Engineering For Social Change
A. Cooper et al. (Eds.)

doi:10.3233/ATDE240957

The Challenge of Ending Fuel Poverty: A Transition Engineering Research Sprint

Paolo CHERUBINI[a,1], Florian AHRENS[a], Merlinda ANDONI[b], Benoit COURAUD[b], Jonathan KILGOUR[c], Desen KIRLI[d], Zafar IQBAL[d], Sonam NORBU[b], Androniki PAPATHANASI[d], Lynda WEBB[c], Susan KRUMDIECK[a]
[a] *ICIT, Heriot-Watt University, Orkney Campus, Stromness KW16 3AN, UK*
[b] *James Watt School of Engineering, University of Glasgow, Glasgow, UK*
[c] *School of Informatics, University of Edinburgh, Edinburgh EH8 9AB, UK*
[d] *School of Engineering, University of Edinburgh, Edinburgh EH9 3BF, UK*

Abstract. The pressure to accelerate just transitions to Net Zero is felt across all disciplines. Moreover, researchers face challenges of developing research aims directed at wicked problems that arise in engineering transitions. Engineering research groups in particular face the challenge of incumbency, following their vested disciplinary inquiries when the just transition challenges are transdisciplinary and require new perspectives. Recent research in transition engineering has developed a transdisciplinary process to navigate a solution space that includes long term sustainability goals, social good outcomes and viable technological enterprises. This paper reports the experience and results of the Transition Engineering Sprint process undertaken by the Engineering and Physical Sciences Research Council (EPSRC) funded Decarbonisation Pathways for Cooling and Heating (DISPATCH) project research group to reframe research questions around the just transition issue of fuel poverty. A Transition Engineering Sprint is a methodology using a series of whole-systems explorations which creates a new narrative around wicked problems and unveils a creative space exploring direct routes to transitions. The sprint team included PhD students and Post Docs in energy, power system and transition engineering, along with data and social scientists. The process resulted in uncovering a root cause for fuel poverty and generating exploratory concepts for research in a sandbox. The new concepts re-framed ongoing research activities in the group and opened novel transdisciplinary research agendas. The results of a critical self-reflection exercise show that the Transition Engineering Sprint proved effective and that it can be applied in similar trandisciplinary engineering research contexts.

Keywords. Transdisciplinary engineering, Transition Engineering, Engineering Research, Energy Poverty, Net Zero

Introduction

Accelerated degradation of ecosystems, global warming, and inequality are interconnected problems of high interest in earth system science, environmental science, and social science [1]. Engineering disciplines are instrumental in delivering just transitions but only transdisciplinary approaches can respond to the pressure of overcoming wicked problems [2, 3]. Transdisciplinary Engineering research has

[1] Corresponding Author, Email: p.cherubini@hw.ac.uk.

developed to address problems of broad societal relevance by application of first principles of engineering. However there is a gap between the methodological capabilities and ability to deliver just socio-technological-economic transitions. Engineering research into decarbonization tends to focus on technology innovation and improvements supported by Net Zero policies. The research aim for this work is to investigate a process of whole-system design, stakeholder involvement and methods for generating path-break invention in markets and business models supported by modelling, data and technology.

The purpose of Transition Engineering is novel projects that downshift unsustainable practices, positioning the field with other corrective transdisciplines like Safety and Security Engineering [4]. Transition Engineering builds on systems engineering, biophysical economics, and design for sustainability [4]. New tools include wicked problem definition and systemic pathbreak design that are suited to workshop settings with experts and stakeholders [4]. The core of Transition Engineering is the seven step Interdisciplinary Transition Innovation, Management and Engineering (InTIME) Design approach. In real-world contexts, InTIME Design is carried out in a research sprint as part of a Transition Engineering Lab Process [12]. The notion of sprints is similar to agile project management, in that sprints enable iterative development of yet unknown solutions [5].

This paper reports on the a Transition Engineering Research Sprint carried out by a transdisciplinary team of engineering, social science, energy systems modelling and data science researchers. The group was motivated to incorporate the wicked problem of eliminating fuel poverty as an explicit societal objective in energy and power system decarbonisation. This paper lays out the Transition Engineering Research Sprint method, the research arising, and preliminary results. Effectiveness and limitations of the method are discussed through a critical self-reflection by the Sprint team and literature review. The Sprint generated novel concepts for future research, demnostrating promise for transdisciplinary engineering researcher's toolbox.

1. Background

1.1. Context of the research project

Decarbonisation Pathways for Cooling and Heating (DISPATCH) is a 3-year research project funded by the Engineering and Physical Sciences Research Council (EPSRC) involving three universities and four different schools[2]. DISPATCH investigates multi-vector energy solutions for decarbonisation in residential settings. During an in-person team meeting in June 2023, the group aimed to gain stronger focus on the wicked problem of ending poverty. A research sprint team was formed, composed of nine PhD students and researchers with backgrounds in energy and power systems engineering, social and data science.

Figures 1-3 present a self-reported characterisation of the sprint team. Figure 1 shows that researchers generally perceive their research to be well-aligned with addressing social needs, and have good access to funding and publishing avenues. Figure 2 shows researchers' previous experience in inter-/transdisciplinary projects [6] featuring

[2] https://dispatch.eng.ed.ac.uk/

at times active integration of different disciplines [7]. Figure 3 gives researchers perception of their prior research alignment with ending fuel poverty.

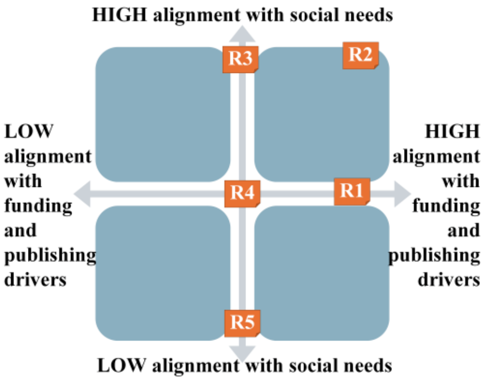

Figure 1. Survey responses for the alignment of research, in their careers, with social needs and with funding and publishing avenues.

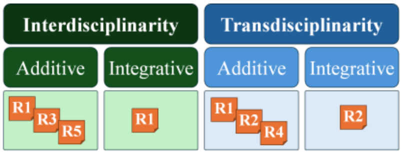

Figure 2. Survey responses on previous experience with inter/transdisciplinary research

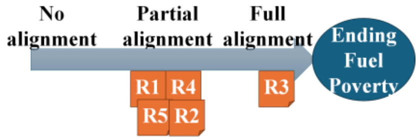

Figure 3. Survey responses on the research alignment with fuel poverty, within the DISPATCH project before the Sprint.

1.2. Fuel poverty in engineering research

Fuel poverty is caused by a combination of fuel prices, household energy efficiency, income, and energy use patterns [8]. In addition to financial distress, fuel poverty causes excess mortality, and other physical and mental health issues [8]. Just Transition is a political objective which includes objectives that decarbonisation and net zero should not increase fuel poverty.

Pathways for decarbonisation are studied through energy system modelling, typically based on cost-optimality criteria [9]. Cost optimisation is considered an element of equity, but other energy justice concerns are usually neglected [9]. Capturing other values, such as incorporating wider socio-political factors, is recognised as a required advancement in the energy system modelling field [10]. The disconnect between standard practices for evaluating pathways to decarbonisation, just transition and fuel poverty frames the research motivation.

2. Method – The Transition Engineering Research Sprint

Transition Engineering specializes in dealing with real-life wicked problems of systemic unsustainability [4]. The approach is to focus on an **essential activity system** in a **specific place** impacted by just transition pressures. Common themes of injustice caused by the current system materialise through stakeholder dialogue. Then, the Wicked Problem Investigation activity [11] reframes the problem definition by uncovering the root cause of unsustainability and injustice. The problem definition is the input for the seven step InTIME Design process [12]. InTIME Design generates disruptive shift project concepts for overcoming the wicked problem.

The DISPATCH research group used the Transition Engineering tools for undertaking a Research Sprint outlined in Figure 4, over a four-month timeframe. The aim was to open disruptive research pathways undergoing a transdisciplinary whole-system exploration of the societal issue of fuel poverty in the context of transition to decarbonization.

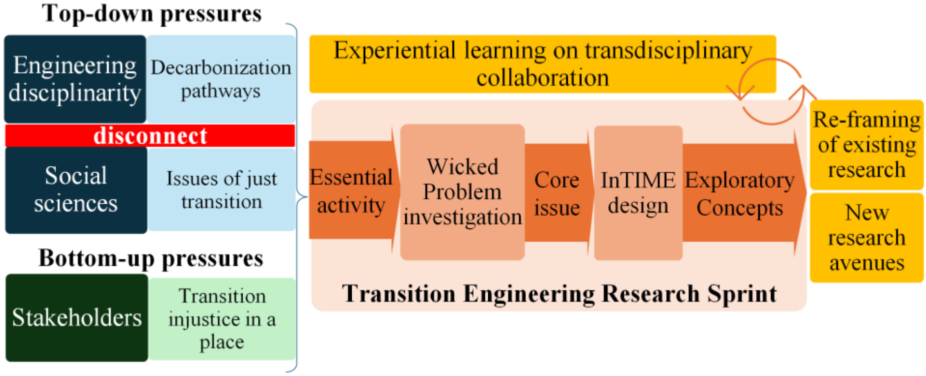

Figure 4. Transition Engineering research sprint process.

Residential access to energy services was the essential activity for investigation and the **place** was Orkney Islands. Orkney is at the forefront of technological innovation while being exposed to high levels of fuel poverty [13]. Local data and stakeholder engagement for the Sprint group was organised by local DISPATCH partner, Heriot-Watt University. The investigation of the Wicked Problem was undertaken during one workshop, according to the approach described in [11], and the results are discussed in Section 3.1.

The InTIME Design approach [12] was carried out during six weekly workshops that led to identifying novel exploratory concepts with potential to overcome the issue at the heart of the matter of the Wicked Problem. The results led to novel research questions presented in Section 3.2.

A Transition Engineering research sprint prompts “blue skies” research questions, scoping for more radical pathways of inquiry that can inform future research and funding applications. At the same time, the sprint team incorporated the novel concepts generated into ongoing DISPATCH deliverables. This phase took place through fortnightly meetings in the following two months, and the results of the subsequent re-framing of research activities is discussed in Section 3.3. At the end of this process, the group organised an open day event with local stakeholders and practitioners experienced in the social, technical, regulatory, and economic aspects of fuel poverty.

The Transition Engineering research sprint also had a broader impact on the research team itself, strengthening integrative transdisciplinarity [7] through an iterative learning by doing approach. The experiential learnings [7] gained, and an evaluation of factors of effectiveness, limitations and replicability of the Sprint process are reported in Section 3.4. The Transition Engineering team designed a self-reflective exercise, inspired by the *post-then-pre* evaluation method [14], followed up by a focus group discussion.

3. Results

3.1. Wicked Problem Investigation

Essential energy services were defined as access to sufficient affordable, renewable electricity for an acceptable threshold of risk, according to the decent living standards

(DLS) hierarchy [15]. Residential energy end-uses in Orkney are all powered by electricity, as there is no gas grid on the archipelago, but some homes use oil for heating [13].

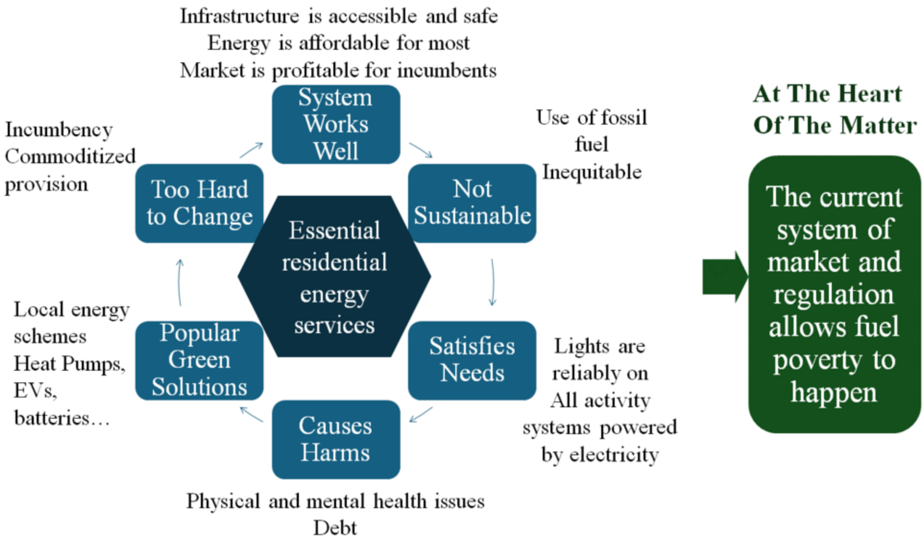

Figure 5. Wicked Problem Investigation structure and results for the problem of essential residential energy services in Orkney.

The Wicked Problem Investigation uses a brainstorming process to examine six different perspectives around the essential activity as shown in Figure 5. The current system **works great**; it is safe, reliable and accessible, and offers viable business opportunities for incumbent market actors. It is **not sustainable**, as it still relies on fossil fuels to balance intermittency of renewables, and it is inequitable for users that have to revert to self-rationing due to lack of affordability or old dwellings. Electricity **satisfies needs,** with limited viable alternatives to using electricity to supply energy services. Yet, the system clearly **causes harms** to people that cannot afford sufficient energy use. There are many **green electricity solutions** such as wind and marine generation and batteries, and many consider energy trading schemes as a solution for grid flexibility. Ultimately, the system is **too hard to change** because of cost and regulatory barriers.

The six perspectives were analysed to uncover the core issue at the heart of the wicked problem. The fundamental nature of electricity provision does not differentiate between satisfaction of fundamental needs and "energy extravagance" [16]. Corrective policies aim at alleviating fuel poverty by promoting efficiency of dwellings and affordability of energy [17] within the current market institutions. The core issue emerged around how ultimately *it is the current system of market and regulation that allows fuel poverty to happen*. The challenge for the InTIME Design phase is eliminating fuel poverty by design, through specific projects that could be carried out in Orkney, focusing on disruptive innovation in the markets and regulations.

3.2. InTIME Design

InTIME Design is a seven-step research and ideation process, outlined in Figure 6. **Step 1** investigates the activity system of interest from an historical perspective of 1911.

Orkney residences experienced hardship and unhealthy living conditions before electricity was introduced. However, a socio-cultural norm provided that housing came with access to a quota of fuel from an area for the household to cut peat. **Step 2** analyses the present situation through key data, and revealed that despite abundance of local renewable generation, the fuel poverty rate is one of the highest in Scotland, as a result of the combination of high retail fuel and electricity prices and poor energy efficiency of the housing stock [13].

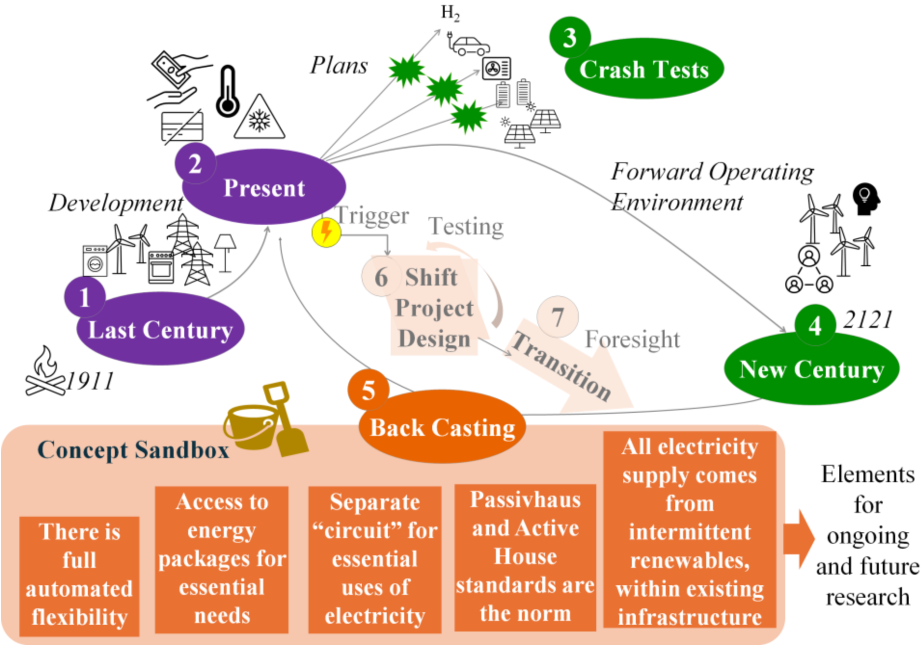

Figure 6. InTIME design and concept sandbox.

Step 3 "crash tests" projected future scenarios as envisioned by current policies. Future scenarios typically involve new power infrastructue, new generation technologies, and adaptation of behaviour. A "crash-test" assesses the proposed solutions' technical feasibility, likelihood of implementation at scale, and suitability to address the problem. If the scenarios do not eliminate fuel poverty, then the forward operating environment is defined where residential energy is net zero and fuel poverty is eliminated. **Step 4** is a "time travel" to 100 years in the future where the wicked problem was overcome. The time travel is a creative brainstorm, envisioning how the essential activities are carried out within sustainability constraints while meeting justice criteria. A future was envisioned where the access to essential energy being limited by the market is culturally unacceptable and impossible by design. **Step 5** involves back casting to understand "what it would take" to reach the desirable future vision. A concept sandbox approach [18] provides an open environment for creativity, within clear boundaries set by the previous InTIME steps 3 and 4. The common vision of the future is the boundary of the sandbox: (i) the energy system is Net Zero, (ii) essential residential needs are met with no fuel poverty, (iii) business models for the actors of the energy system are sustainable and (iv) the physical electrical network infrastructure made best use of current assets. The bounded sandbox space was populated with brainstormed concepts, based on the expertise of all the team members.

Five concepts were generated as shown in Figure 6. The development requirements for the exploratory research concepts were characterized in terms of: (i) provision of essential energy services (ii) market and regulatory arrangements (iii) policy and governance (iv) technology needs for implementation (v) how the user would interact with them (vi) modelling tools and data requirements for quantitative evaluation. Given the fundamental research nature of this iteration of the Sprint, the InTIME design was intended to initiate the shift project design stage (Step 6), with future work evaluation and roll-out of the concepts (Step 7).

3.3. Re-framing of ongoing research

This section highlights how the Transition Engineering Research Sprint re-framed and converged ongoing research activities from different disciplines within the group.

Local energy markets are consumer-centric, providing energy communities with the ability to match residential electricity demand to local and residential renewable energy production. The work done with the Sprint team generated two innovative propositions for future energy markets addressing fuel poverty in Orkney. The first proposal is a dynamic electricity price ceiling. This mechanism would provide the lowest price for people in extreme fuel poverty and the highest price for people not at risk of fuel poverty [19]. The second proposal focuses on energy trading for essential needs (like cooking and lighting) being separated from non-essential energy uses. This scheme would give priority to essential energy needs with net metering at a lower price from local producers [20].

Affordable Net Zero heating concept is approached by combining energy system and grid modelling with fuel poverty analysis. For the case study of the Stromness village in Orkney, data on household energy efficiency is being used to inform a study on local net-zero heating transition and fuel poverty in tandem. Moreover, the electricity network for the whole Orkney Islands is being modelled to perform power system analysis for testing various net-zero heating strategies such as increased penetration of heat pumps. Infrared (IR) directly heats individuals or furnishings. The investigation is looking at the acceptability and cost-efficiency of targeted IR heating for reducing the impact of poor energy efficient residential dwellings.

Flexibility in consumer demand is being investigated through a widely circulated questionnaire to see the ability and willingness of householders to be flexible in their energy use. Opportunistic adaptation of energy use responding to grid congestion events and moments of abundant energy availability, would both benefit the operation of the grid and increase affordability.

3.4. Self-reflective survey

Results of a self-reflective survey and a follow-up focus group on the participants' experience of the Transition Engineering Research Sprint are outlined in Table 1. The survey combines open and closed answer questions and was used to collect perceptions and self-reflections. Five of the eight Sprint team members participated.

The Sprint was judged effective in bringing researchers together and keeping focus on a single previously unexplored topic. The Sprint provided a re-framing of previous and ongoing research, embedding a perspective of just transition in the evaluation of decarbonisation pathways. The end point of the Sprint was the pre-concept stage, so more work is needed to frame new research proposals. The Sprint was not originally part of the DISPATCH project, so represented additional effort in this case. The Sprint was rated highly in achieving transdisciplinarity, although concerns arose about limited involvement of stakeholders before the open day event in Orkney, which provided valuable insights and validation of results and observations. For example, one team member highlighted the importance of meeting ground-level stakeholders instead of treating them as modelling "*users, consumers, prosumers, agents*".

The focus group discussion confirmed observations in literature [21]: communication issues, methodological differences and diverging team goals are common challenges in transdisciplinary research. Engineers expressing opinions on social science topics can feel that their opinions get disregarded quickly, and vice-versa. Striving for collaborative novelty can expose disciplinary barriers and specialisation disconnects, and lead to conflict and discomfort [7]. The pressure for high impact publications [22] can cause problems engaging in transdisciplinary research because the more complex research is slower and harder to publish compared to a siloed results. This can be detrimental for the early career researchers.

In terms of **project management**, a key requirement for effectiveness has been identified as having a consistent meeting schedule and a constant stream of communication within the team. The leadership in carrying the process forward prevented generalised disengagement, as researchers that occasionally got detached from the process flow were able to quickly catch-up while the Sprint moved forward. The Sprint has to fit in other project workstreams and overall academic commitments, so should be part of the original research plan.

In terms of **research rigour**, the unanimous opinion is that the Transition Engineering Research Sprint is engaging, robust, and applicable to other research groups and wicked problems. The Sprint structure was perceived to be aligned with current transdisciplinary research practices. However, personal opinions can distract the Sprint process if they remain unchecked. Preliminary literature review of the wider topics needed could be done by the Sprint leaders and smoothe the process.

The learning by doing approach adopted for the Sprint was deemed effective in fostering **transdisciplinarity**. Participation in the Sprint was perceived as an experiential learning opportunity about transdisciplinary collaboration, which is a capacity that researchers need to nurture and train [7]. The open and tolerant approach in managing the Sprint was appreciated. However, dealing with innovative concept generation for wicked problems is not a straightforward process. Ingenuity demands that the participants set aside assumed solutions, learn about complexity and engage in communication with specialists in other disciplines. Preliminary Sprint results might be fuzzy and inconclusive, and there is the risk of losing focus and effectiveness. A future improvement to the Sprint is to incorporate stakeholder participation from the start and have intermediate reality checks and exchange moments with outside experts.

The **bounded approach** focussing on a specific problem in a specific place was considered crucial. Choosing a place for the study requires consideration for accessibility of data and stakeholders, balanced against other factors like representative conditions. Engaging local stakeholders requires resources and might lead to stakeholder fatigue if too many workshops or surveys are conducted. Committing to focussing on a single location was perceived as a risk of lacking generality at first. However, in the words of a Sprint team member, *"If we didn't choose a place I think we would have spent more time, and [be] lost"*. Further iterations of an Transition Engineering Research Sprint should test the repeatability of the approach in different locations.

Table 1. Transition engineering research sprint - reflection on experience and future outlook.

Theme	Effectiveness	Limitations	Future outlook
Project management	Having regular meetings Management of communications	Time and resource constraints	Embed sprint activity within the project timeline
Research Rigour	Having a structured process, that converges with established transdisciplinary approaches	Risk of bias through introduction of beliefs and ontology	Establish a formalised process for framing background research
Transdisciplinarity	Learning by doing approach	Risk of loss of focus and scope creep	Embed stakeholder participation from the start
Bounded approach	Considering a specific societal problem in a place	Requires a strong local presence, connections, and time from stakeholders	Evaluate how it could be repeated in a different location with different characteristics

4. Discussion and Conclusions

The Transition Engineering Research Sprint approach was used in a transdisciplinary research group to address a wicked problem of just transition to Net Zero energy. The group of transdisciplinary researchers used the Wicked Problem Investigation and InTIME Design workshopping tools to generate exploratory research concepts aimed at eliminating fuel poverty in Orkney, UK. New transdisciplinary insights from the Sprint provide new research avenues for future proposals. Self-reflection on the Sprint experience showed that the approach was effective for team members engagement and focus. The Sprint process narrowed the disconnect between ongoing disciplinary research focused on technology and modelling, and innovative research contributions addressing socio-technological-economic just transitions.

The activities reported in this paper represent the first application of the Transition Engineering Research Sprint. A second iteration is ongoing and expected to bring the research outcomes to fruition. The Sprint provides a replicable approach for overcoming wicked problems and can be picked up by other transdisciplinary engineering researchers.

Acknowledgement and contributions

The work was supported by the EPSRC funded project DISPATCH [EP/V042955/1], for all the authors except FA who thanks Heriot-Watt University for providing a “PhD Watt Scholarship”. The Sprint team is composed by PC, MA, BC, JK, DK, ZI, SN, AP and WL. The Transition Engineering team consists of PC, FA, SK.

References

[1] W. Steffen *et al.*, Sustainability. Planetary boundaries: guiding human development on a changing planet, *Science,* vol. 347, no. 6223, p. 1259855, Feb 13 2015, doi: 10.1126/science.1259855.

[2] D. J. Lang *et al.*, Transdisciplinary research in sustainability science: practice, principles, and challenges, *Sustainability Science,* vol. 7, no. S1, pp. 25-43, 2012, doi: 10.1007/s11625-011-0149-x.

[3] T. Seager, E. Selinger, and A. Wiek, Sustainable Engineering Science for Resolving Wicked Problems, *Journal of Agricultural and Environmental Ethics,* vol. 25, no. 4, pp. 467-484, 2011, doi: 10.1007/s10806-011-9342-2.

[4] S. Krumdieck, *Transition Engineering: Building a Sustainable Future*. CRC Press, Boca Raton, 2019.

[5] L. Eisenstadt. *Managing Complexity*. Social Labs Blog 2.0. https://social-labs.org/managing-complexity/ (accessed 2024/01/18).

[6] S. Lattanzio *et al.*, Classifying the Disciplinarity of Engineering Academic Literature, *Advances in Transdisciplinary Engineering*, Vol. 12, 2020, pp. 23-31.

[7] R. Freeth and G. Caniglia, Learning to collaborate while collaborating: advancing interdisciplinary sustainability research, *Sustainability Science,* vol. 15, no. 1, pp. 247-261, 2019, doi: 10.1007/s11625-019-00701-z.

[8] A. Berner, F. Burns, H. Dunne, I. Impesi, and M. v. d. Weg, *A Perfect Storm: Fuel Poverty in Rural Scotland*, Changeworks, April 2023. [Online]. Available: https://www.changeworks.org.uk/wp-content/uploads/2023/09/A-Perfect-Storm-Fuel-Poverty-in-Rural-Scotland.pdf

[9] O. Vågerö and M. Zeyringer, Can we optimise for justice? Reviewing the inclusion of energy justice in energy system optimisation models, *Energy Research & Social Science,* vol. 95, 2023, doi: 10.1016/j.erss.2022.102913.

[10] M. O. Dioha, M. Montgomery, R. Almada, P. Dato, and L. Abrahams, Beyond dollars and cents: why socio-political factors matter in energy system modeling, *Environmental Research Letters,* vol. 18, no. 12, 2023, doi: 10.1088/1748-9326/ad0a54.

[11] F. Ahrens, P. Cherubini, J. Boulton, M. Bartholomew, and S. Krumdieck, The First Rule of Transition Engineering is Define the Wicked Problem, *Advances in Transdisciplinary Engineering*, UCL East, London, UK, 2024, in press.

[12] F. Ahrens, S. Krumdieck, and D. Kenning, Interdisciplinary Transition Innovation, Management, and Engineering (InTIME) Design: an intersection analysis of design approaches for whole-system sustainability, *Proceedings of the Design Society,* vol. 4, pp. 1169-1178, 2024, doi: 10.1017/pds.2024.119.

[13] Aquatera and C. E. Scotland, *Orkney Energy Audit 2019*, Report for ReFLEX Orkney, 2019. [Online]. Available: https://www.oref.co.uk/wp-content/uploads/2023/04/ReFLEX-Orkney-Energy-Audit-2019-V3.pdf

[14] L. G. Hill and D. L. Betz, Revisiting the Retrospective Pretest, *American Journal of Evaluation,* vol. 26, no. 4, pp. 501-517, 2005, doi: 10.1177/1098214005281356.

[15] N. D. Rao and J. Min, Decent Living Standards: Material Prerequisites for Human Wellbeing, *Soc Indic Res,* vol. 138, no. 1, pp. 225-244, 2018, doi: 10.1007/s11205-017-1650-0.

[16] S. Okushima, Measuring energy sufficiency: A state of being neither in energy poverty nor energy extravagance, *Applied Energy,* vol. 354, 2024, doi: 10.1016/j.apenergy.2023.122161.

[17] D. Charlier and B. Legendre, Fuel poverty in industrialized countries: Definition, measures and policy implications a review, *Energy,* vol. 236, 2021, doi: 10.1016/j.energy.2021.121557.

[18] J. Boulton and S. Krumdieck, Transition Engineering Sprint with oil industry experts: finding the possibility for climate safe business strategies , *Advances in Transdisciplinary Engineering,* 2024, UCL East, London, UK, in press

[19] M. Andoni *et al.*, Local energy markets in energy communities and their impact on fuel poverty, *2024 IEEE International Conference on Renewable Energies and Smart Technologies (REST)*, Prishtina, Kosova, 2024: In press.

[20] B. Couraud *et al.*, Enhancing Access to Affordable Energy through Peer-to-Peer Automated Negotiations, *2024 IEEE International Conference on Renewable Energies and Smart Technologies (REST)*, Prishtina, Kosova, 2024: In press.

[21] J. Sajdakova, E. Carey, and L. Newnes, Understanding the Skill Requirements in Transdisciplinary Engineering Projects, *Advances in Transdisciplinary Engineering*, 2023, Vol. 41, pp. 571-580.

[22] D. Nicholas *et al.*, Early career researchers and their publishing and authorship practices, *Learned Publishing,* vol. 30, no. 3, pp. 205-217, 2017, doi: 10.1002/leap.1102.