Regulatory experiments and real-world labs: A fruitful combination for sustainability

What are regulatory experiments and how can they contribute to sustainability transformations? We seek to answer these questions by considering regulatory experiments in the energy sector and exploring their potential impact pathways. Different kinds of regulatory experiments can be combined with real-world labs to expand their scope and their impacts to the regulatory realm.

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Abstract
Regulatory experiments (RegExs) can be considered an element of mission-oriented innovation policies. As such, we discuss how they relate to real-world labs (RwLs) and how they can contribute to sustainability transformations. We distinguish between two types of experiments: 1. regulatory sandboxes that help innovators to bring new products, services, and other innovations to market, and 2. regulatory-innovation experiments that are specifically designed to explore new solutions for evolving regulatory frameworks. The two types can be linked to RwLs such that an RwL can be embedded in a regulatory sandbox, enabling the RwL to try out solutions that would not be feasible without the sandbox, given the regulatory framework in place. Alternatively, the various experiments in the RwL are complemented by one or several regulatory-innovation experiments. RegExs, as a form of experimental policy engagement, are an important addition to RwL concepts in a sustainability transformation context. They contribute to both innovative sustainability solutions as well as regulatory learning and testing of regulatory innovations. By applying the programme theory approach and developing a Theory of Change for RegEx, we discuss their potential impact on sustainability transformations in terms of the directionality and the acceleration of change, based on examples from the energy sector.

Keywords
energy transition, impact pathway, real-world labs, regulatory experiments, regulatory-innovation experiments, regulatory sandboxes, transformative outcomes

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This contribution focuses on regulatory experiments (RegExs) as policy instruments, their potential relation to real-world labs (RwLs) and their contribution to sustainability transformations[1]. RegEx have recently received increasing attention from policymakers, researchers and innovators as an instrument to promote innovation, both in conceptual terms and in real-world applications (Bauknecht et al. 2021, European Commission 2023). RegExs can have a significant overlap with RwLs as understood in this Special Issue: as formats for experiments on sustainability solutions. Yet the link between them is still underdeveloped.

Research papers on RegExs have focused on the potential of accelerating innovation in regulated sectors such as financial markets and the energy sector (Beckstedde et al. 2023, Schittekatte et al. 2021), but without considering broader policy objectives, let alone sustainability transformation. The same can be observed in RegExs implemented in the past – for example, in the energy sector (e. g., in the UK; for an overview, see EC 2023). However, RegExs are increasingly considered a potential element of mission-oriented policymaking, and can contribute to policy learning and regulatory innovation (Janssen 2020, Larrue 2021, Roth et al. 2022, Veseli et al. 2021).

As for the link between RegExs and RwLs, RwLs "contribute to transformation by experimenting with potential solutions" (Schäpke et al. 2018, p. 86). However, regulation is typically not considered as one of these solutions and RwLs do not include experiments with regulation itself. Rather, regulation is understood as a context condition for RwLs (Caniglia et al. 2017). As we will explore, RegExs can extend RwLs to regulatory aspects, broadening the scope of what can be tried out in RwLs.

RegExs can also explicitly aim at regulatory change for sustainability transformations. In Germany, recent plans by the government to provide a legal basis for RwLs put the question of the role that regulation plays in RwLs centre stage[2].

We do not discuss the concrete impacts of specific RegExs on sustainability transformations, but rather mechanisms through which different types of RegExs can have such impacts. Regulatory change, that is, a regulatory innovation, can be one impact of RegExs but does not have to be the main objective. RegExs can also aim at providing regulatory exemptions which then enable other innovations to be tested. In both cases, RegExs can

be linked to RwLs, and contribute to sustainability transformations or fail to do so.

Scope and methods

Our focus on the energy sector is due to the relatively large number of case studies and available literature. A broad range of energy-related RegExs across different countries is relatively well documented and typologies have been derived (e.g., Bauknecht et al. 2020, Bovera and Lo Schiavo 2022, Schittekatte et al. 2021). RegExs in other sectors have been analysed in the *REraGI* project (Bauknecht et al. 2021)[3]. We also use insights from an international knowledge exchange process on RegExs organised within IEA ISGAN (International Smart Grid Action Network of the International Energy Agency), with a first phase in 2019 and a second phase in 2021[4]. Within this process, several national cases of RegExs and especially programmes for RegExs were documented (ISGAN 2019). At the same time, sustainability transformations and potential impacts on them are particularly relevant in the energy sector.

For the systematic analysis of impacts, we draw on theory-based evaluation (White 2009) and the core idea of the programme-theory approach, which is to formulate intervention logics (Norgbey and Spilsbury 2021). As a basis, we outline a Theory of Change (ToC), that is, a representation of how change is expected to happen (Mayne 2017, Rogers 2014, Claus et al. 2023), which includes underlying rationales of a RegEx policy intervention, and combines different perspectives on impact pathways (from outputs to outcomes and impacts).

Regulatory experiments: Typology and link to real-world labs

Broadly defined, RegExs are an instrument which deliberately deviates from the existing regulatory framework to try out new rules in a real-world setting (Bauknecht et al. 2021). Within that broad definition, there are different types of RegExs. We start with a distinction that we have developed in previous work and that we consider relevant for exploring the link to RwLs: based on energy sector cases in the ISGAN process (Kubeczko et al. 2021) and a cross-sector analysis in the *REraGI* project (Bauknecht et al. 2021), we identified and defined two main types, namely, regulatory sandboxes and regulatory-innovation experiments.

On the one hand, there are *regulatory sandboxes* that help innovators to deliver their trials and bring new products, services, methodologies, or business models to market. The content of such sandboxes is typically defined bottom-up by individual actors, that means, based on the regulatory barriers identified by innovators, even though regulators take the final decision on derogations. Developed on a case-by-case basis or embedded within a broader programme framework, regulatory learning[5] – learning for the development of new or adapted regulation – is not the main objective. Learning tends to be less formal, with less accountability for the results of the experiments. The role of legislators is mainly to provide the legal basis for regulatory bodies to be able to grant exemptions (Veseli et al. 2021). Most of the specific cases in the energy sector belong to this category.

An example is the *SINTEG* ordinance in Germany *(Schaufenster intelligente Energie – Digitale Agenda für die Energiewende)*[6], for which companies in the energy sector identified regulatory restrictions that prevented them from developing and testing new options for demand-side management. While the ordinance provided regulatory exemptions for these projects, it did not consider and test new regulatory options beyond them (Bischoff et al. 2020).

On the other hand, there are *regulatory-innovation experiments (RIEXs)* that are specifically designed to explore new solutions for evolving regulatory frameworks and enable regulatory learning. They are typically set up in a more top-down way, based on overarching system or societal needs. Legislators play a key role in defining the demand as well as in taking up the results. To date, the literature has left out the role of legislators in this context. There is greater accountability regarding the results of the experiments. Experiments are policy-led and require an ex-ante framework that links the experiment to broader policy objectives and ideally provides mechanisms for upscaling the results of the project to the general regulatory framework. This could also include a bottom-up process whereby stakeholders can point out regulatory barriers and options. When embedding the experiment in the broader systemic and policy environment, it is essential in the context of this article whether and how this integration is geared towards sustainability transformations.

In the energy sector, according to the cases studied by Bovera and Lo Schiavo (2022), Italy is currently the only country in which experiments explicitly aim at a new regulatory framework, that means, where RIEXs are carried out. While the *SINTEG* example above was designed as a sandbox, it could also have been set up as a RIEX. Rather than simply providing regulatory exemptions for demand-side management, this would have required considering new regulatory options and designing the experiment so that one or more options would have been tested and conclusions for new regulations would have been drawn. >

1 By "regulation" we mean not only regulation in a narrow sense, but rather the full range of public policy instruments.
2 Cf. Schäpke et al. (2024, in this issue). See also *https://www.bmwk.de/Redaktion/DE/Textsammlungen/Digitale-Welt/reallabore-konsultation.html* (in German).
3 *https://www.sofia-darmstadt.de/projekte/laufende-projekte/reragi*
4 *https://www.iea-isgan.org/knowledge-exchange-on-experimental-regulatory-sandboxes-to-enable-smart-grid-deployment*; update: EC et al. (2023).
5 "Regulatory learning enables competent authorities to gain better knowledge and understanding of the risks and opportunities as well as the need for possible changes to or new interpretations of existing legislation to effectively address new technological developments and enable innovation" (EC 2023, p. 6).
6 *https://www.clearingstelle-eeg-kwkg.de/sites/default/files/SINTEG-V_190513.pdf*, in force from 2017 to 2022.

In the following, we examine recent publications on RegExs in the energy sector to identify whether this typology should be amended when discussing the link to RwLs and to sustainability. RegExs in the energy sector have been analysed by Schittekatte et al. (2021) and Bovera and Lo Schiavo (2022), both of which analysed several country cases. Moreover, the EU provides an overview of the *State of play of regulatory experimentation in the EU* focusing on the energy sector (EC JRC 2023), and, on this basis, the EC published a Staff Working Document on *Regulatory learning in the EU* (EC 2023).

Building on Schittekatte et al. (2021), the EC JRC (2023, p. 6) identifies three main dimensions for distinguishing regulatory experiments:

1. ***Innovation approach:*** bottom-up or top-down. This reflects the two types presented above.
2. ***Way of granting derogations:*** subject to an application procedure, automatically to all parties that comply with certain eligibility criteria or following a case-by-case analysis.
3. ***Geographical scope/extension of the experimentation:*** While this can have relevant implications for the design and can affect the impact of the experiment, we do not consider it relevant in conceptual terms.

Based on this, they present three types of RegExs that combine the above dimensions in different ways: regulatory sandboxes, pilot projects and pilot regulations. For them the key distinctive criterion between a sandbox and the two other types is that the former is established on a case-by-case basis, either top-down or bottom-up, whereas the latter are not. Regulatory pilot projects are characterised by the fact that derogations are only granted to actors that are successful in an application procedure, while pilot regulations automatically apply to all parties that comply with certain eligibility criteria. While we consider this to be important design aspects, we consider them to be only secondary in terms of the link to RwLs and sustainability impacts, and therefore do not include them in our typology.

Our distinction focuses instead on the role of regulatory learning, which is not the main objective in the sandbox, whereas RIEXs explicitly aim at it. This is linked to the fact that sandboxes are typically initiated by individual actors (i. e., rather bottom-up than top-down) who are interested in regulatory exemptions rather than regulatory learning.

Having looked at the recent literature, we conclude that additional types/dimensions to be found in the publications do not need to be included for our purpose. We thus stick to our initial distinction and analyse sandboxes and RIEXs as two main types of regulatory experiments, keeping in mind that there are different ways of using the terminology. In the remainder of this section, we outline the ways in which these two types can be linked to RwLs, and the socio-technical experimentation that takes place within them.

Figure 1 shows two potential ways for linking RegExs with RwLs. In the first type of RegEx (sandbox), the objective is to try out new solutions with the help of regulatory exemptions. Sandboxes in the energy sector and beyond are usually about new technologies and/or business models and cannot be considered an "action-oriented research approach (with the) aim to support – and accelerate – these fundamental changes for sustainability transitions" (quote from the Call for Abstracts for this Special Issue). Yet the approach can still be linked to RwLs to broaden the scope of what can be experimented with in RwLs. If experimentation in an RwL is restricted by the regulatory framework in place, a regulatory sandbox can provide more flexibility. Building on the *SINTEG* example above, if an RwL seeks to experiment with new consumer roles in the energy sector, it may be restricted by existing regulation, while the combination of the RwL with a sandbox could open new experimentation opportunities.

The second type of RegEx (RIEX) can also be combined with RwLs. In a RIEX, the idea of experimentation is extended to new regulatory solutions, rather than just considering regulation as a context factor for RwLs. Combining a RIEX with a RwL allows new socio-technical solutions and corresponding regulatory innovations to be experimented with in parallel. Building on the previous *SINTEG* example, a combined RwL-RIEX would test new consumer roles together with new regulatory options, for instance, for electricity network tariffs.

Regulatory experiments and their potential impacts on sustainability transformations

We now turn to explore how potential impacts on sustainability transformations can be modelled into a ToC for RegEx projects and programmes. We do this by examining impact pathway approaches through which outputs can be linked to their intended impact.

Impact evaluation concepts

For assessing the impacts of regulatory experimentation at programme or project level, we first consider impact pathway approaches, which are meant to outline the link from project activities and instruments to the policy goals and impacts that a RegEx aims at. To do so, we identified two approaches in the literature.

The first impact pathway approach aims at the assessment of impacts of research and innovation (R&I) policy on the natural environment as a pillar of sustainable development. It builds on the DPSIR framework commonly used in the realm of environmental policymaking, which links up driving forces – pressure – state – impact – response (Carnohan et al. 2023, EEA 2020). The approach, developed by R&I-policy experts in collaboration with domain experts in environmental policy (Miedzinski et al. 2014), can be applied to outline causal relations between outcomes of R&I programmes (e. g., technological innovations) as functional driving forces for building up environmental pressure (e. g., exploitation of natural resources, emissions, use of land and use of water) and impact categories for sustainable development (ecosystems health, biodiversity, etc).

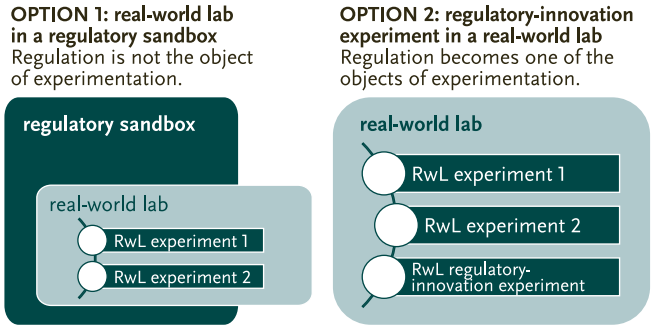

FIGURE 1: How regulatory experiments (RegEx) and real-world labs (RwLs) can relate to each other, based on the two types of RegEx we have presented: the regulatory sandbox and the regulatory-innovation experiment (RIEX). In option 1, the RwL or part of it is embedded in a regulatory sandbox. The sandbox enables the RwL to try out solutions that would not be feasible within the regulatory framework in place. Regulation is not the object of experimentation. In option 2, various non-regulatory experiments in the RwL are complemented by and ideally linked to one or several RIEXs. This means that regulation itself becomes the object of the experimentation. In practice, both approaches may be combined, i.e., part of the RwL operates under the regulatory exemption of a sandbox, while in other parts RIEXs are set up.

The second impact pathway approach, transformative outcomes (TOs) (Brodnik et al. 2021, Gosh et al. 2020), aims at developing and evaluating transformative innovation policy measures. It has, for example, been applied in an evaluation project for the *German Energy Research Programme* (AIT et al. 2022). It is based on the Multi-level Perspective (MLP) as framework for analysing sustainability transitions of socio-technical systems (Geels 2005, Kemp et al. 1998, Rip and Kemp 1998, Kanger et al. 2020) with its distinction of niches, regimes and landscape. In short, TOs refer to the transformative process of facilitating interventions at certain phases: for building and nurturing new niches, for expanding and mainstreaming existing niches and for opening and unlocking regimes.

As the DPSIR framework originates from the environmental policy realm and the TOs approach explicitly focuses on experimental policy engagement in the context of sustainability transitions on the 3 MLP levels (Gosh et al. 2020), these concepts are useful in the assessment of the impact of RegExs on sustainability transformations. Together they can be seen as complementary elements of a ToC of RegExs that addresses impact pathways, with 1. the DPSIR framework capturing the functional dimension of solutions to specific sustainability problems, and 2. the TOs approach capturing the procedural dimension of transformation to be targeted by an intervention.

Assessing impacts based on a Theory of Change

We now turn to the key criteria that the ToC should address. The DPSIR approach can help to outline the relation between goals of sandboxes or RIEXs as R&I measures for building the functional elements of a future energy system (e. g., smart grids) and the impacts of potential solutions on environmental sustainability goals (e. g., net-zero emissions). The TOs approach can outline the relation between the process goals of RegExs and the impact which they have on the phases of the system transition process towards sustainability. Hence, our ToC assesses 1. the directionality towards sustainability goals as the overarching criterion for the functional dimension, and 2. the acceleration of the transformative process as the main criterion for the procedural dimension.

1. ***Directionality towards sustainability***: The DPSIR approach, with the perspective on functions, provides more guidance on how causal mechanisms lead from RegExs to impacts on the sustainability of the energy system. It thus indicates directionality brought about by experiments in tackling sustainability targets (e. g., reduced emissions from the energy system).
2. ***Process acceleration:*** The TOs approach provides more guidance on how RegExs can contribute to accelerating transformative change. The concept of TOs has the explanatory power to differentiate between sandbox and RIEX impacts as it helps to distinguish different phases. While sandboxes are primarily geared towards the phase of building and nurturing niches, RIEXs are more geared towards expanding and mainstreaming niches by innovating new regulation. Although facilitating opening and unlocking regimes can be seen as a long-term goal of RIEXs, related TOs mentioned in the literature such as de-aligning and destabilising (Gosh et al. 2020) would hardly be defined as the direct outcomes of RegExs.

In table 1 (p. 48), we depict how the two types of RegEx can impact the two dimensions of our ToC, namely, directionality and process acceleration. Sandboxes can support innovations in an undirected way (e. g., to develop profitable technologies, see left column in table 1) or as a prerequisite for solutions directed towards sustainability goals. In relation to the procedural dimension, they may be designed for accelerating the building of niches as an opportunity for bottom-up innovation processes or by nurturing niches linked to sustainability transformations. Examples in which no regulatory change is intended to sustainably transform the energy system are the innovation sandbox programme of Ofgem (Office of Gas and Electricity Markets, the energy regulator in the UK) and CRE (Commission de régulation de l'énergie, the French energy regulatory commission). Nevertheless, other energy policy goals (e. g., security of supply, cheap energy) might be targeted strategically.

Though in the second option (see right column in table 1) the sandbox is primarily designed to support innovation, regulatory change as a consequence of the experiments is expected, albeit indirectly via built-in policy learning processes. An example is the Austrian *Energy.Free.Room* programme[7], which is built on a collaboration between ministry, R&I funding agency and energy regulator (Bovera and Lo Schiavo 2022). Other examples >

7 *https://www.ffg.at/Energie.Frei.Raum*

for intended directionality in sandboxes include the regulatory exemptions in the German *SINTEG* programme and derogations for pilot projects by ARERA (Autorità di Regolazione per Energia Reti e Ambiente, the Italian regulatory agency) for specific topics addressed, such as smart meters or storage solutions. A possible combination of a sandbox and an RwL would fall under the second option.

If the RIEX is functionally directed towards sustainability goals (right column in table 1), it might enable the social and economic practice necessary for transitioning to a new sustainable regime. In RIEXs, regulatory change is the main objective with respect to the procedural dimension and a regulatory innovation to be tested aims at accelerating the mainstreaming of niches and might also lead to regime change. An example is the pilot regulation for transitional regulations without necessary case-by-case approvals, which is applied by the Italian regulator (Bovera and Lo Schiavo 2022). Although we have not been able to identify examples in the energy sector with broader engagement of actors such as legislators, such models could become relevant when RIEXs and RwLs are combined.

Table 1 is based on two assumptions from our ToC related to the objectives that can typically be assumed for RegExs. Firstly, RegExs always aim at facilitating innovation and, thus, the acceleration of building and nurturing niches. That is why acceleration is included in both columns. Secondly, RegExs may or may not be geared towards sustainability, but will not officially be geared towards promoting unsustainable solutions. However, in reality and when we consider unintended effects of RegExs, deceleration and unsustainable solutions should be assumed as options in the ToC. These considerations can also be applied to RwLs as well as the combinations of RegExs and RwLs shown in figure 1. The risk of promoting unsustainable solutions is particularly high when there is no directionality towards sustainability, but also exists when the RegEx is set up to promote sustainability transformation.

Deceleration may result especially if an experiment is set up in areas in which it would be better to put in place new regulation straightaway and the RegEx thus delays the process. This risk is higher in RegExs compared to RwLs as the trade-off between experiment and large-scale implementation is more prominent in the case of RegExs and especially RIEXs, in which the experiment is explicitly about testing new regulation before introducing it on a large scale.

The combination of these effects in the two dimensions can lead to different impacts on sustainability transformation. Only if an experiment's objective is directionality towards sustainability transformation and both this directionality and acceleration can be achieved, can a RegEx contribute to sustainability transformation. Otherwise, it can also have negative effects. Figure 2 summarises potential sustainability impacts of RegExs based on the two dimensions of directionality and acceleration.

Conclusions

This paper seeks to fill two related research gaps with regard to the emerging field of RegExs that we have outlined in the introduction: on the one hand, the role that such experiments can play in sustainability transformations has been neglected so far. The papers presented above for the energy sector are a case in point: even where they do mention the energy transition as a context, they do not spell out how RegExs can contribute to that sustainability transition. We go one step further by outlining the mechanisms through which two different types of RegEx can influence sustainability transitions.

On the other hand, the link between RegExs and sustainability-oriented RwLs has not been analysed, even though the need "to approach regulatory issues in more experimental research approaches" has been identified in RwL research (Weiser et al. 2023, p. 336). Both RegEx and RwL approaches rely on experi-

TABLE 1: Options of sandboxes and regulatory-innovation experiments (RIEXs) to impact directionality and acceleration of transition processes. Examples from ISGAN (2021). In the examples, ARERA-Italy and Ofgem-UK are regulatory bodies. *Energy.Free.Room* is a programme driven by the ministry in charge of climate and energy in collaboration with the regulatory body and the research funding agency. RwL = real-world laboratory.

	ACCELERATION OF TRANSITION PROCESS	
	WITHOUT DIRECTIONALITY TOWARDS SUSTAINABILITY	DIRECTED TOWARDS SUSTAINABILITY
	no intention to guide the direction of transformation (not relevant for RwL)	intention to guide the direction of transformation towards sustainability (inside or outside of an RwL)
sandbox	... by niche-building and -nurturing as an opportunity for bottom-up innovation processes (generic innovation policy). *Example:* *Project-based exemptions foreseen by Ofgem-UK do not specify what innovation is intended.*	... by niche-building and -nurturing as a prerequisite for speeding up developing solutions for sustainability transformations. *Examples:* ■ *Energy.Free.Room-Austria specifies what innovations are to be addressed;* ■ *sandbox-RwL combination.*
regulatory-innovation experiment	... by expanding and mainstreaming niches via regulatory change. *No example implemented in the energy sector.*	... by expanding and mainstreaming niches for speeding up sustainable solutions and regime change via regulatory change. *Examples:* ■ *pilot regulation by ARERA-Italy,* ■ *RIEX-RwL combination.*

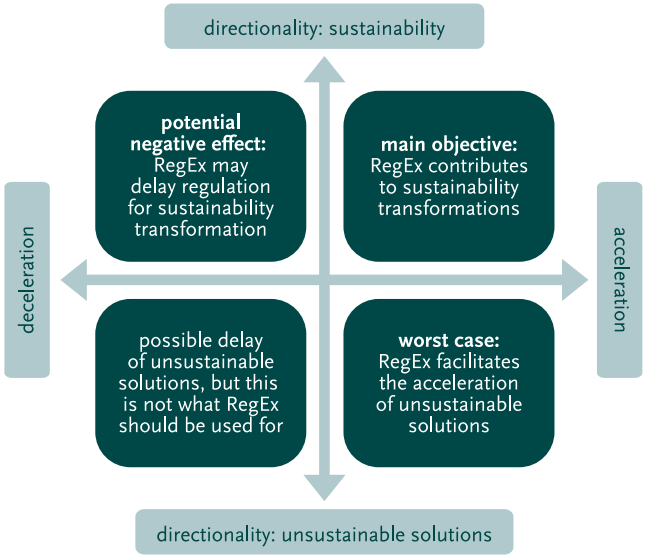

FIGURE 2: Potential sustainability impacts of regulatory experiments (RegExs) based on process acceleration and directionality. Intended effects are covered by the upper-right cell; the other cells refer to unintended effects.

mentation and can benefit from linking to each other: RegExs can be embedded in a broader sustainability context and RwL would no longer consider regulation as a context factor, but could include it in the scope of the experimentation.

Using a theory-based evaluation approach, we have presented two types of RegExs, including how they can be linked to RwLs and have different impacts on sustainability transformations: we identified regulatory sandboxes and regulatory-innovation experiments (RIEX) as two experimental policy instruments which aim at impact pathways in the functional and the procedural dimension in different ways. The application of RegExs is still in an early phase and formal ex-post evaluations of programmes are scarce. Thus, the literature on the topic is limited and attempts to categorise different approaches can only draw on few real-world examples. Additional and alternative design dimensions and typologies that we have found in the literature on energy sector RegExs are important, but not as relevant for the questions discussed in this contribution.

RIEXs bring regulatory innovation into focus and emphasise policy-learning elements. In contrast to existing literature, which focuses on the role and perspective of regulatory bodies (e.g., EC JRC 2023), we therefore also refer to the role of legislators. Regulatory bodies have limited competences to pursue sustainability transformation, and their remit typically focusses on economic efficiency and benefits for energy customers. Legislators, however, can use RegExs for policy learning and regulatory innovation aiming at sustainability transformation and guided by corresponding long-term visions. While regulatory learning is at the core of RIEXs through their testing of hypotheses about the strategic aims of a regulatory innovation, sandbox experiments may also contribute to regulatory learning if they are accompanied by networking activities between innovators and regulators (and sometimes legislators). We further emphasise the role of regulatory learning even in sandboxes as a key component in accelerating the transition process.

The chosen combination of two approaches of outlining impact paths as two dimensions in one ToC is an attempt to address both the functional and procedural elements of sustainability transformations. While the DPSIR approach allows the link between functional outcomes of an experiment and concrete environmental sustainability goals to be conceptualised, the TOs approach conceptualises the link between procedural outcomes and the impact on system transformation. It would be interesting to explore further whether the ToC for the assessment of impacts of RegExs could also be applied to RwLs and other experimental initiatives.

We conclude that RegExs, as a form of experimental policy engagement, are an important addition to RwL concepts in a sustainability transformation context. They address the ways in which experimenting can go beyond trying out solutions to sustainability problems in a pre-defined regulatory context. RwLs can be embedded in a sandbox, thus enabling solutions to be explored which would not be feasible in today's regulatory framework. Experiments in an RwL can also be complemented by one or several RIEX(s), which aim at regulatory learning and the development of regulatory innovations.

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