies can be downloaded from the IPCC web page

Table 10
(continued).

Name	Short explanation
Input-output analysis (IOA)	Input-output analysis is a form of economic analysis based on the interdependencies between economic sectors. This method is most commonly used for estimating the impacts of positive or negative economic shocks and analyzing the ripple effects throughout an economy. More information: Leontief, Wassily W. (1986). *Input-Output Economics*. 2nd ed., New York: Oxford University Press
Interviews and surveys	A simple method for counting people affected by a barrier. Use interviews and surveys when you need information on how many people are affected by something specific, i.e. by an specific barrier (e.g. lack of training)
IPCC guide-lines (2006). Volumes 1 & 2	Monitoring GHG emissions over time More information under http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
Life cycle assessment (LCA)	Permits the assessment of environmental impacts of an LCT over its entire life cycle with a comprehensive view on different environmental impacts, such as climate change, eutrophication or water consumption. More information under http://www.lcaforum.ch/
Life cycle costing (LCC)	A form of LCA looking at economic impacts, e.g., the economic value added of a LCT over its entire life cycle.
Modified competition ranking	Sometimes, competition ranking is done by leaving the gaps in the ranking numbers before the sets of equal-ranking items (rather than after them as in standard competition ranking).
Network analysis	A method for analysing the relationships between nodes that constitute a network. The analysis relies on network metrics, e.g., a node has a certain centrality within a network. An LCT, within a building, can be considered as a node embedded in a network of building components. Network metrics can be used to quantify to which extent the LCT is well integrated in a specific building.
Ordinal ranking	All items receive distinct ordinal numbers, including items that compare equal. The assignment of distinct ordinal numbers to items that compare equal can be done at random, or arbitrarily, but it is generally preferable to use a system that is arbitrary but consistent, as this gives stable results if the ranking is done multiple times.
Social network analysis (SNA)	SNA is a form of network analysis in which human agents (i.e., individuals, groups or organisations) are the nodes of the network. A barrier to an LCT can arise from the lack of network centrality of specific stakeholders. More information http://www.orgnet.com/sna.html
Standard competition ranking	Standard competition ranking, or SCR, is a ranking system in which the mathematical values that are equal are given equal rank and the next, lesser value is given the next highest rank. Items that perform equally receive the same ranking number, and then a gap is left in the ranking numbers.
System dynamics	A method for forecasting the future of a system relying on causal relations between its processes (modelled by mathematical equations) as well as initial conditions at these processes. Regarding barriers to LCTs, it serves a similar purpose as FSA. More information: Sterman, J.D. 2000. *Business Dynamics. Systems Thinking and Modeling for a Complex World*. McGraw-Hill
Water footprinting	Enables one to reduce the scope of an LCA to water consumption. More information http://waterfootprint.org/en/

11 Glossary

Actor (social actor)	In this guideline the term "actor" includes both the stakeholders and the elements of the institutional framework.
Built environment	In social science, the term built environment refers to the human-made surroundings that provide the setting for human activity, ranging in scale from buildings and parks or green space to neighbourhoods and cities that can often include their supporting infrastructure.
Transforming the Built Environment (TBE)	The "Transforming the Built Environment" (TBE) platform of Climate-KIC initiated a project that aimed at analyzing market barriers in the built environment by working with key industry stakeholders to develop a methodology to generate such understanding. The initiative was named Building Market Applied Barrier Categorization (Building Market ABC). The TransBarriers project has been set up to complement the Building Market ABC project and bring in the necessary methodological expertise.
Complex system	Complex systems consist of diverse and autonomous but interrelated and interdependent components or parts linked through many (dense) interconnections or relationships. Complex systems cannot be described by a single rule and their characteristics are not reducible to one level of description. They exhibit properties that emerge from the interaction of their components and which cannot be predicted from the properties of the single components. Some general features of complex systems are emergence, self-organization, collective behavior and the capacity to evolve and adapt.
Deployment	Includes use and adoption of a technology
Guideline	A rule or instruction that shows or tells how something should be done. A guideline is not mandatory.
Institution	Humanly devised agreements that structure human interaction. They are made up of formal constructs (rules, laws, constitutions), informal constructs (norms of behaviour, conventions and self-imposed codes of conduct) and their enforcement characteristics.
Institutional framework	Institutional framework is the set of formal laws, regulations and procedures as well as the informal conventions, customs, and norms that shape socioeconomic activity and behaviour. In this guideline we focus on the formal elements from the institutional framework and their impact on deployment of LCTs in buildings.

Knowledge management (KM)	The deliberate and systematic coordination of an organization's people, technology, processes, and organizational structure in order to add value through reuse and innovation.
Low carbon technology (LCT)	The term low carbon technology (LCT) refers to technologies that reduce the emission of GHG either during their production or during its use-phase. In the context of this guideline we focus on the building sector, thus when using the term "low carbon technology" (LCT) we refer to those relevant for the building sector.
Pathfinder	Is a funding mechanism used by Climate KIC for identifying markets for climate mitigation and adaptation innovations together with their partners. See more at http://www.climate-kic.org/projects/
Quantification	Approximation of a subjective aspect (attribute, characteristic, property) of a thing or phenomenon into numbers through an arbitrary scale. Every aspect can be quantified although it may not be measurable.
Stakeholder	In a wider sense: "any identifiable group or individual who can affect the achievement of an organization's or project's objectives or who is affected by the achievement of an organization's or project's objective" In a narrow sense: "any identifiable group or individual on which the organization or a project is dependent for its continued survival.
System	A system is a set of interacting or interdependent component parts forming a complex/intricate whole. Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning.
Transdisciplinarity	A collaboration across different scientific disciplines and of science and practitioners.
Transferability	It refers to the degree to which research results or outputs from an explicit context (city, country/region) can be generalized or transferred to other contexts or settings. From a qualitative perspective transferability is primarily the responsibility of the one doing the generalizing.

ETH Zürich
USYS TdLab
CHN K 78
CH-8092 Zürich
info-tdlab@ethz.ch

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