CENTER FOR NANOTECHNOLOGY IN SOCIETY
ARIZONA STATE UNIVERSITY
(CNS-ASU)

WORKSHOP REPORT
R15-0001

Advancing Future-Oriented Life Cycle Assessment for Responsible Innovation

Advancing future-oriented life cycle assessment for responsible innovation: A workshop report

Rider W. Foley[*,1,3] Marcel R. Weil[2], Manuel J. Baumann[2], Benedikt M. Zimmermann[2], Jens Buchgeister[2], and Ben A. Wender[3,4]

[1] Department of Engineering and Society, School of Engineering and Applied Sciences, University of Virginia, Charlottesville, USA

[2] Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

[3] Center for Nanotechnology in Society (CNS), Arizona State University, Tempe, USA

[4] School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, USA

Disclaimer:

This workshop report is published concurrently by the Center for Nanotechnology in Society at Arizona State University and by the Institute for Technology Assessment and Systems Analysis at Karlsruhe Institute of Technology.

Acknowledgements:

The authors would like to thank all the participants who attended the workshop and actively engaged in the designed activities. We give our warmest thanks to the S-NET conference organizer from ITAS/ KIT, and their generous support for our work in organizing and accommodating the workshop schedule. This material is based upon work partially supported by the National Science Foundation (NSF) under Grant #1140190, the Center for Nanotechnology in Society at ASU under Grant #0531194 & #0937591, and in part by the NSF and Department of Energy (DOE) Quantum Energy and Sustainable Solar Technology (QESST) Engineering Research Center at ASU under Grant #1041895. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF or DOE. The contribution of the ITAS/KIT researchers is based on work supported by both, the program "Technology, Innovation and Society -TIS" and "Storage and Cross-Linked Infrastructures -SCI" of the Helmholtz Society.

[*] Corresponding Author e-mail address: rider@virginia.edu

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1 Introduction

The goal of applying life cycle analysis (LCA) to guide development of emerging technologies towards decreased environmental burden is documented in LCA literature and shared by many researchers. Nonetheless, numerous methodological challenges diminish the efficacy of traditional approaches to LCA in the context of rapid technology change. These difficulties prompt researchers to depart from codified standards and develop innovative approaches to LCA that may provide actionable information for decision makers in spite of ubiquitous data gaps and high uncertainty. Researchers from the Center for Nanotechnology in Society at Arizona State University (CNS-ASU) and the Institute for Technology Assessment and Systems Analysis at Karlsruhe Institute of Technology (ITAS-KIT) have developed two such approaches, referred to as anticipatory and prospective LCA respectively and largely independently, until now. Prospective LCA is nested within the concept of prospective system analysis, which includes a broad variety and combination of quantitative as well as qualitative methods and tools advanced in the past few years. Prospective system analysis itself follows to certain degree basic principles of Constructive Technology Assessment (CTA) by including different stakeholder perspectives to broaden and positively influence technology development processes (Weil et al., 2014; Zimmerman et al., 2014; Baumann et al., 2013; Boavida et al., 2013 Knoeri et al., 2013; Zieman et al., 2013). During that same timeframe, Wender et al. (2013; 2014a; 2014b) developed anticipatory LCA from the conceptual frameworks of real-time technology assessment (RTTA) (Sarewitz and Guston, 2002) and anticipatory governance (Guston, 2008). While several publications describe these two independent approaches, there has yet to be a coordinated effort to bring together these two research groups and identify commonalities, differences, and opportunities for future advances. To this end, LCA researchers from KIT-ITAS and CNS-ASU convened a half-day workshop at the 6th annual Society for Study of Nano and Emerging Technologies (S.NET) conference in Karlsruhe Germany that brought together LCA experts from the US and EU to build a common research agenda. The overall objective of the workshop was to explore opportunities for LCA to support Responsible Research and Innovation (RRI) of emerging technologies. RRI takes a normative stance on emerging technologies and seeks to integrate broader values into technology development. Yet RRI seems to be an intuitively worthwhile idea but lacks practicable tools for implementation, although some efforts are under way, including but not limited to efforts by the Virtual Institute for Responsible Innovation (Guston et al., 2014), Res-AGorA (Tancoigne, Joly, Randles 2014), and nascent projects like RRI Tools (2014), to name a few ongoing efforts.

Conducting the workshop in conjunction with the S.NET conference afforded a disciplinarily diverse group of participants with varying levels of expertise in LCA and other technology assessment approaches. In total 26 participants from 9 different institutions attended the workshop and pre-workshop presentations. The general structure of the workshop consisted of: 4 oral presentations – two EU researchers and two US researchers – on the day preceding the workshop, two framing presentations to begin the workshop, and four structured activities. All participants attended the presentations and collectively engaged in one activity, and then were free to choose two of the remaining exercises. This report documents the activities and discussions captured in photographs and recorded by note takers.

2 Workshop background and objectives

The workshop was framed through an orientation to future-oriented life cycle assessment and sought to explore collaborations with social scientists, philosophers, political scientists and engineers in different fields. This approach offers a possibility to better understand the current state of technology assessment methods by seeking engagement with a diversity of disciplines. Another implicit goal of the workshop was to build bridges among and between North American, European and the global research community by building trust and working towards a mutual understanding of how life cycle assessment can be explored under the umbrella of RRI. The relation of LCA and RRI needed to be considered in depth, rather than through a brief presentation, and thus a separate workshop was organized to explore five topics identified beforehand:

- Identify commonalities and salient differences between prospective & anticipatory LCA
- Compile comprehensive set of future-oriented modelling tools for LCA researchers
- Explore underlying assumptions, limitations, and future research needs to enable LCA for RRI
- Consider life-cycle costing (LCC) and Social LCA (SLCA) for broadening LCA scope for emerging technologies
- Contextualize LCA for RRI within broader participatory technology assessment frameworks as RTTA and CTA

Additionally implicit goals for the workshop were not stated, but aligned with furthering the goals training graduate students in the process of planning, structuring, facilitating, and capturing information through experiential learning during the course of the workshop itself. Further, the workshop was designed to translate information between and among researchers from different discipline to facilitate knowledge generation between, often disparate disciplinary scholars.

This report serves to document the stated sub objectives, design, outcomes and limitations to this approach. Further, it serves to document efforts that advance the missions of CNS-ASU and ITAS-KIT to advance concepts, tools and practices for analyzing and assessing emerging technologies.

3 Conference session and workshop introduction

On the day preceding formal workshop activities, all participants gathered for a series of opening presentations from both EU and US researchers that detailed motivations for, and advances in, applications of LCA to support RRI. These presentations provided a common foundation for all participants and introduced specific tools under development that the organizers thought were particularly relevant. The first presenter was Claudia Som, who introduced NanoGuidelines and NanoScan tools under development at EMPA through the LICARA project. Both tools are qualitative or semi quantitative approaches designed to support small and medium enterprises (SMEs) in developing nano-enabled products with reduced environmental risks. Next Dr. Thomas Theis presented a network-based model for LCA of emerging technologies, with particular emphasis on understanding how consumer behavior influences market adoption and the eventual environmental impacts of an emerging technology. Dr. Theis presented a case study of consumer adoption-and-response to solid state lighting using agent based modeling that demonstrated the potential for significant rebound effects in total energy consumption as a result of this emerging technology. Next Dr. Thomas Seager discussed challenges faced in interpretation of LCA results of emerging and rapidly developing technologies, where significantly larger uncertainties may render existing approaches misleading. Finally, Dr. Bert Droste-Franke discussed the role of LCA in supporting robust policy advice in the context of government calls for responsible research and innovation. Dr. Droste-Franke finished with several recommendations for LCA practitioners, including shifting their focus to future rather than past decisions, always presenting uncertainty and sensitivity analysis alongside any LCA results, and "multi-disciplinary embedding" to broaden perspectives to include social, ethical, and economic dimensions.

Through these presentations, all participants were exposed to several innovative demonstrations of how LCA and life cycle thinking may inform the responsible research and innovation of emerging technologies. One challenge was that several of the presenters were expert LCA practitioners or researchers, whereas many participants were joining the workshop from broader participatory technology assessment backgrounds. Although these presentations began to build common language between the diverse participants, many of the more specific LCA findings and LCA challenges were perhaps inaccessible to the entire audience.

The following morning, the half-day workshop began with two introductory opening presentations by co-organizers Dr. Marcel Weil and Ben Wender, which described the workshop goals, format, and introduced the complementary approaches of prospective and anticipatory LCA. Both presentations used multiple illustrative examples of emerging technologies (e.g., photovoltaics, bucky paper, carbon nanotubes) to call for LCA to be applied early in technology development processes, called for greater efforts to involve stakeholders, and identified opportunities for blending qualitative and quantitative methods to explore uncertain futures.

4 Workshop Design

The workshop design intended to gather data in an explorative way to support the five explicit goals and started to explore the intersection between LCA and responsible innovation. The framework being tested builds upon the theoretical research by Wender, Foley et al., (2014a; 2014b) and in depth case studies by the research team directed by Marcel Weil (Weil et al., 2014; Zimmerman et al., 2014). These theoretical and empirical case studies were shared with the participants to make the concepts and data tangible for the participants and to frame the workshop. The workshop then shifted to engage participants in activity-based exercises that were each designed to support the separate workshop goals. Persons with specialized knowledge from a diverse set of disciplines and professions that perform technology assessment were solicited to attend. The researchers that attended held diverse specialties including: decision analysis, time-resolved LCA, LCA guidelines; bibliometric analysis, constructive technology assessment, traditional knowledge, science policy, material flows analysis, and energy analysis. Despite repeated invitations, only four researchers from North America and two from South America were present. The remaining participants hailed from the European research community. This is not surprising, since the organizers had limited funding to support international travel. The intention was to elicit participation from a wide spectrum of international researchers, as a means to structure a broadly focused, yet grounded workshop. This was achieved, but only to a limited extent.

The activity-based interdisciplinary workshop was conducted following the structure and schedule detailed in Table 1, below. Upon arrival at the workshop, participants were first welcomed to ITAS-KIT by Arianna Ferrari and then the workshop goals were explicitly stated. Participants were then provided an overview of the workshop agenda and expectations from the research team. Presentations by Marcel Weil and Benjamin Wender provided background information and orientation to all the participants in plenary. The orientation provided context to the participants and framed the workshop. It also created a space for participants to offer information and contribute insights during the workshop.

Table 1: Workshop Design. The table details the activities and desired outcome of the specific activity.

Setting	Activity	Intended Outcome
	Greeting	Welcome participants
Plenary	Introduction & framing	Orient participants to the expectations, theory and cases studies that frame the workshop and identify commonalities and salient differences between prospective & anticipatory LCA
Plenary	Activity 1: Ordering lunch	Consider life-cycle costing (LCC) and Social LCA (SLCA) for broadening LCA scope for emerging technologies
	Break	Offer an opportunity for informal networking
Breakout groups	<u>Round 1: Participants directed</u> Activity 2: Building blocks Activity 3: Filling the tool box Activity 4: Stakeholder values	 Explore underlying assumptions, limitations, and future research needs to enable LCA for RRI Compile comprehensive set of future-oriented modeling tools for LCA researchers Contextualize LCA for RRI within broader participatory technology assessment frameworks as RTTA and CTA
Breakout groups	<u>Round 2: Choose your own</u> Activity 2: Building blocks	 Allow the participants the to explore and learn

	Activity 3: Filling the tool box Activity 4: Stakeholder values	from another activity. Get a more diversified picture of the outcomes based on the goal alignment named above in this table
Plenary	Activity report outs	Allow participants the opportunity to share what they had created, learned, discovered during the activities.
	Feedback, reflections and closing thoughts	Allow participants the opportunity to offer the organizers feedback, reflect upon the workshop and share closing thoughts in plenary.
	Thank you & future events	Allow participants to understand next steps for the research project.

5 Workshop Activity Outcomes

5.1 Activity 1: Ordering Lunch

Before breaking into small-group activities, all participants were presented with a fake restaurant menu and asked to make selections to be provided for lunch. Ordering proceeded iteratively: each round introduced new types of information, the participant reconsidered and reported their lunch selection, and this data collected to track the impact of additional information on decision maker preference.

Goal

Social LCA (SLCA) and Life Cycle Costing (LCC) are often considered as methods to broaden the scope of environmental LCA to include social and economic performance metrics respectively. Combined, these methods constitute the three pillars of Life Cycle Sustainability Assessment (LCSA). In practice LCSA presents decision-makers with three incommensurate metrics, and there is little guidance regarding how to translate this into decision-guidance. The goal of this activity is to illustrate the difficulties faced in integration of economic, environmental, and social data and foster discussion regarding practicable paths forward.

Structure

The workshop organizers wanted to present participants with a decision-context that was familiar, time-constrained, and not immediately recognized as an exercise. The activity of ordering lunch from a small pre-set menu satisfied these objectives and allowed translation of the abstract activity goal into a tangible experience. *Pre-workshop setup* consisted of:

1. Drafting the menu alternatives and voting card as shown in Figure 1,
2. Conducting screening level environmental LCA (data from the Danish Food Database (Nielsen et al., 2003) for each item considering impacts in global warming potential (GWP) and photochemical oxidant formation (Photo),

3. Conducting screening level SLCA (calculated in openLCA with data taken from the Social Hotspot Database) for each menu item considering the indicators of Child labor and toxics and hazards (Tox & haz.), and
4. Selecting direct and indirect cost estimates for each menu item such that no single alternative was least burdensome across all three SLCA methods, the final results and menu are presented in Figure 2.

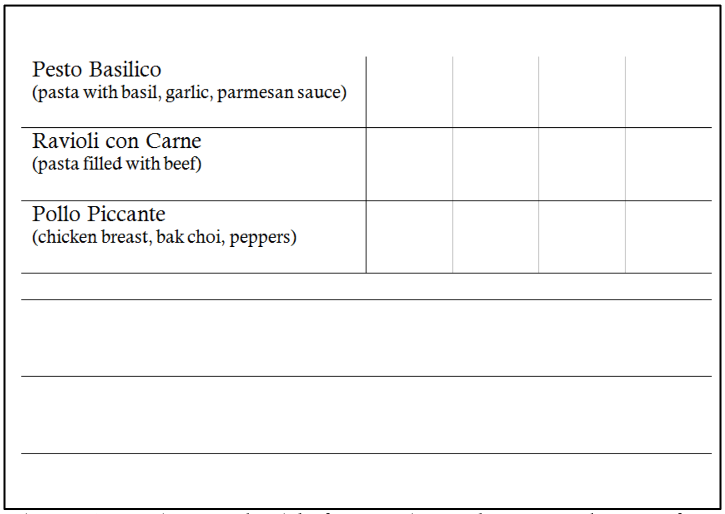

Figure 1: Voting card with four voting columns and space for comments on the bottom.

During the workshop the activity proceeded through a sequence of votes each with increasing quantities of conflicting information. Voting cards were distributed and three menu options from a local restaurant – Pesto Basilico, Ravioli con Carne, and Pollo Piccante – were presented with only a short description and no associated cost, environmental, or social data. Voting was not presented as a workshop activity, but rather a genuine solicitation of lunch requests. Initially each participant selected their lunch option based only on its name and a short description, and recorded their preference. Next, participants were told that the conference organizers were only able to provide partial cost support lunch accommodations, and that there would be a direct additional cost for some menu items. The updated menu was presented, lunch selections reconsidered, and preferences recorded on the distributed voting card. Following this general pattern, additional environmental and social impact data was introduced sequentially, and resulted in an information-saturated menu, as shown in Figure 2.

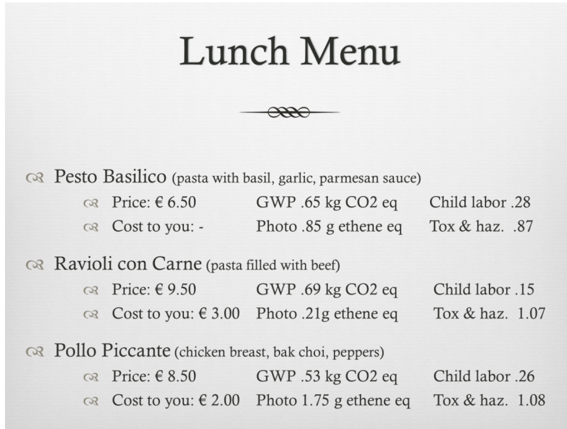

Figure 2: Final menu slide depicting numerical results in select economic, environmental, and social impacts. Note: Results were presented sequentially, with votes collected in-between the introduction of each new piece of information. No results were presented graphically to further challenge interpretation.

During voting, the participants realized that the activity was an illustrative exercise and that their votes had no bearing on the lunch provided, which may have resulted in decreased engagement. Nonetheless, the voting activity called attention to challenges faced in conducting LCSA, specifically regarding decision-maker integration of incommensurate and conflicting data, and fostered critical discussion regarding use of LCC and SLCA to broaden the scope of environmental LCA.

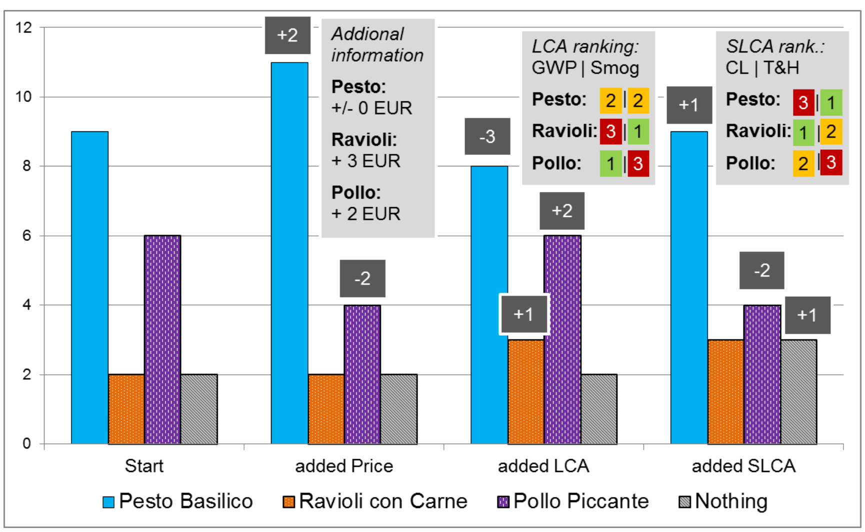

Figure 3: Number of participants requesting each alternative each round, with emphasis on the number of votes changed with the addition of new information (Note: CL=Child Labour, T&H=Toxics and Hazard).

Following voting, workshop coordinators led participants through an *in-session discussion* focused on how individual decisions were made or revised as a result of new information. Two broad strategies emerged: a 'tradeoff paradigm' and 'heuristic' or 'identity-based' decisions. The activity (and perhaps

LCA more broadly) targeted the 'tradeoff paradigm', while the guided discussion presented the same information in the form of relative rankings. Several workshop participants described their decision-making process as entirely disconnected from the information presented, thus calling into question the value of more information for 'better' decisions. For example, one participant described how their self-identification as vegan eliminated all but one menu option, and another said that since they had chicken last night they didn't consider it for lunch. Ironically, several other participants indicated that the information presented was incomplete. There was a request for reporting on additional environmental impact categories, specifically agricultural land transformation. There was general consensus that the results presented were not transparent, and difficult to utilize for a specific, simplified decision. Debrief concluded with one participant asking how frequently we (as LCA practitioners) use LCA results to change our own decisions, and remarking that if we don't, no one will.

During the debrief, one organizer collected completed voting cards (n=19) and presented back the number of participants requesting each meal, shown in Figure 3. The voting cards that had empty columns were assumed to maintain their preceding selection unless comments indicated otherwise. At least two participants revised their initial selection when presented with additional cost information, three revised when presented with cost and environmental data, and two revised when presented with cost, environmental, and social data. This small relative rate of change on each alternative suggests that most decisions were made or remained unchanged irrespective of introduction of new information.

Reflection

Although the menu activity served as an effective opening exercise that fostered an open and engaged discussion, many participants quickly realized the illustrative purpose of the game and some stopped voting all together. This diminished investment may have contributed to fewer decision changes as demonstrated in Figure 3. The activity did not focus discussion on difficulties of reconciling conflicting economic, environmental, and social data as initially planned. Nonetheless, discussion called attention to striking divergence with regard to decision-making strategies employed by individuals within the group. There was consensus that pre-selection of environmental and social indicators, and their non-transparent presentation, was trying for the LCA researchers and practitioners.

Recommendations

In order to improve participant investment in the exercise, the organizers recommend conducting this activity over a longer time-frame, interspersed between other workshop activities, and using new voting cards for every decision. This may more effectively disguise the true purpose of collecting votes and potentially result in greater fluctuation in decision-outcomes. Imposition of additional time constraints may pressure participants to make more *ad hoc* decisions and challenge attempts to rationalize the best decision. Additionally, the organizers recommend expanding the menu to include vegan options, although serving sizes may have to be adjusted to ensure that no single menu option performs worst or best on all alternatives.

5.2 *Activity 2: Building Blocks*

In small groups (n~8) participants assembled simple physical structures out of wooden blocks labeled to represent the data, assumptions, knowledge gaps, or limitations of LCA when applied to emerging technologies. After dedicated building time, participants presented their model to the group and identified commonalities, differences, and opportunities for combining models into a broadly applicable framework.

Goal

Applying LCA to emerging technologies is challenging because of limited data characterized by high uncertainty, rapid changes in technology performance, and incomplete impact assessment methods that lack characterization factors for emerging contaminants such as engineered nanomaterials. Nonetheless, innovative demonstrations of application of LCA to emerging technologies emerge from the literature. However, these advances proceed largely in insolation. The goal of this activity is to use physical models to help participants identify and articulate available data, critical assumptions, limitations, and data gaps relevant to a streamlined LCA of a developing technology they are familiar with, and then combine multiple models together to build consensus on critical future research needs that are applicable across emerging technologies more broadly.

Structure

The workshop organizers wanted to create a 'play-type' atmosphere where participants had to quickly create high-level models – without excessive detail or nuance – using metaphorical building blocks. For *pre-workshop setup* coordinators labeled 56 wooden blocks in an equal ratio with either: D, representing data available or used in an LCA; A, representing a necessary assumptions made in LCA modeling; G, representing a critical knowledge gap; and L, representing a methodological limitation that LCA is incapable of addressing. Four different color index cards were prepared and labeled (D,A,G,L) for participants to document their reasoning. *In-workshop execution* began with all blocks piled in a tower, and participants took turns removing a block labeled either D,A,G, or L without toppling the tower, as shown in Figure 4. The participant then wrote a short description of what the block represented in their model on the corresponding color notecard while the next person began drawing. Play continued this way for several rounds. Initially, removing blocks from the tower was easy but as the game progressed the tower became significantly less stable and participants were unable to retrieve a particular type of block. Thus, participants often had to choose an alternate block-type to continue building their LCA model – for example, replacing data with an expert assumption. After each participant assembled a tower of ~5 blocks, shown in Figure 5a, play concluded when the tower collapsed or no more blocks could be removed as shown in Figure 5b. Participants then began in-session discussion by briefly presenting their models to one another in an attempt to identify similarities, differences, or opportunities to combine multiple models together.

Figure 4: Participants build metaphorical towers representing a screening-type LCA of an emerging technology of their choice, and document the available data, modeling assumptions, knowledge gaps, and limitations encountered.

Participants entered the activity from different disciplinary backgrounds with varying levels of LCA expertise, and thus developed diverse models representing unique approaches to applying LCA to emerging technologies. The majority of participants listed available **data** sources such as Ecoinvent and GaBi, and a few participants named specific scholarly publications, technology developers, and/or laboratories. Some towers employed mathematical models and **assumptions** in place of measured data, for example estimates regarding product performance or user behavior were necessary **assumptions**. These in turn enabled discovery of additional "possibility spaces" that would otherwise be inaccessible. The majority of participants identified uncertainties regarding future changes to energy generation systems as well as product end-of-life impacts as critical **data gaps** relevant to many LCA models. Fewer participants identified incomplete databases of characterization factors in the context of emerging contaminants and one participant focused on **gaps** in understanding and modeling human behavioral responses to emerging technologies. Participants described uncertainties regarding market penetration and potential regulation of emerging technologies as **limitations** beyond the scope to current practices in environmental LCA. Beyond LCA-specific limitations, discussion between participants also focused on the inherent limitations – for example general inability to validate or verify results – of applying any complex environmental model to inform decision-making.

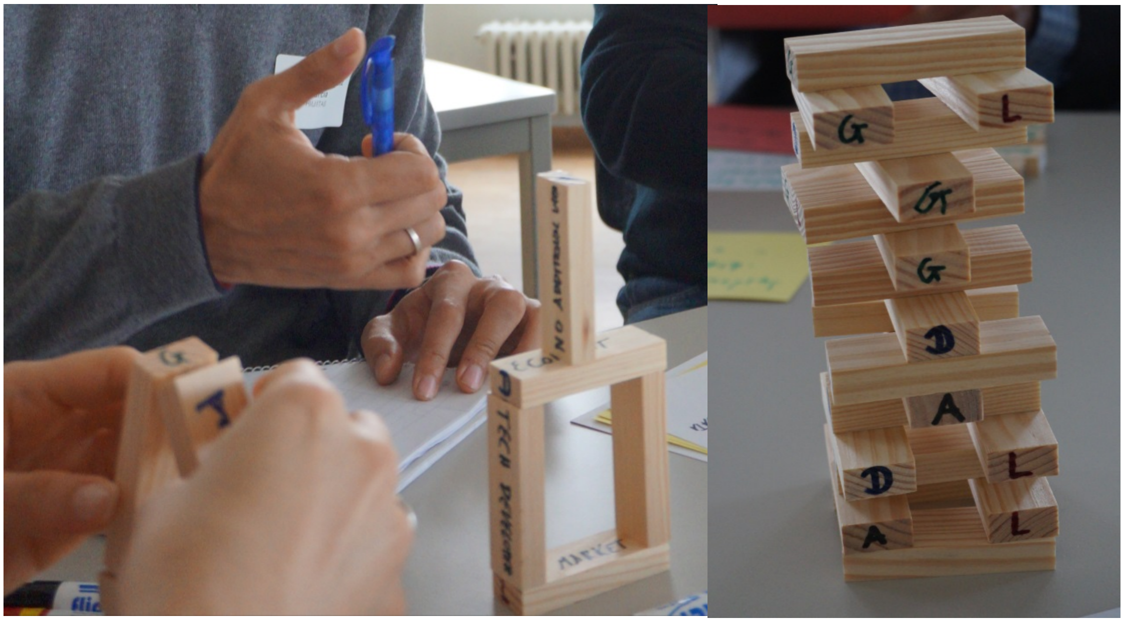

Figure 5 a) Participants creatively arrange blocks representing data, gaps, assumptions, and limitations into metaphorical LCA models, and b) the game ends when the tower falls or no more blocks can be removed.

Reflection

The activity engaged participants with diverse backgrounds, which was simultaneously beneficial and challenging. Specifically, the range of limitations and assumptions identified was broad and inclusive, yet it was challenging to build consensus regarding current LCA practice and future research needs. The coordinators identified three general categories of participants.

1. LCA practitioners were the most experienced with conducting practical LCA studies, often began with the necessity of LCA databases, and identified the need for additional LCI data.
2. LCA theorists had less case-specific experience although being LCA experts, often began with necessary assumptions and current limitations, and generally focused on developing LCA methods rather than improving database quality and availability.
3. Participants from other disciplines, predominantly social sciences, had the least knowledge of LCA and identified issues related to user behavior, market acceptance, and regulatory interventions as critical uncertainties to include in LCA of emerging technologies.

All participants complained that the distinction between the types of blocks was unclear, and there was substantial overlap between identified **limitations**, **gaps**, and occasionally **assumptions**. The organizers expected a correspondence between **gaps** and **assumptions**, but conceived of all categories as distinct: data being currently available and useable numerical values, gaps representing missing numerical values, assumptions providing numerical values to address the gap, and limitations being questions beyond the scope of LCA.

Recommendations

In future iterations of this activity it is critical for facilitators to clearly articulate what each block-type represents, and perhaps consider consolidating some categories. The short description of each block was often difficult to interpret, partially because participants were encouraged to explore a case relevant to their expertise, often a specific technology, which included content-specific knowledge not shared by the group or facilitators. One possible modification would be to focus all participants on one common, timely case study such as in-vitro meat. Different participants occasionally documented the same information, which is useful for identification of common trends but is limiting when generic answers are provided, thus facilitators should help participants avoid standardized answers. Another potential modification that may increase collaboration between participants would be to collectively build a single tower by discussing each successive addition. In this configuration, participants would first build individually about a common topic, and then work cooperatively in a second phase to discuss and build consensus regarding the most important blocks to assemble into a cohesive model.

5.3 Activity 3: Filling the Toolbox

In small groups (n~8) participants conceptualized a tool – broadly described to include methods, databases, and knowledge sources – exogenous to LCA that could be incorporated into LCA practices to improve its applicability to emerging technologies. Participants individually completed an open-format questionnaire then described their tool to the group and looked for similarities and differences to other participant suggestions.

Goal

Application of LCA to emerging technologies has benefitted from inclusion of methods and tools such as scenario analysis and thermodynamic process modeling that provide valuable insights in spite of insufficient data and high uncertainty. These innovative approaches emerge in the literature, but have yet to be documented comprehensively. The goal of this activity is to develop an initial catalog of such diverse tools – complete with relevant description of potential contributions – that may inform future-oriented LCA.

Structure

The workshop organizers wanted the activity to take advantage of the diverse experience and expertise of the participants while keeping discussion focused on LCA and not a discipline the suggested tool grows from. In *pre-workshop setup*, organizers iteratively developed a series of open-ended questions that challenged participants to articulate how a tool they are familiar could be implemented within existing LCA frameworks. From a list of more than 20 questions, the organizers settled on the following seven questions.

1. Name and describe the tool (defined broadly including methods, modeling procedures, etc.) and how it could be used in LCA of emerging technologies. What insights does it provide that would otherwise be missed?
2. Provide a high level example (e.g., a previously published study or a hypothetical case) of how the tool can be used to improve LCA of emerging technologies.
3. Where in LCA (e.g., inventory, impact assessment, interpretation) could the tool be applied and how does it connect with existing practices?
4. Is there one type of LCA (e.g., attributional, consequential) or uncertainty (e.g., scenario, parameter) that the tool best-suited for? If so, why?
5. What additional uncertainties are introduced by using this tool and how may they be assessed?
6. What data and/or modeling requirements does the tool have? What are potential barriers to broader application of this tool?
7. Who is using the tool outside of LCA and how? How could sharing of the tool among LCA practitioners be improved?

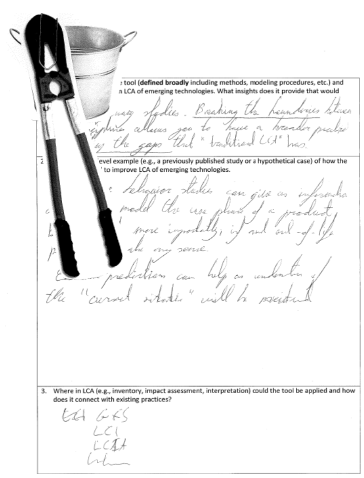

Figure 6: Example worksheet and affixed tool image.

The workshop organizers also cut out an assortment of images including office supplies, craftsman tools, toys, small machines, and vehicles. *In-workshop execution* began with all pictures spread across a table while participants brainstormed a tool they are familiar with. Participants were instructed to select an image that caught their attention and represented their tool metaphorically. Participants spent ten minutes answering the preceding questions, and then affixed the image to the worksheet with tape, as shown in Figure 6. With all worksheets completed, participants began *in-session discussion* by briefly summarizing their worksheet to the group. If time permitted participants then discussed how the tools presented related to one other, with particular emphasis on understanding if tools shared a common motivation (i.e., were expected to address a similar knowledge gap) and possible synergies between sets of tools. The activity resulted in 12 completed worksheets describing tools that span engineering, economics, multi-criteria decisions analysis, and social science perspectives. Two representative tool descriptions are summarized and compared in Table 2, below.

Table 2: Comparison of two representative completed Toolbox worksheets.

Question focus	Participant 1	Participant 2
1) LCA usage & information	- diffusion of innovation models project scenarios of emerging tech adaption	- agent based modelling shows dynamic behavior, user behavior
2) High level example	- results of consequential LCA results [per FU] can be converted to aggregate impacts representative of the technology on the whole	- agent based modelling can estimate potential rebound effects associated with adoption of renewable energy technologies
3) Application details	- it would be an additional step in interpretation, after LCA is conducted	- it acts in inventory to estimate net impacts associated with adoption of emerging tech.
4) LCA type and uncertainty type	- is best suited for consequential LCA (attributional is product focused) and scenario uncertainty regarding adoption rates	- consequential LCA (b/c user behavior not attributed to a product) addresses scenario uncertainty
5) Additional uncertainty	- uncertainties in Bass model regarding "neighbor" effects, early adopters, relevance of historical parameter to emerging tech	- emergent behavior predicted is not certain and is a function of input assumptions & properties which may not be accurate
6) Data & modelling requirements	- need to know parameters of Bass-Model -- generally based on historical examples	- should be based on solicited values and engaged tech. Users - have to learn additional software
7) Sharing with LCA peers	- economists use tool - make LCA community aware, understand context	- system modelers, social scientists - don't know

As with other activities, the diversity of backgrounds represented was both benefit and a challenge, particularly with regard to integration of multiple tools. In the first group discussion focused largely on modeling economic forces in LCA and tools for addressing uncertainty in process scale-up. The second group, which contained less LCA expertise but several broader perspectives focused on methods such as surveys for eliciting social data and incorporating diverse stakeholders in LCA.

Reflection

In both rounds, discussion was too brief to explore the intersections and similarities between all tools presented, which diminished the capacity for higher level insights. Not all participants completed the worksheet within the allotted time, several questions required further clarification, and some participants requested further structure to the exercise. Descriptions in the completed worksheet detail methodologies that hold potential to support application of LCA to emerging technologies, however many suggestions remain difficult to implement and introduce further uncertainty to analyses.

Recommendations

In future iterations of this activity the worksheet should be shortened to a maximum of three questions (~1pg hand-written) to provide more time for tool explanation and discussion. Participants and organizers agree that the wording of the questions should be reformulated into shorter statements that can be answered with less detail. Facilitators should spend more time framing the exercise with published examples of integration of exogenous tools into LCA. It may be beneficial to clearly define a specific technology context for a specific group of stakeholders to allow easier identification of synergies between tools, although others disagreed with this suggestion as it may limit broader participation.

5.4 Activity 4: Incorporating Stakeholder Values

In small groups (n~6) participants were assigned character role cards and adopted those perspectives to sort six environmental impact categories analogous to weighting in environmental LCA. After briefly presenting their highest two selections, participants worked together to negotiate one common rank ordering of impact categories and then participated in facilitated discussion that contextualized LCA within broader participatory technology assessment approaches.

Goal

Current practices in LCA incorporate value preferences via weighting of environmental impact categories, however the diversity of stakeholders involved across the life-cycle of emerging technologies typically precludes consensus. Approaches to participatory technology assessment seek to integrate diverse stakeholder perspectives into analyses and influence technology research and development decisions. The goal of this activity was to illustrate challenges in identifying and integrating stakeholder values into LCA and contextualize LCA within broader participatory technology assessment approaches such as constructive technology assessment (CTA) and real-time technology assessment (RTTA).

Structure

The workshop organizers wanted participants to adopt an unfamiliar perspective associated with a fictitious stakeholder implicated along the life-cycle of photovoltaic technologies, and consider how the diversity of values and environmental preferences could inform LCA practice. For pre-workshop setup coordinators developed six Character Cards detailing biographical information about an individual and seven Values Cards that visually represented common LCA impact categories. In-workshop execution began with each participant individually sorting the Values Cards from highest (left) to lowest (right) priority from the perspective of their character, for example as shown in Figure 7, below. Each participant then briefly explained their character's background (see Table 3) and prioritization of certain environmental impact categories over others, see Table 4.

Figure 7: Representative results of one participant's prioritization of environmental impact categories presented graphically as Values Cards.

Table 3: Character's defining attributes.

Character Card	Location	Profession	Motivation	Concern/Fear
Franz Gottlieb	Munich, Germany	Rooftop solar installer	Economic stability	Nuclear energy
Quentin Rodriguez	Santiago, Chile	CEO silicon mining company	Prove mining is sustainable	Smog in local city
Deke Hamana	Nairobi, Kenya	Owns electronics store	Installing photovoltaic cells will reduce smog	Poor air quality is affecting family health
Lenora Williamson	Phoenix, USA	Operations manager at utility company	Deliver constant electricity	Photovoltaic made in China hurt US economy
Quan Li	Chengdu, China	Production manager	Economic growth	Local drinking water is affecting family health
Umay	Vishnevka, Kazakhstan	Shepard	Transform family business to produce electricity	Cost of disease on herd.

Table 4: Impact categories as ranked by each 'character' over four rounds

Character	Round 1	Round 2
Franz	smog; energy demand; human toxicity; greenhouse gas emissions; land use; water depletion; acidification	energy demand; human toxicity; greenhouse gas emissions; acidification; smog; land use; water depletion
Quentin	smog; greenhouse gas emissions; energy demand; human toxicity; acidification; water depletion; land use	smog; energy demand; greenhouse gas emissions; human toxicity; water depletion; acidification; land use
Deke	smog; greenhouse gas emissions; energy demand; human toxicity; acidification; land use; water depletion	energy demand; smog; human toxicity; greenhouse gas emissions; land use; acidification; water depletion

Lenora	water depletion; energy demand; greenhouse gas emissions; land use; acidification; smog; human toxicity	energy demand; greenhouse gas emissions; smog; water depletion; acidification; human toxicity; land use
Quan	water depletion; human toxicity; smog; energy demand; land use; acidification; greenhouse gas emissions	human toxicity; water depletion; energy demand; greenhouse gas emissions; acidification; smog; land use
Umay	human toxicity; smog; greenhouse gas emissions; energy demand; water depletion; acidification; land use	energy demand; smog; water depletion; human toxicity; acidification; greenhouse gas emissions; land use

After all participants shared their individual selections, the group collectively and deliberatively prioritized one set of Values Cards within strict time constraints (~5 minutes). Although alliances rapidly formed between individuals that prioritized the same impact categories, no group reached consensus in the compressed timeframe. *In-session discussion* began with participants questioning how the different rankings offered by stakeholders could inform LCA, or any decision, given the presence of tradeoffs and value conflicts values. Discussion also focused on an inherent tension between the global focus of LCA and the regional interests of each character. The short descriptions shaped participant perception of the social context experienced by each character, and thereby influenced prioritization of impact categories. One participant questioned whether they should prioritize ‘professional values’ or ‘personal values’, calling attention to internal conflicts regarding tradeoffs between impact categories in addition to tensions between different stakeholders. This generated fruitful discussion and deliberation regarding cultural and regional differences in approaches to reconciling personal and professional values.

The diverse background of participants resulted in discussion that questioned the capacity for LCA to effectively integrate of stakeholder values through impact category weighting only. Some participants believed that LCA should be tailored to a specific decision maker and context while others suggested that LCA should not solely target elite decision-makers but rather seek to engage, incorporate values from, and report results to a broad range of actors. Discussion also identified the need to more effectively communicate LCA practice and results to diverse stakeholder groups.

Reflection

The role-play activity was effective at helping participants explore diverse and unfamiliar perspectives, and there was general consensus that engaging stakeholders to inform LCA was valuable and should occur throughout the LCA process. Nonetheless, there was little consensus regarding methodological improvements that could foster transparent and meaningful integration of stakeholder values in situations of conflict. Furthermore, the Character Cards are oversimplifications of human stories, and an individual’s process of prioritizing impact categories is abstract in this exercise.

Recommendations

In future iterations of this activity, additional time for deliberation during group prioritization should be provided, which may allow participants to reach consensus on environmental values. Several participants suggested that they should create their own Value Cards, and not be forced to select from a previously determined list. To more effectively connect the activity to opportunities for improving LCA practice, the participants should be challenged to think of other decision points in LCA, in addition to weighting of impact categories, through which stakeholder values could shape the analysis. This notion directly challenges the International Standards Organization (ISO) 14040/14044 for conducting LCA in a manner that is objective and value free, except for weighting which is optional because of its inherent subjectivity (ISO, 2006). For example, the participants could be engaged in designing alternative functional units and systems boundaries that reflect different stakeholder perspectives.

6 Conclusion

The goal of the LCA for RRI workshop at the S-NET 2014 conference in Karlsruhe was to advance LCA in the context of RRI. For this, four group activities were performed: integration of LCA, SLCA and LCC into a life cycle sustainability assessment decision context; finding assumptions and limitations for LCA on RRI; integrating values in LCA; and finding new tools for realizing these objectives.

The discussions and feedback showed that all of these activities objectives were achieved in a sense that participants' awareness on the topics was raised and a foundation for further research was laid. Future events will determine if research will be built on this foundation. Certainly, as the goals of the workshop were formulated rather ambitiously, this half-day event could not fully reach its aims in a strict sense.

Conclusions on the workshop and future steps were discussed among the organizers during a 3-day debrief meeting in Arizona. During this debrief, specific recommendations for the improvement of the activities, general discussion on the context of LCA in RRI and plans for further research and collaboration were made.

6.1 Discussion on activities

Overall the workshop activities faced two major limitations. On the one hand time was too limited and the breakout groups were too large to gather and in-depth-discuss all ideas and topics that came up during the activities. Due to these time restrains, participants could only do the plenary activity and two out of three breakout group activities, so the activity's results do not represent the complete group. On the other hand the variety of expertise among the participants made it hard to find a common denominator for in-depth discussions. Besides LCA experts, the group consisted of sociologists and philosophers, of whom many did not have explicit knowledge in the field of LCA or life cycle thinking and therefore could only contribute to some tasks at a limited extend. Under these workshop conditions it would have been necessary to explain basic terminology, for example what 'emerging technology' meant in the context of this workshop. Furthermore, a more structured introduction about each activity, e.g. definitions of the terms 'assumption' and 'data gap' in the building blocks activity, and clearer description of the participants' tasks would have been helpful.

As most activities were built from scratch around the LCA in RRI research questions of this particular workshop, they still have certain improvement potential. Some activities turned out to be more refined and suitable than others. Participants pointed out that the lack of topic focus, i.e. one or few emerging technology case studies, made it hard to find common ground and absorbed the participants' time for thinking about a technology they could do the exercise on. Instead of the food picking activity a theme including an emerging technology could have fitted better into the workshop context and would have prevented the involvement of certain personal, cultural and ethical restrictions regarding food preferences. In order to facilitate the discussion, some attendees suggested providing the participants of future events with a catalogue of basic literature in order to prepare everyone for the tasks and create a basic state of knowledge among the participants. Furthermore, upcoming workshops should invest time explaining the terminology and methods used in the LCA for RRI context. Finally, clustering the participants would have allowed statistical sampling of the results, which could have shown interesting correlations. However, the very limited sample size of the participants does not allow for any robust, representative results. Rather than the activities' results, the important outcome of the activities is thus the sharing of ideas and different point of views.

The exercises that were developed for the workshop still have considerable improvement potential, which has, to some extent, been identified during the workshop and over the debriefing-phase. These exercises should be refined and could be used for further conferences, in the RRI context or at dedicated LCA events, as well as for teaching purposes.

6.2 Conclusion regarding LCA in the RRI-context

The very different expertise among the group of participants, who work in contexts of LCA, RRI and technology assessment, was both a challenge and a chance. The challenge was to integrate all different scientific fields and provide an exercise platform in which everyone was able to attend regardless of their knowledge about LCA. The chance of the inhomogeneity among the participants was to receive ideas and feedback from adjacent areas of science which could help to broaden the scope of LCA and integrate new tools into the LCA methodology toolbox in order to advance LCA in an RRI context. The workshop showed that a multitude of sciences, involved in RRI-activities and beyond, that are currently not regarded in most LCA approaches, can contribute to the future advancement of LCA.

Likewise, RRI research could benefit considerably from the holistic, quantitative life cycle thinking approach of LCA.

Overall, the idea and most activities of the workshop were positively reviewed by participants of all trades and similar events with more refined activities should be held in future in order to go deeper into the LCA for RRI topic, generate and spread new ideas, built foundations for research and create research networks in this new field of LCA.

6.3 Outlook

The workshop's organizational team, consisting of Arizona State University, Karlsruhe Institute of Technology and University of Virginia, aims to sustain their cooperation on the topic LCA for RRI and work on exploring theoretical and practical approaches to future-oriented LCA as well as on further evaluation of commonalities and differences between anticipatory and prospective LCA. Additional international networking activities, including the participants of the workshop and beyond, are to be planned. Future work will also look at extending the "tool box" for future-oriented LCA studies. Also, the workshop activities will be developed further for use in conference and academia contexts.

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