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Enabling Effective Consumer Adoption of Local Renewable Energy Systems through Integrating Societal-Readiness Thinking

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Abstract. To overcome the multi-faceted barriers faced in significant upscaling of embedded renewable energy generation, a design process complementing the necessary engineering and economic development activities it proposed here which centres around a fully inclusive co-creation process in designing energy and information layers to the immediate benefit to individuals, communities and grid operators.

Two innovations are suggested here, where one is to involve all stakeholders in a structured iterative co-creation process, letting suggested solutions emerge in the process. The second innovation is to include a systematic testing of the suggested solutions using a digital twin before finalising and implementing the solution.

Key words. Embedded Renewable Generation, Societal Readiness, Transition Engineering, Systems Thinking, Solution Co-creation.

1. Introduction

Renewable energy generation and integration technology has matured across a broad range of resources and balancing solutions to a degree where technical challenges in a particular project are frequently the least of the problems. Stumbling blocks are often regulatory constraints, contract options or market conditions, or other less well-defined social factors. The latter have become more prominent in the political discourse and translated into requirements to secure funding from major governmental funding bodies, such as the Horizon Europe programme [1] or the UK's UKRI [2].

One of their concerns is to ensure that their investment into technology development translates into real impact on the ground with effective uptake of sustainable solutions by all stakeholders, with the aim to achieve an 'Energy Transition' which is also a 'Just Transition'. By the very nature of the problem, this necessitates a move towards an interdisciplinary approach, potentially leading to a transdisciplinary methodology to scaffold the established engineering solutions into a 'society-ready' solution which not only provides the intended functionality within technical regulatory and reliability parameters as well as Health & Safety requirement but also full acceptance and adoption by the local stakeholders.

This paper aims to develop a guide as to how to fully integrate the social aspect into the design process of an engineered sustainable energy solution. It does so by introducing the concept of 'Societal Readiness' [3] and its implementation into a planning tool as well as drawing from the emerging trans-discipline of 'Transition Engineering' [4] as a guide for the design and implementation process. This will then be illustrated for a use case for a narrow scope of a particular challenge in building an effective energy community, namely trust in the energy allocation decisions made by an automated algorithm.

2. Societal Readiness

A. Concept

The concept of 'Societal Readiness' has evolved over the past few years, for technology development in general but also renewable energy adoption specifically [3]. Coming from the conventional framework of diffusion of innovation [5] and the context of a market economy — built on technological development driven initially by technology push at the early stage and then replaced by market pull once the technology reaches market maturity—, the discourse of societal readiness is steeped in terminology of 'persuasion and education' [3, p. 171] to drive adoption of renewable energy. This portrays the implicit premise that the technologists know best which technological product or solution should be rolled out into the world, with social factors necessitating maybe some modification of an intended product or system, or maybe only changing the narrative with which it is pushed into society. A potential consequence is that societal-readiness compliance becomes only a necessary but unwelcome additional step in parallel to technology development and deployment. In that case, it might be viewed as meaningless by stakeholders who fear that any consultation is only carried out to comply with regulation where the input of the smaller or less vocal stakeholders is ignored. In that case, the intended impact of achieving a Just Energy Transition is effectively lost.

B. Societal-Readiness Level, SRL

Recently, inspired by and intended to complement the well-established concept of 'Technology Readiness', the term *Societal Readiness Level*, *SRL*, has been defined [6] where an assumption was that stakeholders would only need to be identified (= SRL 1) once a technology has reached TRL 4, incrementally increasing the consideration and involvement of benefitting stakeholders up to an SRL 6 with community benefit plans in operation alongside the system operating at TRL 9. However, that parallel build-up of societal involvement might miss significant unintended consequences in the technology development. Furthermore, creating a parallel, closely aligned progress does not recognise the fact that TRL is focussed on the technology, and therefore agnostic of its societal deployment environment, while the societal constraints may vary significantly from one setting to another.

C. Societal-Readiness Thinking Tool

Even if one can avoid alienating the end-user by ineffective 'consultations', opportunities to develop solutions with societal compatibility at the very core might be missed if technology development and consumer take-up are viewed as essentially two parallel tracks. The challenge as to how to integrate societal factors fully into the development of technology or technology-based solutions become should therefore be fully embedded from the very beginning of the process with a clear foresight as how the societal factors at all SRL levels are met when planning a first demonstrator or even when developing the principles for the development of a component for such a demonstrator. A clear step to help this is the 'Societal-Readiness Thinking Tool' [7,8], referred to in the following as SRTT.

This tool asks the user questions about a range of questions from public engagement through ethics to governance, with the questions grouped into categories originating 'Responsible Research and Innovation'[9], frequently described as 'anticipation', 'reflexivity', 'inclusion' and 'responsiveness'. As projects need to have a start and finish, the process is organised into four phases or stages, each approached through a 'Stage Gate' as

1. ***Ideation***, where the ideas for discovery or development are conceptualised and translated into a project plan;
2. ***Implementation***, which covers data collection, experimental testing or device design, manufacture and testing;
3. ***Evaluation*** of findings, such as data analysis;
4. 'Launching and dissemination' as originally called from the 'research' perspective, which can be translated to '***Deployment'*** and impact for innovation projects.

This SRTT was designed initially with a focus on research projects but intended to have a wider reach, including innovation in engineering. Since a sustainable energy solution always has an Engineering task at the core but also the design of a system used by a variety of stakeholders, inspiration as to how to address this might be found in frameworks which embed Systems Thinking [10] into an established or emerging Engineering discipline, where the fundamental shift is from adjusting a 'creation' until it is successful to a full 'co-creation' of that engineered solution with all stakeholders. Our position is that the emerging discipline of 'Transition Engineering' provides a useful blueprint for this.

3. Transition Engineering

A. A new discipline

'Transition Engineering', formalised as a new trans-disciplinary Engineering framework in [4], was inspired by the emergence of the Safety Engineering a century earlier. Safety Engineering was a response by the Engineering bodies to the situation that the number of fatalities during rapid expansion of the industrial base and infrastructure became socially and economically unacceptable. The solution was not to stop the industrial development but provide a systematic framework as to how to carry that development in a safer way. The transfer to the current climate crisis is that our current industrial practice does bring growth but at the increasingly unacceptable cost to climate. While that cost is now well known, societies appear unable to shift sufficiently far and fast away from hitting climate tipping points. Just this year, there has been an analysis of the climate system which suggests that we are approaching some of the tipping points even faster than previously thought [11]. This dilemma is visualised by the 'three doors' [12] in Fig. 1, where going through door 1 represents business as usual, door 2 is the attractive door of developing technically potentially challenging but conceptually straight-forward solutions which under close analysis fail to meet climate targets, and only door 3 of 'unthinkable' options achieves that goal. The question is how to open door 3 and explore what lies behind it?

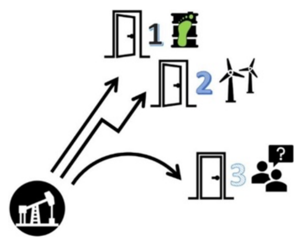

Fig.1. The 'Three Doors' paradigm, from [12]

The underlying tenet of Transition Engineering is that new solutions have to be designed to work within the current 'market' framework. This means that one should not expect a solution to work if it is unattractive or difficult for the end user. With that, and staying within the current framework of technology push at early stages of development to market pull for maturing technologies, the burden is firmly placed on the Engineering profession to embed sustainability and consumer action fully into Engineering practice.

B. Engineering practice in Transition Engineering

The path forward is to view the end-user, individually and as part of a community, as part of the system, thereby necessitating a System Thinking approach and methods coupled with rigorous Engineering practice. This is encapsulated in the 'TransitionScaping' workflow [13] shown in Fig. 2, of a sequence of processes or 'STEPs', completed in a 'Transition Lab', built on appropriate digital infrastructures.

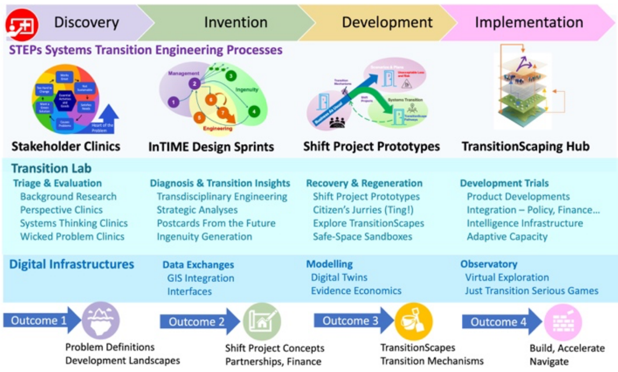

Fig.2. The TransitionScaping workflow for the STEPs programme, from [13]

The start of the process includes extensive 'Stakeholder Clinics' where the key actors are not the engineers but those eventually using the system, be that the end user of the system or facilitators, such as authorities, aggregators, or Distribution System Operators. At that stage, the problem, desired outcomes and barriers are explored and identified.

The second phase progresses from the problem and drivers identification to solution co-creation where the 'Ingenuity' of all is allowed to envision any desired future and path, while 'Engineering' identifies which of desired options are feasible and functional through rigorous analysis of the Visions and Scenarios.

One or more selected solutions are then developed into real-world projects or prototypes with evaluation of their performance judged by 'citizens juries' to ensure societal aspects are evaluated with the same importance as technical or economic performance.

Finally, the proven project can be rolled out into the community or marketplace. Since any project is necessarily time-limited, Fig. 2 has a linear progression from Problem Definition to Build and Impact. However, there is always the option to return to an earlier phase, be that to revise the problem definition, or the envisaged solution characteristics.

4. Proposed Framework

The TransitionScaping workflow from [13] is adopted here to result in the solution design process shown in Fig. 3, where the various methods available in Transition Engineering can be employed, but all steps guided by careful consideration of societal factors using the SRTT, translated from its 'research' origin into innovation at high TRL and diffusion of established technology into society. Stages where input from all stakeholders is essential are indicated by the 'S' pointing into the activity, while those where the 'S' points out of the activity are those where the deliverable of that activity is used by the stakeholders for testing and evaluation. In the same way, where the input of Experts or Engineers is essential is indicated by the 'E' pointing into the activity.

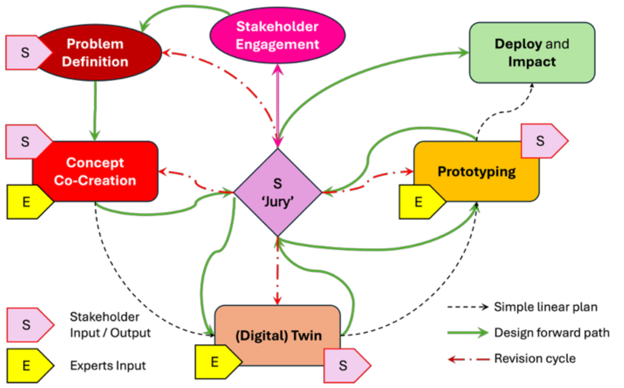

Fig.3. Proposed workflow

Fig. 3 suggests that a stakeholder 'jury' is at the centre of the process. The term 'jury' is taken from the concept of the citizens' jury used in the Development step of the STEPs programme, though the composition of that jury might include law, policy makers and grid operators to guarantee that an accepted solution is feasible under current constraints, or how feasible it would be to adjust the regulation to enable a preferred solution. Furthermore, the exact role of that body might vary from that of a jury as specified by the specifics of the project and stakeholder community. For consistency, we will use the term jury in the following without restricting its remit.

Aligning Fig. 3 with the four stages in the SRTT and the four phases of the STEPs in TransitionScaping is suggested in Table I. As Table I shows, there is no direct one-to-one equivalence between the approaches but the apparent disjunction can be resolved if it is recognised that the initial research SRTT was developed to be used for specific research projects with a hard time limited given by the funded duration of a project, and not for a longer innovation and deployment process. For that reason, the societally ready renewable energy system deployment encompasses a number of progressive idea implementations in the form of (digital) twins and prototypes before the aim of the system deployment is reached.

Table I. – Alignment of stages and phases

STEPs	SRTT	Proposed
Discover	Ideation	Stakeholder Engagement. Problem Definition
Invention	Ideation, Implementation, Evaluation	Concept Co-Creation
Development	Implementation, Evaluation	(Digital) Twin, Prototyping
Implementation	Deployment	Deploy

In the following, some detail for each phase in Fig. 3 will be discussed.

A. Project Launch

The first task of the coordinator of a project would be to identify and engage all relevant stakeholders and to establish the jury. Part of that process should involve framing terms of reference and a code of practice. Given human nature, the risk of ending up in an eternal loop is high if there are not guide rails to guide decision making, and set conditions for revision of earlier stages or progression to the next stage.

B. Problem Definition

Once stakeholder have been identified and recruited to the process, their first task is to explore the problem and desired future conditions in the *Problem Definition* stage. While experts will participate in that stage, their role would be largely for explanations or clarifications while teasing out challenges and opportunities would need to be primarily elicited from stakeholder input. Once the coordinator feels that the problem is sufficiently well defined to move on, the problem definition will be presented to the jury for approval.

To be as inclusive as possible while fostering thoughts emerging through discussion, the problem definition should employ a variety of methods, from townhall meetings and break-out sessions in a community venue to individual drop-in sessions or visiting those unable to come to the venue, as well as using online communication tools.

C. Concept Co-Creation

Here, the stakeholders and experts need to be creative to open ‘door 3’. The tasks required by this stage are best illustrated in Fig. 4 by an adaption of the **In**terdisciplinary **T**ransition **I**nnovation, **M**anagement and **E**ngineering InTIME approach described in [4, §5.1 and Figure 5.1] and merged with the 3 doors view of the challenge. InTIME uses Futures tools such as largely unconstrained Visioning of desired futures which are then refined to more constrained Scenarios (the forward arrows) and Backcasting (the backward arrow from the future to the present). The selected scenarios are then underpinned by analysis to describe pathways or roadmaps. That analysis must at the very least be an engineering analysis to ascertain the technical feasibility but should also include consideration of other constraints such as regulatory or economic factors.

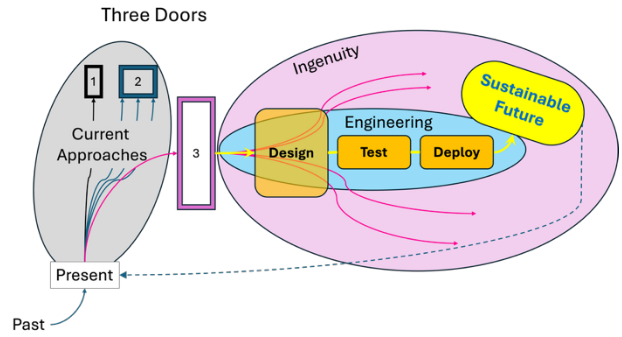

Fig.4. Adapted InTIME approach with 3 doors.

While the ultimate goal is the *Deployment*, the *Concept Co-Creation* starts with creating a vision of the sustainable future in Design Sprints, which are then narrowed down through rapid engineering-based forward and back-casting fact-checking to scenarios, which can then be illustrated in conceptual models created by the experts for review by the stakeholders.

One key use of this stage to test the robustness of the outcome *Problem Definition*. It is likely that the process will need to return to refine the problem definition at least once before stakeholders and experts feel that the concepts are sufficiently well-founded to present a firm project proposal to develop a *(Digital) Twin* for approval to the jury.

E. (Digital) Twin

The purpose of the *(Digital) Twin* is to simulate the system behaviour and stakeholder response to the system in a safe environment, akin to the Pilot-scale validation in a relevant but safe environment. The term “digital twin” is used here as the deliverable of this stage would indeed often be a digital twin of the proposed system. However, the digital is placed in parentheses as one could also use a physical representation of the system, for example as a game to be played. It is likely that a variety of system twins would be created, each designed for different sectors of the stakeholder community where some would engage easily with a digital form but others more readily with a physical embodiment.

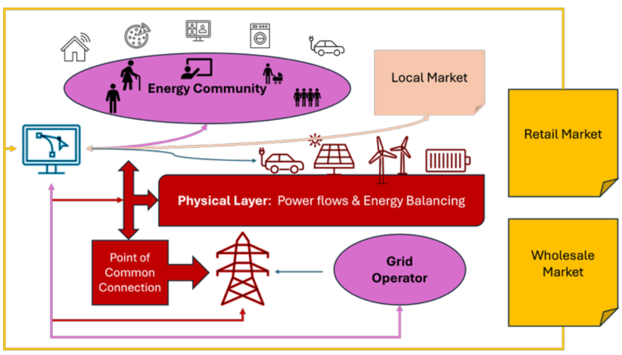

Fig.5. Digital Twin architecture.

That digital twin has several distinct interconnected layers. At the core of it is the *Physical Layer* which uses power flow and energy balancing for the physical assets including variable and dispatchable generators, energy storage including EVs, buses and substations. This is traditionally the domain for the electrical engineers. The energy balancing will also need models of the loads, both inflexible and flexible. The estimation of variable generation and loads will require forecasting, these days commonly based on some artificial intelligence tools, the domain of data scientist. A further constraint is the response of the various stakeholders to the external factors such as market conditions, estimated by economists and policy makers. At the core of the balancing or control problem then sit the decision makers: consumers or prosumers and grid operators. Their response needs to be estimated those will feed back into the resulting power flow; this can be simulated through agent-based models. The decisions themselves are a multi-objective optimisation problem.

In a system perspective, the physical layer provides hard constraints of power and energy balancing, with bounding constraints for energy storage. The external regulatory factors relevant for the physical layers will set bounding constraints such as frequency limits. The external market information will provide incentives feeding into decision-making objective functions. Available variable generation and demand will be estimated to feed into the state variables for the physical layer. Effects of the participants' behaviour in response to different options will be estimated in agent-based models to estimate achieved demand side response and their benefits to both, the demand side and the operator. Having explored a number of response options, the algorithm could then either present the participants with options prior to actuating, or it might be allowed to send actuation signals to the physical assets directly.

Because such a twin would be configured to estimate human and societal response, the exact formulation of the constraints other than fixed physical layers and market constraints will need to be developed and defined in the *Problem Definition* into the *Concept Co-Creation* stages, after which the resulting operation would be crash-tested by the stakeholders in a gamified version of the digital twin. Therefore, it is possible that a return to some of the *Problem Definition* is necessary, followed by a revision of the pathways and resulting changes to the twin. Furthermore, the nature of the optimisation process cannot be pre-defined as the *Co-Creation* stage will need to identify the relevant factors in the objective functions, whether it would be allowed to find a single solution through a weighted-sum reduction of the multiple objectives into a single objective, or whether a consensus will need to be negotiated based on a set of pareto-curve balance.

E. Prototyping

Once the *(Digital) Twin* stage has established not only that the system works but works in a way where the stakeholders are invested in it sufficiently to adopt its implementation in their daily lives, the twin is the firm basis to progress to implement a prototype but already in the working environment, corresponding to a system-TRL 7 to 8. However, as the twin has tested societal acceptance, the system would already be at SRL 5 with sufficient confidence for meeting SRL 6 due to the jury's continued approval. This will ensure that the investment into installing a physical prototype will meet societal acceptance.

The risk of that prototype failing because of resistance from stakeholders is minimised, thereby preparing the path for roll-out into the community or marketplace with real impact.

5. Discussion

Laying out the societally compliant solution design in the previous section highlights that embedding social factors and continued stakeholder involvement will certainly slow down the design stages but provides a degree of confidence that problems are very quickly identified, with a clear route to addressing those problems before proceeding with a flawed solution. While stakeholder engagement costs time at the early stage, it delays substantial investment in system design, assembly and installation to a point where the risks are much reduced.

One key challenge is to give the *Concept Co-Creation* and *(Digital) Twin* stages enough time and space to eliminate barriers but still be time-limited to progress to *Prototyping* in a reasonable period. To address that challenge, careful stakeholder selection and engagement is needed, as well as a careful formulation of a Code of Practice to which decision-making stakeholders have to sign up to.

While the standard intended use of a digital twin is to shadow (and ideally feedback to) an operational system, our *(Digital) Twin* pre-empts the physical system but has to have the same functionality to fulfil its purpose as a reliable testbed of the real system operating in its environment encompassing the renewable resources as well as stakeholder actions. In a way, the *(Digital) Twin* stage is currently the most critical stage of the proposed approach. As the twin needs to represent human behaviour as well as the physical laws of the energy system, it currently presents the largest challenge to achieving the aim of this paper.

While energy system modelling is well developed, a computer-based manifestation of the system needs to include the human response through gamification of the problem. However, quantification or modelisation of human behaviour tends to be relatively crude compared to the nuances of real behaviour. To date, there is no clear tool available to reliably predict individuals' behaviour, and frequently it is simplified to a simple cost model representing humans as driven largely by financial value while reality is more complex.

At the same time, a third complexity is given by the variable nature of the renewable energy sources which will invariably be a significant part of the energy supply. This will require forecasting of both renewable generation potential as well as likely responses from some or all participants in that energy system, in the same way as such forecasting is essential in operating an energy system with variable (non-dispatchable) generation and variable load. As a result, in addition to the human response to energy available comes the added factor of trust in the algorithmic decision making by the (AI-based) forecasting-optimising decision-making algorithm. Using a post-hoc, or 'bolt-on' explainability tool to a black-box algorithm will be a weak attempt at adding some justification after the end, as opposed to implementing a fully societal-ready solution.

Here, a research need and opportunity presents itself, namely how to embed trust into the design of an algorithm from the very 'get-go' of the control algorithm. As the exact factors promoting or preventing trust are not fully understood, it appears sensible to apply the principle of the renewable energy system design to the algorithm design itself, by using the *Problem Definition* and *Concept Co-Creation* approach to identify which factors of the design-making process, which aspects of the algorithmic implementation, and which aspects of the computer-human interface would restrict or foster building of trust in that algorithm to result in a reliable and fair control decision for the system to everybody's benefit.

6. Conclusion

This position paper has merged concepts from societal readiness and the associated Societal Readiness Thinking Tool, developed for socially responsible research project planning and execution, with concepts and tools from Transition Engineering.

It has illustrated opportunities to embed societal concerns into the core of research or innovation projects as well as specific renewable energy systems solution.

One key outcome of this paper is that the additional steps and complexities introduced at the very beginning will add time commitment to the planning and testing phases of a project but, by doing so, will avoid potential costly mistakes or lack of solution adoption by the consumer at the implementation stage.

A second key outcome was that it identified the creation of the twins, digital or physical, as a critical step as well as a research opportunity. Being able to test how humans or communities approach technological solutions embedded in their daily lives, as renewable energy solutions are, provides an ideal environment to learn much more about societal and human factors, as well as to test how engineering solutions can be designed to communicate effectively with stakeholders. As this is currently the least well-developed aspect of the proposed approach, it is recommended to explore this aspect as an immediate priority for enabling a Just Energy Transition.

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