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Transforming living labs into lighthouses: a promising policy to achieve land-related sustainable development

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Abstract. The previous rather abstract debate about sustainable development has been focused by the introduction of the United Nations (UN) Sustainable Development Goals (SDGs) in 2015 and the related European Union (EU) Green Deal (GD) in 2019. Restricting attention to agriculture, proposed targets and indicators are, however, not specific enough to allow a focus for developing innovative and sustainable management practices. Clarity is needed because farmers are suspicious of governmental actions. To confront these problems, the European Commission (EC) has presented the Mission concept that requires joint learning between farmers, scientists and citizens. For the soil mission, "living labs" are proposed that should evolve into "lighthouses" when environmental thresholds for each of at least six land-related ecosystem services are met. This presents "wicked" problems that can be "tamed" by measuring indicators for ecosystem services that are associated with the land-related SDGs in a given living lab. Thresholds with a character that is occasionally regional are needed to separate the "good" from the "not yet good enough". Contributions by the soil to ecosystem services can be expressed by assessing soil health. By introducing the mission concept, the policy arena challenges the research community to rise to the occasion by developing effective interaction models with farmers and citizens that can be the foundation for innovative and effective environmental rules and regulations. We argue and illustrate with a specific example, that establishing Living Labs can be an important, if not essential, contribution to realizing the lofty goals of the SDGs and the Green Deal as they relate to agriculture.

Highlights.

1. Joint work in living labs can realize genuine transdisciplinarity.
2. Land-related SDG targets need specification by indicators and thresholds for ecosystem services.
3. Lighthouses can make crucial contributions to the societal sustainability discourse.

1 Introduction

As society faces serious environmental problems, the presented storylines are now rather confusing for land users and the public at large. Different environmental issues often receive separate attention in the media: greenhouse gas emissions in the context of climate change; ground- and surface water pollution; polluted soil resulting in unhealthy crops, nature deterioration, biodiversity decline and land degradation to mention just six issues of high societal importance. How do we deal with this?

To structure and clarify the debate, the policy arena launched a welcome series of initiatives, such as the worldwide United Nations (UN) Sustainable Development Goals (SDGs) in 2015 (https://sdgs.un.org, last access: 10 October 2022) which list 17 goals that are summarized in a one-page pictogram from which abbreviated descriptions were copied in this paper. The associated European Union (EU) Green Deal (GD) in 2019 basically follows the SDGs (https://climate.ec.europa.eu/eu-action/european-green-deal_en, last access: 10 October 2022). However, even though goals and associated targets and indicators are defined for the SDGs and the GD, as yet hardly any attention is being paid to how the implementation of all these lofty goals should be realized in the real world. The European Commission (EC) is, however, certainly aware of current communication gaps between land users and the scientific and policy arenas; hence they are promoting the mission concept: "a new role for research and innovation and a new relationship with citizens" in their Horizon Europe Research and Innovation programme 2021–2027 (EC, 2021; Dro et al., 2022). Due to space constraints, attention in this paper will be restricted to land use associated with agriculture, but of course the SDG concept also applies to other forms of land use such as forests, city green spaces, industrial sites, recreational areas, etc. The mission for "A Soil Deal for Europe" suggests establishment of "living labs" and "lighthouses" (defined as "spaces for co-innovation, through participatory, transdisciplinary systemic research"). These living labs would "contribute to Green Deal targets for sustainable farming, climate resilience, biodiversity and zero-pollution". When contributions are successful by meeting their particular threshold values for a set of indicators, a lighthouse is established to be used for education and communication purposes focused on other farmers, the public at large and the policy arena. Selecting indicators and their measurement methods as well as determining threshold values will require a major research effort considering local soil and environmental conditions. The living lab, thus defined, should be considered as a starting point for further development of the sustainability debate as local modifications of indicators and thresholds may be needed. However, it provides a solid standard and starting point, based on an international agreement for such an analysis that otherwise might drift apart. Additionally, there is no doubt that some lighthouses already exist and identifying and documenting such positive examples would be highly stimulating for the overall debate.

However, the current lack of operational implementation plans for living labs presents a problem because farmers have to be convinced to see a clear connection with sustainable development that most of them would support, in principle, when clearly articulated in a manner that would recognize their entrepreneurial activities. The fact that some environmental goals are not directly defined in current regulations but rather in terms of means to reach the goals, increases the confusion. For example, water quality (SDG6, to be discussed later) is not directly addressed in the Netherlands by the measurement of water quality but in terms of the soil–nitrogen content in the fall at the start of the leaching season or in terms of a critical level of cattle density (Bouma, 2011, 2016). Such indirect values have quite different effects in different soils and distract attention from the real issue at stake which, in this case, is water quality. Finally, living labs have de facto been proposed top-down by the European Commission, but the concept will only work in practice when it is embraced and comes alive in a bottom-up procedure, presenting yet another challenge for the research, stakeholder and policy arenas.

Citizens also receive mixed messages: the media, often inspired by action groups, seem to focus on environmental problems associated with agriculture: pollution of water, decrease of biodiversity, nature deterioration and land degradation. Little attention is paid to existing farming systems that already successfully satisfy both economic and environmental goals. The agricultural community, their leaders and the research community are ineffective in communicating such successful efforts. Identifying and documenting already existing lighthouses would be helpful in this context, as there is no time to lose.

How do we move beyond the current state of the art? The policy arena, represented here by the United Nations and the European Union has clearly presented a challenge to the science community that should now rise to the occasion. An open discussion on the future role of research, interacting with stakeholders, citizens and the policy arena is urgently needed, if only because the SDGs should be reached by 2030. The large body of literature on interactive, transdisciplinary research (e.g. Bunders et al., 2010; Functowicz and Ravetz, 1993; Habermas, 1984; Hessels and Lente, 2008; Hoes et al., 2008; Peterson, 2009; Tress et al., 2001; van Mierlo et al., 2010; Wenger et al., 2002) should now result in real practical results.

The issue will be addressed here from four perspectives focusing on (i) the farmers; (ii) the research community; (iii) public perceptions and (iv) the policy arena. Reference is made to a published case study, illustrating a proposed roadmap.

This sequence reflects the need for a bottom-up approach to jointly develop management systems on different types of soils in living labs that satisfy the targets and indicators of the SDGs and the goals of the GD, thereby creating lighthouses. Then, effective policies with transparent rules and regulations should follow, being inspired by results obtained in such lighthouses and results should be widely shared as inspiring examples aimed at colleague farmers and citizens at large, using modern interactive communication methods.

The above discussion shows that soils have to be considered in a broad societal–political context, and this is well described by the recent proposal by Australian scientists to introduce the overall concept of soil security. "How to secure our soils?" (Field et al., 2017). They define five C's for a given soil: condition (= actual soil health); capability (= potential soil health); capital (= comparison with other soils), connectivity (= interaction with scientific colleagues, stakeholders and policy makers) and codification (= transparent and effective environmental laws and regulations). The living lab and lighthouse attempt can contribute to achieve soil security, thus defined.

2 Engaging the farmers

Farmers are confused about current environmental rules, regulations and the overall thrust of environmental policies aimed at achieving sustainable development. They feel that current regulations de facto act as suffocating barriers hampering their entrepreneurial activities as they appear to reflect a lack of understanding among bureaucrats of the adaptive requirements of modern farming. Of particular concern are (i) economic prospects; (ii) unclear environmental regulations, and (iii) lack of independent advice (e.g. Bampa et al., 2019; Schröder et al., 2020; Bouma, 2021). A recent I&O (https://www.ioresearch.nl/actueel, last access: 5 November 2022) survey of dairy farmers in the Netherlands showed that 88 % of them did not trust government! Above all, farmers want clarity! Their rallying cry is the following: "provide clear goals and we will reach them!"

However, if farmers do not adopt appropriate practices, environmental laws and regulations are bound to remain a dead letter. Veerman et al. (2020) report that 60 %–70 % of European soils are degraded in various ways. Even though technical solutions are well known in many cases after decades of research, they are not effectively communicated to practitioners. More effective communication about environmental goals in the context of achieving sustainable development is therefore needed with both farmers and citizens. This is necessary because there is now much information on a wide range of farming systems provided by various groups of supporters often operating in the social media: organic, biological-dynamic, circular, regenerative, nature-inclusive, enriching, high-tech precision and others, many of which only considering a limited number of ecosystem services on the SDG spectrum. One example is organic farming that does not allow the application of agrochemicals, but when applied with precision techniques, non-organic sustainable farming systems can be realized. What about greenhouse gas emissions and water quality? Focusing on SDG and GD indicators and corresponding thresholds offers an objective measure that is valid for all farming systems, even for some possibly new ones to be developed in living labs. Some living labs may not yet have reached certain thresholds, but an introduction of management measures that will most likely lead to meeting the thresholds in future should be recognized as a positive signal.

When focusing on agriculture, primary attention will not only be on the traditional role of producing healthy crops to combat hunger (SDG2 and SDG3), but also on clean ground- and surface water (SDG6), increasing carbon sequestration and limiting greenhouse gas emissions for climate mitigation (SDG13), and on reduction of land degradation and biodiversity preservation (SDG15). Furthermore, energy use (SDG7) and sustainable production and consumption (SDG12) are relevant, where the latter has much in common with SDG2 and SDG3.

Nevertheless, current targets and indicators are broadly defined and do not allow direct measurement, e.g. the SDG target 2.4 (abridged) – "by 2030, ensure sustainable food production systems and implement resilient agricultural practices that help maintain ecosystems". The associated indicator – "proportion of the agricultural area under productive and sustainable agriculture" – represents a top-down effort towards quantification, but this will be difficult to assess when there are no clear methods and quantitative criteria for "sustainable agriculture" that farmers can apply in order to adapt their management. The same lack of indications regarding the way goals are defined in practical terms applies to the very important recent Berlin declaration of 68 agricultural ministers who emphasize the crucial role of soils in contributing to food security and environmental quality in 24 points (GFFA, 2022 and: https://gffa-berlin.de/en/, last access: 5 November 2022), which is in line with Lal et al. (2021). Clearly, the scientific community is challenged to produce clear procedures to assess the SDG indicators and establish living labs that may result in successful lighthouses, linking farmers with the scientific community and society at large.

In this context, measuring and judging ecosystem services (es), defined as "services contributed by the ecosystem to mankind" (https://www.millenniumassessment.org, last access: 5 November 2022), can be a suitable bottom-up procedure to specify the current general indicators for the various targets (e.g. Bouma, 2014; Keesstra et al., 2016). For example, part of SDG2 is defined by the es: *production of biomass*; part of SDG6 is defined by es: *transformation of agrochemicals*; part of SDG7 is defined by es: *reduction of energy use*. The definition of SDG13 by es follows: *reduction of greenhouse gas emissions* and by *carbon capture*. Part of SDG 15 is defined as *enhancing biodiversity and combatting land degradation*. Note that ecosystem services fit into a much broader socio-economic societal context of the various SDGs and they therefore *support the* SDGs providing the desired "clear and concrete objectives" as required by the EC (2021).

The various ecosystem services are strongly interrelated and some form of multifunctional soil use and management therefore has to be realized in living labs that will have to be very different in different regions. A distinction of ecosystem services at farm level in living labs has at least two advantages: (i) it allows quantification of as yet broadly formulated top-down indicators for the various targets of the SDGs as discussed above, and (ii) the European Union proposes financing of provided ecosystem services as part of their new Common Agricultural Policy 2021–2027 with a budget of EUR 350 billion. This partly answers the question: "What's in it for me?" (Shirk et al., 2012) for European farmers, but they also appreciate that their particular farming system will finally be tested with clear, objective indicators. In fact, farmers are now like chess players, required to perform simultaneously on six separate SDG playing boards, an impossible act that needs to be unified into a comprehensive single approach. And while the rules of the game for chess are clear, the rules for sustainable development are as yet rather murky.

Where does all this leave the target group of land users, of which, again, farmers occupy the largest land area? In the Netherlands, there are approximately 50 000 farmers with different specializations and individual approaches ("farming styles") based on various forms of adaptive management (e.g. Van der Ploeg et al., 2004). Interaction between scientists and farmers in living labs can therefore only be successful when the actual farming system on any given farm is studied first and when adoption of existing research results and recommendations for possible new research are based on the features of the particular living lab being analysed. In fact, every farm acts like a living lab! This implies a need, based on a gradually developing trustful relationship, to compromise because neither farmers nor researchers have all the, certainly not perfect, answers. Definitions of important ecosystem services in line with the SDGs and GD may sometimes require regional thresholds to distinguish the "good" from the "not yet good enough" (Scholte-Uebbing et al., 2022) (see Sect. 6). This should, however, not result in a relaxation of thresholds at farm level because the implicit expectation that other farms will contribute more than what is formally needed to meet regional thresholds would defeat the overall aim of meeting the thresholds: "the Tragedy of the Commons".

Returning to the three major points of farmers' concerns, as discussed above, when ecosystem services are measured and assessed, the farmer will know which thresholds will have to be met and this will present a welcome and clear "point at the horizon", providing much desired clarity. Moreover, the transdisciplinary work in living labs will provide focused, clear and independent information that is not necessarily commercially nor ideologically inspired. But whether or not economic goals are reached depends on market conditions and consumer choices that are beyond the direct scope of the environmental issues and also require transdisciplinary research.

3 Research approaches

The role of the scientific community in addressing the SDGs currently appears to lack a practical focus. There is no lack of theoretical analyses, as cited in the introduction. Clearly, to reach the SDGs, an interdisciplinary systems approach is needed. Separate scientific disciplines, such as agronomy, hydrology, climatology, soil science and ecology tend to follow their own disciplinary regimes, each one also with limited contacts with disciplines like economy and sociology. Individual disciplines are essential for contributing to the needed broad systems approach, but separate disciplinary contributions cannot do the job by themselves. So far, this fact has not been internalized widely by the various scientific disciplines, judging from the largely disciplinary articles in scientific environmental journals. However, the proposed definition of soil health (Veerman et al., 2020) clearly reflects the link of soils with ecosystem services and the SDGs and the GD: "the continued capacity of soils to support ecosystem services in line with the SDGs and the GD". Note that the SDGs have a worldwide scope while the EU Green Deal follows the SDG principles.

Of course, widely applied and well-tested simulation modelling of the soil–water–atmosphere–plant system is a de facto illustration of an interdisciplinary effort, as soil scientists, hydrologists, climatologists and agronomists and ecologists have to provide basic data for the models (e.g. White et al., 2013; Kroes et al., 2017; Holzworth et al., 2018; Bieger et al., 2017; Falconi and Palmer, 2017; De Vries et al., 2022). Modelling is therefore a key methodology when assessing ecosystem services.

Most research is of the "tame" type: a problem and a hypothesis are formulated, experiments are made and the hypothesis is either accepted or rejected. Acceptance always implies a probability, of, for example, 95 %. This implies that in 5 % of the cases, the hypothesis is not true. This explains that "the truth" does not exist in scientific experiments, which is difficult for the public and more than a few politicians to understand. However, the research community does not only face this "truth" issue but also the challenge of dealing with different types of knowledge from different scientific disciplines, politicians and the public at large. In this context, the concept of "wicked problems" has been applied in policy studies for at least 50 years, considering conditions where several different and conflicting goals have to be realized at the same time, as is the case with the SDGs (e.g. Rittel and Webber, 1973; Peterson, 2009). Termeer et al. (2019) analysed the concept that has been defined as "a class of social system problems which are ill-formulated, where (i) information is confusing; (ii) there are many clients and decision makers with conflicting values; and (iii) the ramifications in the whole system are thoroughly confusing". It can be put more simply in one of two ways: (i) "lack of consensus on problem definition, and lack of consensus on solutions", or (ii) "there are no solutions in the sense of definite and objective answers". Bouma et al. (2011) analysed wicked problems in the context of future land use policies by defining various options from which a selection can be made.

Noordegraaf et al. (2019) point out that the way people experience problems and practices are complex and may involve a mix of emotions, divisions, secrecy, competition, resistance and distrust. They prefer to talk about wicked situations rather than wicked problems. Be that as it may, when defining ecosystem services, the research community can, in our view, tame such wicked problems by providing measured data and thresholds for ecosystem services in line with the SDGs. Available methods can provide part of the data, but new research is also needed as defining indicators and thresholds still need much future attention (see Sect. 6). Fol-

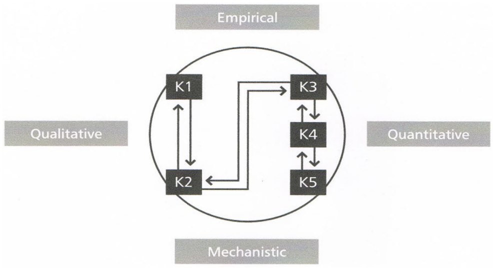

Figure 1. Schematic representation of five types of knowledge, as discussed in the text.

lowing Shirk et al. (2012), the question can also be raised here: "what's in it for us?". Apart from the fact that substantial funding is available now, the non-material satisfaction of having contributed to sustainable development will be (should be) rewarding as well.

4 Engaging the public

People show increasingly individualistic behaviour in the information age where social media play an important role and this results in criticism of governments who issue rules and regulations that are experienced as being overly restrictive and top-down. Critical opinions about government actions, that often remained isolated in the past, become more visible now as they are embraced by social media, forming isolated "bubbles" based on mutual confirmation of critical thoughts, also leading to major and disruptive demonstrations and protest actions. There is clearly a widening gap between government and the people in many countries.

How to deal with different forms of knowledge when attempting to improve communication between citizens and the policy arena, with science acting as a possible intermediary?

First of all, different knowledge levels can be distinguished. Figure 1 (Bouma et al., 2011) shows two vertical axes: qualitative versus quantitative and empirical versus mechanistic. Level K1 represents tacit knowledge by practitioners and interested citizens. Type K2 moves to the expert level, while K3 and K4 represent increasing levels of scientific insights; K5 is the domain of cutting-edge research. Most soil research is focused on publishing K5 results in international refereed journals, if only to advance scientific careers. But if research has to reach stakeholders and the policy arena, such results will often not register. Figure 1 represents the challenge of realizing effective research in living labs where K1/K2 knowledge will feed and inspire K3/K4/K5 research, while the latter will increase tacit K1/K2 knowledge. The two-way arrows in Fig. 1 are essential to realize joint development of knowledge in living labs.

Bouma et al. (2015) showed that environmental studies can sometimes be resolved by applying available knowledge (often of the type K3–K5) and that the Pavlov reaction of researchers to ask for new research funds when a problem or question is raised is not always justified. It should first be based on an application of available expertise, showing gaps that justify new research (Sect. 6).

Apart from the knowledge level, communication among people is also affected by the perception of knowledge where three aspects can be considered (Bouma, 2005): (i) opinions are "true", as defined by objective, quantitative standards; (ii) they are "right" when they agree with established norms of groups of people, and (iii) they are "real" when they correspond with personal, individual feelings. In short, these aspects are respectively denoted as "IT", "WE" and "I".

A first priority is joint learning of individual scientists and farmers in living labs, combining the respective I levels that will usually consist of lower K values for the farmers and higher ones for the scientists. Both groups should certainly consider existing rules and regulations of the policy arena, as well as opinions of citizens and action groups, but meeting ecosystem thresholds is their first priority to avoid loss of focus. That has occurred when large, diverse groups tried to guide living lab activities right from the start, demotivating busy farmers. Of course, in theory, "the public" are already represented right from the start because the SDGs have been approved by 193 governments in 2015, ideally representing their people. The SDGs, their targets and indicators represent a form of "problem framing" that calls for further refinement, avoiding repetitive discussions about goals.

Listening to different opinions and effective dialogues can result in a convergence of the IT issue. When successful interaction, built on gradually increasing mutual trust, results in lighthouses, the larger WE can come in, not only relating to other farmers, but to interested citizens and politicians as well. Having specific, well-documented lighthouse examples will be very helpful, if not essential, for enabling effective communication and interaction.

Clearly, communication should focus on the process by which the various I's, all of them with specific ideas about IT, can evolve into a shared WE of a majority of the people, realizing the questions "what's in it for me?" (Shirk et al., 2012). There will always be a minority with different WE perceptions. So be it.

5 Policy development

Current environmental rules and legislation in Europe focus on separate issues. For example, the EU Habitat Directive (http://data.europa.eu/eli/dir/1992/42/oj, last access: 5 November 2022) focuses on nature and has defined protected areas in the NATURA 2000 network in Europe. The EU Water Guideline (http://data.europa.eu/eli/dir/2000/60/2014-11-20, last access: 5 November 2022) only pays attention to water quality. Directives dealing with greenhouse gas emissions, biodiversity and soil health are likely to follow in future.

However, as discussed, ecosystem services associated with the separate SDGs have to be satisfied at the same time. How do we combine the separate judgements about ecosystems into a general conclusion about environmental aspects of sustainable development? Defining threshold values for each ecosystem service allows a selection between services provided by a given living lab that are satisfactory versus those that are not. Only when all services satisfy their particular threshold values, can a living lab transform into a lighthouse, the ultimate objective (see also Sect. 6). Selection of operational threshold values is therefore a key research activity for the near future. Water quality (SDG6) already provides an example. Threshold values for ground- and surface water have already been defined at EU and national level based on human health studies. Comparable research is needed for the production of healthy food, climate mitigation and biodiversity preservation (see the case study in Sect. 6).

While establishing effective future environmental policies is not only a technical matter focused on defining and assessing ecosystem services, it also needs to acknowledge the current communication problems where "trust" plays an important role. When environment-oriented organizations are trusted, effective implementation of innovative management, focused on sustainable development, are potentially more successful (e.g. Gordon-Arbuckle et al., 2015). Then, as discussed in Sect. 4, policies are successful when a majority of people ("WE") feel that policies are "right". There will always be a, probably and hopefully, small group that does not agree, no matter what is being proposed. They can best be ignored.

Policies that focus on the measurement and assessment of ecosystem services, as discussed above, should be convincing to farmers and citizens alike as their relationship with sustainable development can clearly be demonstrated. Lighthouses can play a central role here, certainly when presented with modern communication techniques where "storylines" can be quite effective (e.g. Bouma, 2020).

6 A case study

Discussions so far are summarized in Fig. 2. Living labs receive information from farmers, scientists and citizens and have to consider existing environmental rules and regulations. Ecosystem services are determined to specifically define existing environmental targets for the various SDGs, and when they meet regional thresholds, a lighthouse is established. If not, the activities at the living lab have to continue. Lighthouse information is communicated to colleague farmers, citizens and to the policy arena with the objective to improve information exchange, future regulations and public information.

An exploratory case study was made for an arable farm on calcareous light clay soils in the Netherlands, testing the analysis articulated above. Details are presented by Bouma et al. (2022). Results are summarized in Tables 1 and 2. When assessing six ecosystem services for this living lab, three services could be assessed. Biomass production can be judged by comparison with local yields, but an independent estimate based on modelling water-limited yields (Yw as defined by van Ittersum, 2013) is preferable. These authors consider 80 % Yw as a threshold and it represents a highly generalized level expressing what is theoretically possible. This varies considerably for different areas where climates and soils differ and will certainly become even more important in future because of climate change. The Yw approach originates from the science arena and requires additional field testing when applied in the SDG context, considering different crops. Soil and water pollution can be assessed by applying existing rules and regulations that already contain critical thresholds. Land degradation is characterized by soil health to be discussed next. Three ecosystem services could, however, not be assessed. The quality of ground- and surface water was not measured on the farm but only at some distance. This can easily be corrected, preferably by installing automatic monitoring equipment, but a lack of specific data in this case had to result in a negative judgement. Water quality indicators and thresholds are provided by legislation in contrast to greenhouse gas emissions on farm level, that can, however, be estimated by modelling. A major problem is biodiversity preservation where targets and threshold indicators have not yet been defined. Biodiversity has a strong regional component and whatever is required on farm level, let alone corresponding thresholds, are as yet undefined. In conclusion, this living lab does not yet qualify as a Lighthouse. The analysis also allows a focus for future research on water quality and greenhouse gas emission measurement as well as developing indicators and thresholds for biodiversity. Bouma et al. (2022) emphasize the need for modern sensing technology to improve the measurement of soil characteristics and greenhouse gas emissions and for attention to develop rapid, user-friendly on-site tests.

Table 2 shows that the soils at this particular living lab are healthy, based on judging a number of indicators that essentially reflect conditions favoUrable for root growth (Veerman et al., 2020). As soil biodiversity is not yet defined in terms of indicators, let alone thresholds, the organic matter content is applied here as a (poor) proxy value since the average value at this farm is significantly higher than the threshold. This is unsatisfactory, but considering soils to be unhealthy because of a lack of operational indicators for soil biodiversity would not be realistic. The distinction of different soil types is important because carbon dynamics vary significantly among soil types. Bouma et al. (2022) emphasize the need to develop more operational methods to measure bulk density and organic matter contents, applying available sensing techniques that rapidly produce many data while the traditional laboratory analyses based on soil samples are costly and time consuming. Besides, small core samples are not representative for many structured soils, resulting in high

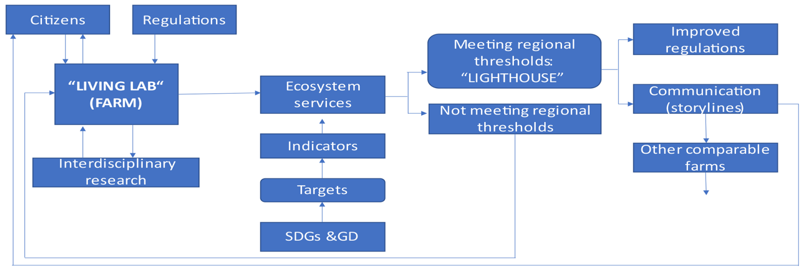

Figure 2. A schematic representation of processes and interactions involved when transforming living labs into lighthouses (see text).

Table 1. Ecosystem services determined for a living lab, an arable farm on calcareous light clay soils in Flevoland, the Netherlands (from Bouma et al., 2022). Conclusion: this living lab does not yet qualify as a Lighthouse.

Ecosystem service	Indicator	Threshold	Result
SDG2: biomass production	Local yields and Yw	80 % Yw	Positive
SDG3: pollution	EU & local reg.	EU & local reg.	Positive
SDG6: water quality	EU & local reg.	EU & local reg.	Negative
SDG13: greenhouse gas em.	Not defined	Not defined	Negative
SDG15: biodiversity pres.	Not defined	Not defined	Negative
SDG15: land degradation	Soil health	Of 5 indicators	Positive

variabilities among replicate samples that make comparisons based on thresholds difficult if not impossible. Note that no single value for soil health, somehow representing an arbitrary mix of six indicators, was presented. The "one-out/all-out" principle was applied showing which indicators need more focused research when they are negative.

Overall, the applied analysis of this particular farm could provide much needed clarity on goals to be achieved and on the role of soils. When certain ecosystem services do not meet their threshold, an application of innovative forms of management needs be derived by joint research on other living labs on this particular type of soil or by literature. Particular attention is needed for living labs where certain indicators are not yet met but where management measures have been initiated that are likely to result in positive indicators in future. For example, an increase of organic matter contents may take years and the introduction of management that will increase the organic matter content in time should be acknowledged by regulating agencies. When criteria for a lighthouse are met, the farm qualifies for support measures, such as those provided by the Common Agricultural Policy of the European Union, as discussed above.

7 Conclusions

1. Focusing sustainability research on the United Nations Sustainable Development Goals (SDGs) and the associated Green Deal (GD) of the European Union offers a welcome focus and "point at the horizon" for scientists, stakeholders and policy makers in what used to be the rather hazy concept of sustainable development.

2. Recognizing that a communication gap exists between government, stakeholders and citizens, the European Union deserves credit for proposing missions for their new research programme "Horizon Europe 2021–2027". The soil mission emphasizes joint activities in living labs focused on establishing lighthouses as a means to improve the research process and communication between science and society.

3. Establishment of living labs aimed at realizing lighthouses can be an effective procedure to realize the lofty goals of the SDGs and the GD and presents a challenge to the scientific community to realize real-life transdisciplinarity. As lighthouses probably already exist, their rapid documentation would provide a valuable boost to the living lab/lighthouse discussion.

4. Existing targets and indicators for ecosystem services in line with the various land-related SDGs are not yet clear enough to allow a focus of activities in living labs. The measurement of SDG-related ecosystem services is therefore proposed with specific indicators. Threshold values will have to be defined for such indicators to allow expression of successful efforts, resulting in lighthouses. Research on thresholds needs particular emphasis. This also applies to thresholds for soil health indicators.

5. Effective communication processes are crucial, not only when working in living labs but also when addressing farmers and the public at large when successful lighthouses have been established. How do we merge widely different individual opinions and attitudes into proce-

Table 2. Soil health indicators for the living lab described in Table 1. Conclusion: this soil is healthy and offers a positive entry point for SDG 15 in terms of lack of soil degradation.

Soil-health indicator	Actual value	Threshold	Result
Soil pollution: EU& local reg.	Below thresholds	In env. laws	Positive
Soil structure: bulk density	1.35 g cm^{-3}, SD 0.08	1.55 g cm^{-3}	Positive
Penetrometer res.	0.67 Mpa, SD 0.31	5 Mpa	
Organic matter content	2.9 %, SD 032	2.0 %	Positive
Soil biodiversity	% org matter as proxy	Not yet defined	Positive
Soil fertility positive	Regime based on soil testing		Positive
Soil moisture regime	Well drained	Mod. well drained	Positive

dures that can form a solid basis for governmental rules and regulations? Focused and inspired work in living labs, based on gradually established mutual trust, can provide an answer.

6. Only an interdisciplinary approach can address the measurement of ecosystem services. Contributions by separate disciplines, such as soil science, therefore have to be framed in terms of "support for ecosystem services" as shown for soil science in the presented case study. This, rather than pontifications about the importance of certain scientific disciplines, is most effective to illustrate the relevance of such disciplines.

Data availability. Data are available in source publications on transdisciplinarity mentioned in Sect. 1 and on modeling of the soil–water–atmosphere–plant system mentioned in Sect. 3.

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