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Strange, Wonderful, and Disturbing:

Using foresight exercises to understand the governance implications of distributed ledger technology for a sustainable energy systems transformation

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Strange, Wonderful, and Disturbing?

Using foresight exercises to explore the governance implications of distributed ledger technology for a sustainable energy systems transformation

by

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To obtain the degree of Master of Science in Environmental Science (Sustainable Development)
from Utrecht University, the Netherlands
Defended publicly on 11 of December, 2018

Project Duration: April 23, 2018 – December 3, 2018 (45 ECTS)

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Academic Track: Earth System Governance
Annotation: Sustainable Business & Innovation
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WE SET THIS HOUSE ON FIRE,

FORGETTING THAT WE LIVE WITHIN.

- JIM HARRISON

Quick References

Looking for…

Acknowledgments

Professional Acknowledgements

First and foremost, I wish to thank the people who volunteered their time and knowledge to engage with such an unorthodox project. Thank you for trusting me with your candor. I am aware that it posed a professional risk to some of you, and I respect your willingness to speak anyway. I cannot adequately express my gratitude, your words propelled me through this year.

I wish to thank my thesis supervisor, Dr. Joost Vervoort, who I practically bum-rushed with my project pitch last year. To my happy surprise, you were game. Taking on an independent research project is always a gamble, but you helped guide me while also helping me to stand on my own two feet. I look forward to working with you in the future. Additional thanks are due to Dr. Frank van Laerhoven, who, in addition to having taught several of my courses, is also my second reader. Thank you both.

To Sjors Hijgenaar, John Mohamed, Morteza Karimzadeh, and Yolanda Krielen, this project was made better by you all. Thank you for all your guidance, and helping me avoid rookie mistakes, or at least minimize the impact thereof.

To the team at Seats2Meet Utrecht CS, especially Martine Maris and Nynke Visser. I'm very grateful to you both for your help.

I would also like to express my gratitude to the Environmental Systems Analysis team at Chalmers University of Technology, who I will be joining next year. Thank you for letting me make use of your space this October, and for welcoming me into the fold.

In the blockchain world, I'd like to thank @ev0k3d and @inbari0. I'm lucky to have met you at the edge of this rabbit hole. Your advocacy is keeping human rights, freedom, and dignity at the forefront of the decentralisation conversation.

To my mentor, Ronnie Fong. You are a great person to have in one's corner. I appreciate your insights, which always run pleasantly against the grain of conventional wisdom. Thank you for keeping me sharp.

Personal Acknowledgements

Most simply put, I appreciate the hell out of my family. Water or blood, I have no preference. Either way, it's a question of presence.

Thank you to my mother. You jokingly told me that "Prva mačka se baca u rjeci" (First kitten of the litter gets thrown in the river). This poesje learned to swim, and I promise to make my way upriver back to you. To my father, thank you for letting me run free and pull your hair. My brother and best friend, Adrian, I'll keep making mistakes if you promise to keep learning from them. To my grandparents, who used education to drag themselves out of bleak situations, thank you for encouraging me to keep pushing forward.

To my Many Mothers… Suada Pandza, Gloria Höfler-Fernández, Azra Sečerbegović, Renata Galić, and Li Ng, thank you for providing me with the model for a well-worn, thoroughly-examined woman's life. You all pursued graduate school in spite of war, unexpected pregnancies, isolation from family, and/or xenophobia. Cirque du Soleil pales in comparison to the acrobatics you all achieve on a daily basis. Collectively, you have taught me that there are enough forces in the world which are working against us- it is important that we avoid assisting them. Thank you for your guidance and words of encouragement.

I would also like to thank the Djuherić and Haurdić families, Draženka Lučić, Azra Sečerbegović, and Renata Galić for essentially adopting me during my time here in the Netherlands.

Hoću da se puno zahvalim mojoj Evropskoj familiji: Djuherići, Haurdići, Draženka, Azra, i Renata. Vi ste me svi usvojili kao da sam bila vaša kčerka. Hvala vam za vaše lekcije o integraciji, vašu ljubaznost, učenje iz vašeg iskustva, i za otpuštenu atmosferu kod svih vas. Izvinite što sam bila ponekad živčana, prošla sam kroz fazu u kojoj sam se morala suočiti sa mojom identitetom i dugoročnim ciljevima. Volim vas puno, i gdje god budem išla u svijetu, uvjek ste dobro došli kod mene.

Summary

Worldwide, energy systems are currently undergoing a process of simultaneous digitalization and decarbonisation. This is not without its challenges, primarily the variable and decentralised nature of many renewable energy sources. Digital solutions are being explored for management of distributed energy resources, among them machine learning, big data, predictive analytics, automation, and distributed ledger technology (DLT; commonly, yet speciously referred to as blockchain technology).

With proponents making claims that distributed ledger technology enable ownerless peer-to-peer exchange, it presents novel governance challenges (TIR Consulting Group LLC, 2016). Peer-to-peer energy trading between household is not explicitly enable by any regulation, only within regulatory sandboxes. As of November 2018, DLT-enabled energy trading was in an experimental phase, without any commercialized products scaling out into mainstream energy markets (Boucher et al., 2017; Munsing, Mather, & Moura, 2017; Pieroni, Scarpato, Di Nunzio, Fallucchi, & Raso, 2018; Voets, 2017). Private consultancies, energy suppliers, and the European Union have invested in technical proof-of-concepts for a variety of use cases, some of which have demonstrated promise for wider-scale implementation. Regulation has been commonly cited as a barrier to adoption of DLT-based solutions. The validity of this claim, and whether other barriers exist, is of interest to this research. Concurrently, the question of governance has repeatedly been raised without substantive cross-actor discussion to provide clear, actionable visions set for future transformation.

This research explored the potential role of distributed ledger technology in energy systems change. Foresight exercises were conducted in a variety of contexts, in which participants explored governance and policy imaginaries within the energy sociotechnical system over the first half of the 21st century. The criteria for a "clean, modern, affordable, reliable, and democratic energy system" outlined in Goal 7 of the United Nations Sustainable Development Goals was used an endpoint for desirable futures. Alternative endpoints were also created and explored.

The research consisted of literature review, visioning interviews with stakeholders and experts, participatory scenario design and policy-stress testing workshops, follow-up interviews with workshop participants, and external expert consultations. Interviews were conducted with domain experts and actors currently active in either DLT development, innovation science, or the energy sector. In total, forty-five respondents contributed input to this investigation.

The literature review provided background on the theoretical frameworks applied in this research, in addition to starting knowledge on energy systems and distributed ledger technology. It further informed the content and design of the interviews and workshops. In the visioning interviews, drivers of change and proposed policy steps were collected. The drivers were categorized by levels according to criteria outlined in the Multi-level perspective of sociotechnical change, and by STEEPLE criteria. The proposed policies were sorted into time periods of plausible implementation and categorized by targeted innovation system functions. A policy pathway from 2018 to 2050 was synthesized from the collective visions and policy.

During the foresight workshops, drivers from the interviews were presented. Scenarios were then designed, ranked, and selected by participants. Policies from the proposed pathway were presented, and then discussed and selected by participants. The selected scenarios were then used to stress-test each individual policy. These findings were used to create a new, more robust version of the policy pathway. This was then presented to and discussed with workshop participants and industry experts for further validation.

In the follow-up interviews and external consultations, workshop had the opportunity to reflect on which drivers of change they deemed most important to a DLT-enabled energy transition, order the policies and DLT use cases by hypothesized order of emergence, and discuss additional scenarios. The policy pathway was iterated following these sessions. Policies which were deemed fruitful for development of valuable DLT use cases and robust under multiple scenarios included energy/data literacy campaigns, both in the general population and at the policy-making level, transitioning to dynamic pricing from time-of-use pricing (albeit with several ethical and market-related corollaries), de-siloing of metering data, and establishment of DLT interoperability standards.

The consensus among respondents was that specific legislation oriented towards DLT is not necessary. Robust policy instruments included a wide spectrum of soft, economic transfer, and regulatory policies. Formal governance

mechanisms which support research and development, such as financial commitments establishment of official research networks, regulatory sandboxes for exploring peer-to-peer trading, and cross-sector and inter-competitor information-sharing, were described favorably. Additionally, policies which shift market models to enable complementary physical and digital technological developments, such as Internet of Things, artificial intelligence, energy storage, and improved metering, would also lead to more fertile ground for transformative blockchain use cases.

The most commonly selected drivers of change (in decreasing order) included development of blockchain scalability, societal openness towards information-sharing, orientation of environmental solutions (long-term versus short-term thinking), reform of end-user financial incentives (such as Feed-in Tariffs, and adoption subsidies), IoT enablement, trust in institutions, social cohesion, legal structure of data ownership, and the impact of the effects of climate change on society. While the most commonly selected driver corresponded to the niche level, landscape factors comprised the majority of drivers, highlighting the complexity of the issue area.

Energy infrastructure and info-socioeconomic systems change compatible with the UN Sustainable Development goals was envisioned in half of the created scenarios. Of those scenarios, approximately half (i.e. five) had clearly outlined transformative blockchain use cases (i.e. self-sovereign identity management, enhanced demand response, and peer-to-peer energy trading). This suggests that DLT may not be essential for sustainable energy system development. Further, transformation of digital and physical energy infrastructure wasn't tightly coupled to info-socioeconomic transformation. This raises an important consideration, of reconciling technological progress with the broader goals of sustainable development. While climate targets may be met with technological progress alone, it could be at the expense of long-term societal, political, and economic stability. These landscape factors would eventually be expected to exert such pressure on the new regime that a collapse may occur, and progress may be lost. Conversely, a system transformation or re-configuration (in which a relatively smooth shift towards more sustainable energy generation, distribution, and consumption is achieved) is only envisioned in scenarios in which technological and info-socioeconomic development progress in tandem. This empirical finding should serve as a message of caution to policy-makers and policy-critics alike. Effecting change in such domains as complex as energy systems can be unpredictable, and it is difficult to predict the results of policy measures with certainty. What is clear, however, is the importance of a transdisciplinary policy approach in effecting a system transition which minimizes the risk of socioeconomic dislocation.

Concerns about dictatorship were trumped by the those regarding monopolization or corporatocracy. Under scenarios in which several large actors control the majority of the market, blockchain is not expected to play a transformative role for the end-user, only on the organisational side, with respect to cybersecurity, administration efficiency, and machine-to-machine communication. End-user engagement was also a contentious driver of change. Approximately half of participants found a shift in societal value systems essential for a sustainable energy transition, with the other half citing the importance of convenient service and properly designed price signals. Moreover, the desire for convenience and aversion to complexity by end-users was described by some respondents as a potential factor in the rise of energy service monopolies.

The primary difference between DLT-facilitated and non-DLT-facilitated energy system transformations was not in the types of policies deemed robust, but rather in the mode of governance envisioned. For transformative scenarios which did not involve DLT, governance modes ranged from centralised, decentralised, public-private and self-governance. In DLT-transformative scenarios, interactive modes of governance were predominant. This is confirmed in interviews with members of several DLT/energy projects. Successful pilot projects typically involved collaboration between national and local state actors, DLT specialists, local utilities, and willing citizens who chose to engage with the experiment. Furthermore, multi-actor data-sharing contributes to improvement of models which better define the precise value proposition (or lack thereof) of the claimed DLT use case.

This research found that for every transformative use case of blockchain technology, there exist as many incremental applications which are not expected to necessarily contribute to a more democratic, green, nor affordable energy transition. Identified use cases include (in order of expected emergence and transformative potential) Guarantee-of-Origin/certificate trading, data reconciliation, billing/settlements/clearing, self-sovereign identity management, enhanced demand response management, and peer-to-peer household energy trading. Of the many energy systems scenarios generated in the workshops, those with identifiable blockchain use cases varied greatly in their transformative potential. This suggest that distributed ledger technology, which is lauded by many as a liberator from traditional market models, could just as easily be co-opted by the incumbent regime, fade into the administrative fabric, or be confined to niche application areas.

The key finding of this research is that the governance arrangement is a key differentiating factor between envisioned DLT- and non-DLT-facilitated comprehensive energy systems. In colloquial terms, there are many ways to skin the cat of energy governance, when transformative DLT use cases are not a factor. If technological progress continues, a non-democratic energy transition may even be successful, facilitated by distributed ledger technology, no less. For example, it may enable machine-to-machine transaction on platforms held by incumbent regime actors. Based on our findings, in order to shape a future in which distributed ledger technology is advantageous to an affordable, modern, reliable, and low-carbon energy future, interactive governance and either a transformation or reconfiguration pathway is seen as the most promising way forward.

Our results enrich the robustness of contemporary knowledge on the arrangement and planning for transformative governance structures which can promote opportunities for sustainable development provided by novel technologies such as distributed ledger technology. Practical insights are provided to stakeholders situated in various contexts of the energy sector, who may be considering how to approach the governance of DLT-enabled peer-to-peer energy markets.

Future research might be directed towards more deeper investigation into the governance of, versus governance via, versus governance of a system in which DLT is a technical component. These are three different avenues which were not adequately delineated in this research. Additionally, this research calls for investigation of distributed ledger technology from a political ecology perspective, namely further empirical investigation into the dynamics of regime co-option, and the role of military research and development in shaping development pathways in the civilian sphere. There is indisputably a power dimension involved, which this research didn't include as a unit of analysis. Deeper investigation into the epistemological foundation of assessments made by respondents regarding the proposed policies is also recommended.

Disclaimer:

Everything written in this research are solely the findings and opinions of the author. It does not represent the public opinion of CGI Group or any of the other involved companies nor its employees unless explicitly stated.

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Abstract

Global energy consumption is expected to increase over the course of this century. Continued generation with the current energy mix is expected to further threaten climate tipping points. In order to meet emissions reduction targets, there has been a global push by governments to increase their share of renewable energy sources (RESs). Adoption has grown across scales, in addition to demand for new market models which allow for more flexible energy distribution. Liberalization of energy markets has expanded the number of actors involved, further contributing to the complexity of the issue. Adapting management systems and market models to better incorporate distributed energy sources poses a unique challenge to current energy system actors.

Information and communication technologies (ICT) are increasingly explored as a means of increasing efficiency and enabling more dynamic markets. Among these is distributed ledger technology (DLT), a decentralised, immutable, and cryptographically secured record of transactions which proponents claim can enable peer-to-peer energy trading. As of November 2018, DLT-enabled energy trading remains in an experimental phase. The question of governance has repeatedly been raised without clear strategic visions set for integration into future energy systems.

This research is a single case study which employed participatory foresight methods to understand how governance arrangements, actor networks, and innovation policies can be shaped over the first half of the 21st century in order to facilitate a sustainable energy system transformation enhanced by distributed ledger technology. The foresight methods used are visioning, driver mapping, scenario design, and policy-stress testing. Participants came from various levels, roles, and competencies within the energy sector. Several DLT application areas were identified, along with drivers of change, which were used to frame scenario narratives applied later in policy stress-testing.

Results show that while DLT is not deemed a necessary part of a sustainable energy system transformation, an interactive mode of governance would be most conducive to a future in which it would have a role. Further, results suggest that there are ample opportunities for DLT and/or innovation policies to be co-opted by vested interests and locked into a non-transformative pathway. The importance of data-sharing in enabling sociotechnical change and, moreover, the legitimacy debate surrounding data collection methods is another key insight. This research enriches the robustness of contemporary knowledge on the arrangement and planning for transformative governance structures which can promote opportunities for sustainable development provided by novel technologies such as DLT, in addition to the role of foresight exercises in anticipatory governance.

Key words: transformative futures, anticipatory governance, innovation policy, distributed ledger technology, sustainable energy systems, foresight methods

Introduction

The Sustainability Issue

From majestic thousand-year old Syrian water wheels (*norias*), to Henry Ford's gasoline engine, humans have been harnessing energy from beyond the physical limits of their bodies in order to achieve their ends. As standards of living increases, so does energy demand (IEA, 2017b). One of the overarching calls to action in the United Nations Sustainable Development Goals (SDGs) is to raise the standard of living for human beings everywhere (Alloisio, n.d..; United Nations, 2018). The human population is steadily growing, and expected to reach ~11 million by 2100 (United Nations, 2017). If the standard of living is to be raised for all, energy demand can be reasonably expected grow at a massive scale. This expectation is echoed in energy demand scenarios modelled by the International Energy Agency, even those which operate under highly optimistic assumptions (IEA, 2017b).

The SDGs also call to preserve the health and stability of our planetary resources. Reducing greenhouse gas emissions, such that global temperature rises either falls within the +1.5 or +2 C range by 2050, as detailed in the Paris Agreement, is widely considered a critical aspect of securing a safe and habitable future (Cooper, 2018; IEA, 2018; Vervoort & Gupta, 2018). However, it is possible to reduce anthropogenic greenhouse gas emissions, and one of the ways in which this can be achieved is by transforming the energy sector, specifically electricity generation (IEA, 2018). Electricity generation is one of the largest contributors to global greenhouse gas emissions, accounting for 25 percent[1] of global GHG emissions in 2010 (IEA, 2017b). From 2017 to 2040, annual global electricity demand is expected to increase from ~16 TWh to ~25 TWh (IEA, 2017b). Countries have been scrambling to add capacity to their grid systems, in anticipation of this growth (IEA, 2017b). Most energy is generated from thermal sources, such as coal, gas, and oil. These are highly emitting sources of energy, but they are currently most accessible and prevalent within the developing world. If the growing human population continues to make use of fossil fuels as a primary energy sources, this will result in a failure to meet the goals set in the Paris Agreement. Missing the target means potentially triggering climate feedback loops which are expected to result in runaway climate change (Steffen et al., 2015). Our planetary system will be pushed out of predictable and known survivable operating bounds into a complex cascade of consequences, including societal displacements, resource scarcity, and ecosystem degradation (Steffen et al., 2015).

Transitions in Energy Sources

Economic growth tends to track consistently with emissions, but there is a growing effort to decouple the two by introducing greater efficiency and flexibility, and procurement from renewable energy sources into the electricity sector (Brand-Correa & Steinberger, 2017; Guevara & Domingos, 2017; IEA, 2014, 2017a). By reducing the carbon footprint of electricity generation and distribution, developing countries

[1] Followed by "Agriculture, Forestry, and Other Land Use" (24%), Industry (21%) in the top three.

can continue to grow their economies and improve living standards while reducing the impact of those activities on planetary boundaries. The tension between the 2050 emissions targets and human development goal highlights the conflict of development and emissions reduction (Brand-Correa & Steinberger, 2017). A pathway to reconcile these issues is increased adoption of renewable energy sources (RES) (Rijksoverheid, 2017). The SDGs call for shifting from fossil fuels to renewable sources of energy, such as hydropower, photovoltaic, biomass, and wind (Rosa, 2017). These sources are either carbon neutral, or do not generate GHG emissions. Hydropower is a consistent source but raises significant concerns about social displacement and ecosystem degradation. Biomass, depending on the source, either comes into land competition with agricultural food or timber production, is costly, or raises monocropping/GMO concerns. Wind and photovoltaic are rapidly decreasing in material cost, increasing in generation capacity (early wind turbine models in the 1970's had a power output of 5 kilowatts, whereas a 12-Megawatt prototype will be tested in mid-2019), can be deployed on an individually distributed and massive scale, and don't pose as much of an ecosystem disruption as biomass or hydropower (IEA, 2018). However, the main downside is that wind and PV are variable in nature, and long-term storage is not currently technically feasible. Variable renewables do not have to be centrally distributed, they can be decentralised (Boutin, Feasel, Cunic, & Wild, n.d.; Hadush & Meeus, 2018; IEA, 2017a).

Energy Market Liberalization and Digital Transformation

There has been a trend of market liberalization within the energy sector, decentralising the control of the supply and distribution (Rijksoverheid, 2017). SDG 7 calls for a clean, modern, affordable, reliable, and democratic energy transition (Rosa, 2017). People are increasingly adopting renewables and generating energy locally. This energy is generally not used at the point of generation, but rather returned to the grid (Hijgenaar, 2016). Even with self-generation, people are not self-consuming, and remain dependent on supply from substations, which are supplied by a variety of actors. There is also a growing niche demand for the ability to trade energy peer-to-peer within a network (Hojčková, Sandén, & Ahlborg, 2018a; Mengelkamp, Gärttner, & Weinhardt, 2018; Munsing et al., 2017). Effective integration of variable renewables on a broad, decentralised scale is not possible without increasingly sophisticated information technologies (IEA, 2017a). Two processes primarily fall under the term "flexibility": energy storage and demand response. Energy storage refers to the process of diverting energy generated into a hardware unit, from where it remains accessible in a stable state for a known amount of time. Demand response management refers to the broad practice of matching energy demand with energy supply, and it becomes an increasingly complex task with increasing decentralisation of generation (Goldenberg, Dyson, & Masters, n.d.; Nolan & O'Malley, 2015). Multiple actors will require accurate, trustworthy, and timely data in order to realize this potential (Nolan & O'Malley, 2015). Distributed ledger technology (DLT) has been proposed as a means of facilitating this decentralised record sharing (Luke, Lee, Pekarek, & Dimitrova, 05/18; Munsing et al., 2017; Pieroni et al., 2018; Voets, 2017; Zhang, Parizi, & Choo, 2018). DLT is a new technology, and has raised many questions regarding its scalability, security, governance, development, and relevance to the energy sector (Boucher et al., 2017; Hijgenaar, 2016; Luke, Lee, Pekarek, & Dimitrova, 2018; Voets, 2017). This is part of a broader trend toward greater integration of information and communications technologies (ICT), in order to increase efficiency and better manage complex systems (IEA, 2017a).

Due to the high cost of investing in infrastructure, there is a strong incentive to avoid risk (and consequently innovation) in that area (Munsing et al., 2017; TIR Consulting Group LLC, 2016). Reliability is the primary prerogative. Therefore, actors within the energy sector are investing heavily in the promising offers of digital transformation, a word which is shrouded in hype and ambiguity. This refers to increasing digitization of previously analog services within a sector, in addition to enhancing the value of operations through better insights, facilitated by technologies such as big data, machine learning, or cloud computing (IEA, 2017a). By leveraging these technologies to make their existing processes and hardware more efficient, market actors either expect to buy time in their infrastructure transition or bypass it altogether (IEA, 2017a; Mengelkamp, Gärttner, & Weinhardt, 2018; Munsing et al., 2017; Pieroni et al., 2018).

Societal Challenge

Renewable energy source adoption at the household, neighborhood, or cooperative level is limited by variety of factors. Aside from off-grid scenarios, the energy generated from an on-site renewable energy source does not immediately power the house upon which it is installed. Instead, that electricity is fed into the distribution grid, and the household continues to procure their energy from the traditional supplier. Instead of acting as their own supplier, most households are compelled to act as distributed generation agents for whatever authority is responsible for distribution system management (Hijgenaar, 2016). Societally, there is a gap between the distribution possibilities presented by decentralised energy generation, and the enabling system environment in which to pursue them (i.e. peer-to-peer trading)(Hijgenaar, 2016; Mengelkamp, Gärttner, Rock, et al., 2018; Munsing et al., 2017). If a technology is claimed to facilitate this, then it is worth investigating the value propositions and governance implications thereof (Raikov, 2018).

Research Gap

The research gap targeted by this investigation is that of a participatory policy foresight approach taking a systemic view of DLT-enabled energy systems transformation.

Foresight approaches have been previously employed to investigate the potential role of DLT in energy systems (Luke et al., 2018; Voets, 2017). Methods used included literature review, and scenario design. Voets conducted a scenario design workshop with a group of industry actors, in which possible configurations of actor networks and resource flows were investigated. Two drivers of change were used to frame the scenario narratives: Degree of Government Centralisation and Rate of Innovation. They found that in a decentralised/high innovation scenario, DLT applications contributed to the most significant and disruptive changes in existing electricity market structures and called for investigation of scenarios in which other drivers were incorporated (Voets, 2017). Luke et al. conducted a literature review to create multiple blockchain energy scenarios (Luke et al., 2018). They did not use scenarios matrices, but rather adopted a free-form narrative approach, and ultimately called for further policy foresights.

Research Objective

We aim to explore potential roles of distributed ledger technology within the energy sector, develop a clear and actionable understanding of influencing factors, identify robust governance approaches and policy steps which may facilitate development of a DLT-enhanced sustainable energy systems transformation. This is to be done by using a foresights approach, namely visioning interviews, driver mapping, scenario design, and policy stress-testing.

Guiding Questions

The research will be structured by the following questions:

1. *Which applications of distributed ledger technology (DLT) hold the most transformative potential for sustainable energy systems change?*

2. *Which drivers may influence the development of these applications?*

3. *How can these drivers be considered (in terms of governance) by stakeholders in such a way as to support a DLT-enabled energy system transition?*

The research was conducted in several stages. First, the research began with visioning interviews with actors within the energy sector, from the United States, Germany, and the Netherlands. The following was collected from these interviews: DLT use cases within the energy sector, holistic visions of a sustainable energy future in 2050, relevant drivers of change, normative/regulatory/market barriers to realizing the visions, and potential regulatory steps and governance approaches which might facilitate the realization thereof. This informed the next stage of the research, in which policy foresights workshops were conducted in the Netherlands, with actors from Russia, India, the Netherlands, and France. In these workshops, the drivers from the earlier interviews were used by subgroups to develop future energy scenarios. Several scenarios were selected from the total generated, and these were then used to stress-test selected policies from the visioning interviews. Lastly, follow-up interviews were conducted with workshop participants, in addition to external consultation sessions with subject area experts. During this phase of the research, validation of the previously selected scenarios, driver, and policies was assessed.

Report Outline

This report consists of six parts. First the sustainability issue, proposed solution, and knowledge gap are introduced. The theories which informed the scope of the research and methodology are then presented.

This is accompanied by a brief empirical mapping of the research scope. Next, the methodology and analytical framework are presented. In the fourth section, the research results are presented, followed by a discussion section, policy recommendations, and directions for further research. The final section concludes the report. In the appendices, one may find supplementary materials regarding the composition of the research participants.

Theory and Empirical Mapping

Theory

The theoretical framing of this research stems from several fields: three discipline: earth system governance (specifically anticipatory governance of emerging technologies, and transformative futures), innovation science (multi-level perspective of sociotechnical systems change, innovation systems and functions, innovation policy), and foresight approaches for creation of normative futures. (Figure 1).

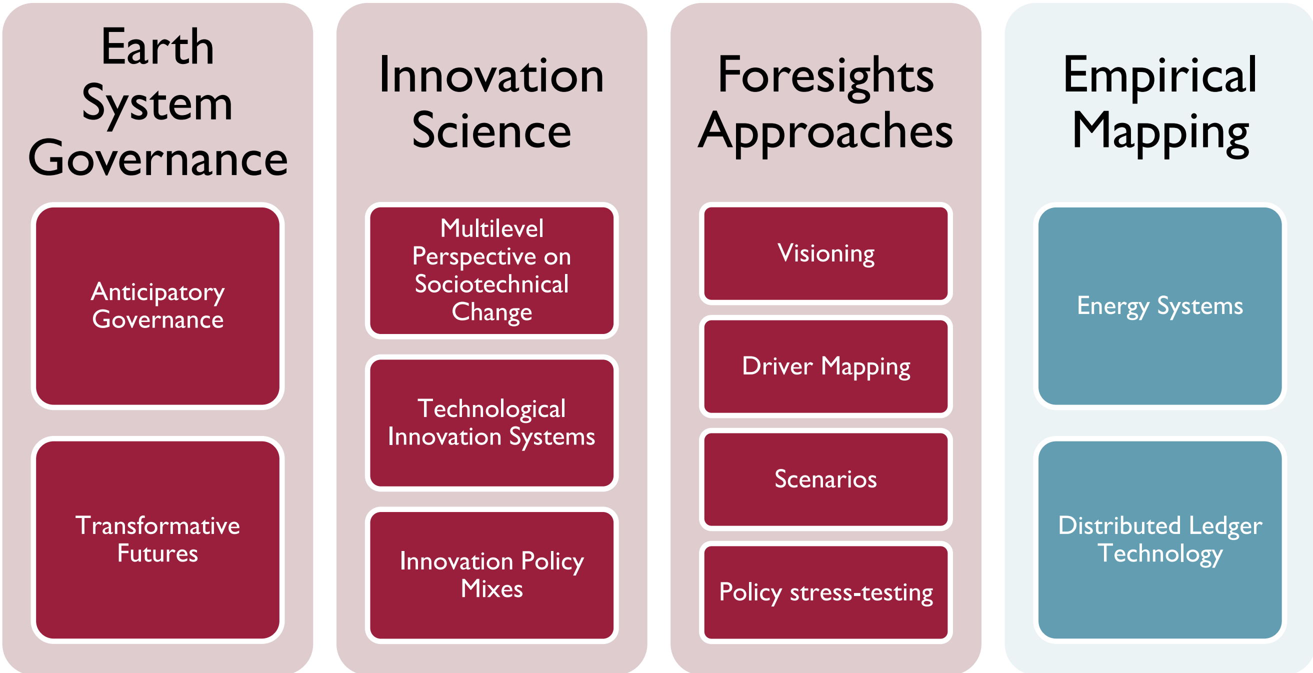

Figure 1: Collected theories which influenced the direction of this research.

Earth System Governance

Environmental governance is a governance concept referring to the means by which societal actors define, coordinate, and execute measures to achieve environmental objectives (Driessen et al., 2012). The unifying aim of environmental governance is to pre-empt or ameliorate negative impact on the environment (Arapostathis et al., 2013; Brizga et al., 2014; Driessen et al., 2012). This covers a wide range of application areas, such as biodiversity policy, emissions targets, or renewable energy technology subsidies (Rosa, 2017). Before proceeding further, it is important to provide further background on *governance* itself.

A core tenet of governance is that government is not always the sole or key actor in addressing societal issues (Driessen et al., 2012; van Witteloostuijn et al; 2012). Additional actors include civil society and market actors (Broekmanweg et al., 2014; Driessen et al., 2012; van Witteloostuijn et al., 2012). Civil society can include non-governmental organisations (NGOs), families, and individuals. These categories can overlap. For example, a CEO is simultaneously a member of civil society, when they are acting without consideration for their enterprise, whereas when functioning in a business capacity would be considered a market actor. In the European energy sector in particular, consumers are being increasingly factored in as market actors, further muddying the waters (Foxon, Pearson, Arapostathis, Carlsson-Hyslop,, 2013; IEA, 2014; Kungl & Geels, 2018; Rijksoverheid, 2017; van Witteloostuijn et al., 2012). Government actors are constituted by the individuals and organisations which are formally granted agency within a given political systems. This can include elected and non-elected individuals, such as senators or judges. Market actors are entities which can make decisions within and affecting a given economy. These actors can operate collectively over various times periods, frequencies, scales, levels of area specificity, degrees of formality, and participation (Driessen et al., 2012). The roles and relations of actors can be arranged in various *governance modes*. Five main general categories defined by Driessen et al. include centralised governance, decentralised governance, public-private governance, interactive governance, and self-governance (2012). The configurations of role and relations can be found in the figure below (Figure 2).

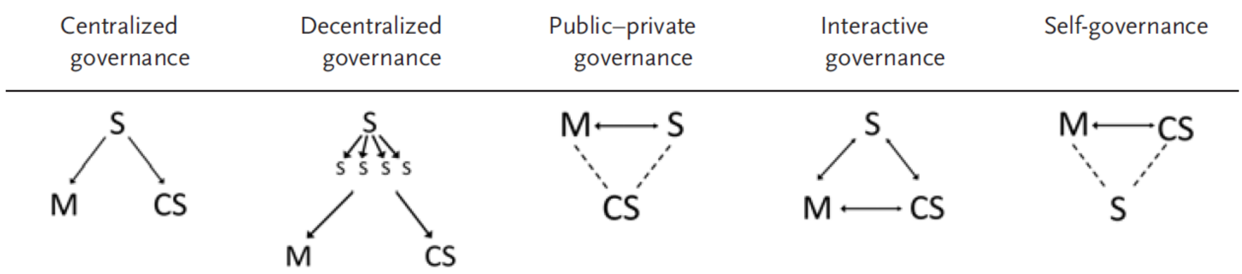

Figure 2: Various modes of governance as proposed by Driessen et al. (2012). "CS" = Civil society, "M" = Market Actor, "S" = State. Unidirectional arrows a dominant role, bidirectional arrows indicate equivalent role, and dashed lines indicate a background role.

These modes of governance are marked by variations in their actor features, institutional characteristics, and content (Driessen et al., 2012). Actor features more specifically refers to who initiates the governance process (initiating actors), the position and ability of the stakeholder in participating in the process (stakeholder position), the level of government where policy is introduced (policy level), and which dimensions actors draw power from (power base) (ibid.). Institutional characteristics include the means by which constituents are represented, rules by which actors guide their interaction, and mechanisms of social interaction (ibid.). Content features include areas such as the uniformity of the goals/targets, policy instruments used, integration of policy sector and policy level, the policy-science interface in which knowledge is gathered and used to inform decisions (ibid).

Centralised governance is characterized by state-guided policy, and policy instruments are typically binding legislation and permits. In *decentralised governance* modes, the state still plays an initiating role, however policy is enacted at lower levels of government, in addition to presenting more opportunity for stakeholder involvement. Public covenants, in which actors make promises to do or refrain from doing something, are common in this mode. *Public-private governance* is driven equally by market and state actors, and market actors have a formally outlined role in the governance arrangement. This can take place at all levels of government, from local to international levels. Contractual obligations and competitiveness mark the foundation of power in this mode. Policy instruments include market-based instruments, such as technology subsidies, incentives, and research grants. *Interactive governance* is an arrangement in which civil society, state, and market actors have an equal role in initiating the arrangement. This arrangement is marked by trust, deliberation, negotiated agreements, and a wide range of informal and formal rules of interaction. The state plays a background role in *self-governance* modes of governance, with market and civil society actors leading policy design and interaction. Informal and self-designed formal rules are predominant in this arrangement. Trust, social capital, and autonomy guide the interactions and form the power base. In centralised and decentralised modes of governance, legitimacy is derived from democratic representation, whereas in public-private, interactive, and self-governance modes, legitimacy stems from the involved actors agreeing on their respective roles, interaction, and procedures.

Anticipatory Governance

Anticipatory governance is defined by Guston as 'a broad-based capacity extended through society that can act on a variety of inputs to manage emerging knowledge-based technologies while such management is still possible' (Guston, 2014). This is not a governance mode, but rather used to define practices of governance oriented around development of emerging technologies. At the heart of anticipatory governance is the importance of designing governance arrangements in which scientific, societal, and economic concerns factor into decisions and outcomes (Granjou, Walker, & Salazar, 2017; Gupta, 2011; Vervoort & Gupta, 2018). These concerns are focused on the effects of an emerging technology which have not yet come to pass. In the past, state actors have modified their regulatory framework of a particular field, from strictly science-based to also include broader socioeconomic considerations (Gupta, 2011). On the topic of GMO governance in India, Gupta states that

> "…GMO governance will have to engage with a highly politically and normatively contested environment, whereby consultative and messy democratic processes…will become both necessary and inevitable" (Gupta, 2011)

Political power can be bolstered or modulated based on the knowledge possessed by acting parties, raising the question – how does one generate knowledge of the future? Common approaches include relying on historical data, quantitative models, and pure speculation. Knowledge to inform anticipatory governance can be also generated from futures-oriented methods, namely foresight methods, which are deemed important in helping actors determine which capacities will help them prepare for the future (Vervoort & Gupta, 2018).

Transformative Futures

Rather than "transformation" alone, Hebinck et al. offer a definition of "transformative change". They describe transformative change as a series of occurrences which lead to change in the very foundations of a system, namely its "structure, system functions, and relations within and between elements of a given system" (Hebinck, Vervoort, Hebinck, Rutting, & Galli, 2018).

The concept of *transformative futures* has developed in recent years as means of describing imaginaries in which unsustainable circumstances are left behind, leading into new mechanisms and processes which shape and guide society in a more desirable direction (Hebinck et al., 2018). Given the urgency of meeting the Sustainable Development Goals and various climate agreements, there has been an increasing acknowledgment of the need for exploring pathways to desirable climate futures. This is seen to require mobilization of new networks, while still engaging with the established actors who hold power (ibid.). A strategy of "incremental change with a transformative agenda" has been proposed as a means of achieving change within the ever-increasing complexity and fragility of our planetary boundaries (Patterson et al., 2017). Imagining transformative futures is argued to be an important step in effecting societal change and can be explored and be made more impactful by means of foresights exercises, which are discussed later in this section.

Innovation Science

Within the field of innovation science, the Multilevel Perspective of Socio-technical Transitions and Technological Innovation Systems theories describe complementary areas (Edmondson, Kern, & Rogge, 2018; Geels, 2011; Meelen & Farla, 2013). The MLP approach describes the structure of the area of theoretical scope (i.e. innovation systems), while the TIS perspective aims to describe the dynamics thereof (Geels, 2011).

Multi-level Perspective of Socio-technical Transitions

The multi-level perspective is a theory which takes a broad perspective on how change comes to pass within a system (Geels, 2010; Geels & Schot, 2007; Raven, 2006). Their scope covers *sociotechnical systems*, which is the collection of societal and exogenous factors, incumbent actors, and upcoming development areas around a particular technology (e.g. the cement, silicon chip, photovoltaics). At the heart of the Multilevel Perspective are the concepts of "landscape", "regimes", and "niches" (Figure 3).

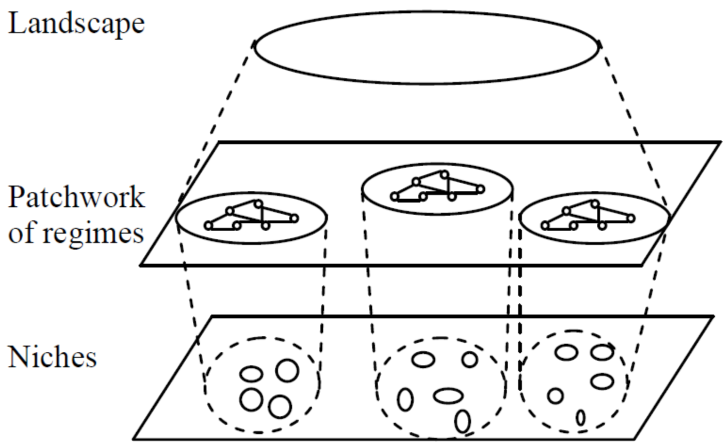

Figure 3: Multi-level perspective on socio-technical change (Geels, 2002)

They are also referred to as macro, meso, and micro levels. The micro level is tightly comprised of the technological niche, defined by Raven as "a loosely defined set of formal and informal rules for a new technological practice, explored in societal experiments and protected by a relatively small network of industries, users, researchers, policy makers and other involved actors." (Raven, 2006). The meso-level is comprised of the incumbent technical regime, and surrounding policies, economic, and societal characteristics structured around it. While there are multiple definitions, the most frequent versions are summarized by Raven et al. below (R. Raven, Van den Bosch, & Weterings, 2010):

1. a coherent set of rules and institutions that enables and constrains the choices and behaviour of regime actors (including firms, users, policy actors, scientists, etc)
2. the meso-level in technological and social change
3. the dominant socio-technical system or the 'establishment' that represent power, is resistant to fundamental change and has a long history of existence
4. a constellation of structures, cultures and practices that is dominant in the way social needs are fulfilled
5. the selection environment for innovations

The macro-level, also referred to as the sociotechnical *landscape*, consists of exogenous factors which may stem from non-related arenas, but still exert a pressure on the meso-level. This includes geopolitical, environmental, and macroeconomic factors. The sociotechnical landscape is defined by Geels as "the technical and material backdrop that sustains society, but also includes demographical trends, political ideologies, societal values, and macro-economic patterns." (Geels, 2011).

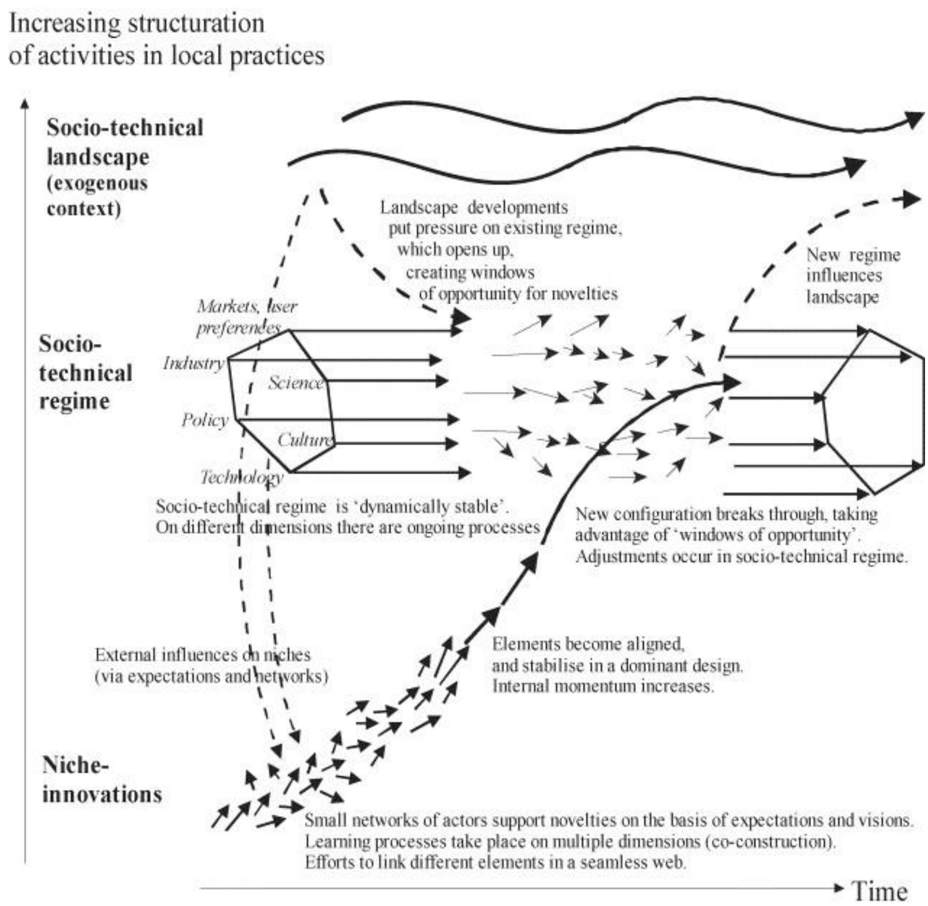

Figure 4: Landscape of a Socio-technical system, and transition dynamics. (Geels & Schot, 2007)

Geels emphasizes that the MLP is not a "… 'truth machine' that automatically produce the right answers once the analyst has entered the data." (Geels, 2011). The framework is used to guide conceptualization of a complex system and lends itself well to narrative explanation.

Conceptualizing Systems Change

Geels also notes a tendency of MLP researchers to cast the existing regime in an adversarial light, with the role of the niche development to overcome and eradicate the regime, something he refers to as "bottom-up bias". Systems change does not follow a single path, nor do the interactions between the various levels occur in a uniform time sequence (Geels & Schot, 2007; Raven, 2006). Niche developments do not always have to be *competitive* with the existence of the regime, a *symbiotic* relationship is also possible (Geels & Schot, 2007; Raven, 2006). For example, the Android operating systems are developed by Google, but are built on a Linux kernel, which is open source. Keeping in mind the variation between the nature and timing of multilevel interactions in systems change processes, Geels and Schot propose four *transitions pathways:* transformation, reconfiguration, technological substitution, de-alignment and re-alignment (Geels & Schot, 2007). In a *transformation* pathway, niche developments are not yet mature; however, landscape factors are applying pressure on the existing regime. This forces actors within the regime to rework their long-term strategy and modify their development goals. The niche innovation does not replace the regime, but the regime is nevertheless forced to change, and some niche developments might be adopted in the new regime structure. *Reconfiguration* pathways differ from transformation pathways primarily in the development stage of the niche technology and nature of the relationship between the niche and the regime. It is more mature, and symbiotic to the regime. When landscape factors are compromising the stability of the regime, solutions offered by the niche technology can be co-opted into the regime where useful. Like grafting a branch onto an apple tree, the tree doesn't die, but there is a new branch bearing a different varietal. *Technological substitutions* occur when mature niche innovations are competitive with the existing regime. The regime may either be experiencing tensions, or the niche may have strong external support from political, economic, or societal sources. In this moment of either tension or momentum, the niche can break-through and replace the previous regime. Finally, in a *de/re-alignment* pathway, landscape pressures are such that the incumbent regime collapses. During this inchoate period, multiple niches may simultaneously spread into the regime, competing, and eventually settle into a new balance.

Table 1: Typology of system transition pathways (Geels & Schot, 2007).

	LANDSCAPE EXERTING PRESSURE ON REGIME	NICHE COMPATIBILITY	NICHE MATURITY
TRANSFORMATION	Yes	Symbiotic	Immature
RECONFIGURATION	Yes	Symbiotic	Mature
TECHNOLOGICAL SUBSTITUTION	Either	Competitive	Mature
DE/RE-ALIGNMENT	Yes	Competitive	Immature

Change or rate of transition can be obstructed in a system by "*lock-in*". Occurring at the regime level, this can take place across a number of contexts, namely Institutional, Social, and Technologically (Grin, Rotmans, & Schot, 2010; Raven et al., 2010). Institutional lock-in covers rules and practices which can be legally defined (i.e. regulations, schemes, laws), or "soft" institutions such as cultural norms and value (i.e. virginity cults). Social lock-in refers to the current actors and social networks within a regime already having their well-worn ways of doing, making it difficult to imagine, much less introduce alternative practices. Technological lock-ins are related to production methods, infrastructures, and the physical technologies themselves, with the regime having invested heavily into the development thereof and therefore incentivized to continue to use the extant system for as long as it still functions.

Technological Innovation Systems and Innovation Policy

This theoretical field is focused on the innovation processes and policy-making surrounding the development of a technology. Innovation is a term used to describe a process of renewal within an area, whether it be a process, service, organisation, or technology. Baregheh et al. conducted a review of the many definitions of innovation, analyzed their scope and commonalities, and propose the following integrated definition:

> *"Innovation is the multi-stage process whereby organisations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace."*
>
> - *(Baregheh, Rowley, & Sambrook, 2009)*

Meanwhile, the system can be defined as, "*…the set of actors and rules that influence the speed and direction of technological change in a specific technological area*" (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008).

Technological Innovation Systems (TIS) theory is an approach to analyzing innovation and identifying areas in which relevant and robust policy may be designed to promote it (Hekkert, Negro, Heimeriks, & Harmsen, 2011). A large amount of empirical research has been conducted using a TIS lens for emerging clean energy technologies (Bergek et al., 2015; Bolton & Foxon, 2015; Edmondson et al., 2018; Hellsmark & Söderholm, 2016; Reichardt, Negro, Rogge, & Hekkert, 2016). The frame of analysis (institutional structure, actor configurations, system functional dynamics) allows for exploration of drivers of change, emerging trends, and both internal/external factors which may affect technological development (Hekkert et al., 2011).

Aside from understanding the structure and actor configurations of a TIS, understanding the functions within that system provide a valuable point of analysis. These functions represent the dynamics between actors and the structure. These functions include: entrepreneurial experimentation, knowledge development, knowledge exchange, guidance of the search, formation of markets, mobilization of resources, and counteracting resistance to change (Hekkert et al., 2011). These functions have interdependencies and dominances which are contingent on the technological development phase (i.e. pre-development, development, take-off, acceleration, stabilization)(Hekkert et al., 2011). For instance, knowledge development (F2) is considered the most important systemic function during the pre-development phase. Experimentation and entrepreneurial activity (F1) is deemed the most critical function during the development phase. It continues to be important in the take-off phase, and entrepreneurs need to pivot towards becoming systems builders, which involves establishing legitimacy (F7), mobilizing resources (F6), guiding the search (F4), and market formation (F5). During acceleration, market formation is the key system function (F5), with the system functions assuming supporting roles. Knowledge exchange (F3) continues all throughout. Policy instruments can be designed which specifically stimulate various functions. Implementation of policies which target the different phases simultaneously has been found to be an important factor in successful system building within the Swedish biorefinery industry (Hellsmark & Söderholm, 2016).

Recently, in a nod to Arthur Schumpeter, innovation scholars have argued for further distinction within the system functions, categorizing them into "niche creation" and "regime destruction" groups (Kivimaa & Kern, 2016). They propose a new analytical framework composed of eleven systemic functions, with seven to "creative" niche support functions, and four corresponding to "destructive" regime destabilization (Table 2). Policies which stimulate specific functions are also proposed, but the researchers do not distinguish between different types of policy instruments within the system function (Kivimaa & Kern, 2016).

Table 2: Creative and destructive innovation systems functions, an analytical framework (adapted from Kivimaa and Kern, 2016)

	PROPOSED SYSTEM FUNCTION (adapted from (Kivimaa & Kern, 2016)	EXAMPLES OF POLICY INSTRUMENTS WHICH TARGET IT (adapted from (Kivimaa & Kern, 2016)
Creative system functions	Knowledge Creation, development and diffusion	R&D funding schemes; subsidies for demonstrations, Innovation platforms and other policies aiming to increase knowledge creation and diffusion through networks; reference guidelines for best available technology, educational policies, Training schemes, coordination of intellectual property rights,
	Establishing market niches/ market formation	Tax exemptions, certificate trading, feed-in tariffs, public procurement, deployment subsidies, labelling.
	Price-performance Improvements	Deployment and demonstration subsidies enabling learning-by-doing; R&D support (cost reductions through learning).
	Entrepreneurial Experimentation	Policies stimulating entrepreneurship and diversification of existing firms, relaxed regulatory conditions for experimenting. Low-interest company loans, venture capital, Advice systems for SMEs, incubators
	Resource mobilization	Labour-market policies, R&D funding, deployment subsidies, low-interest loans, venture capital, Secondment of expertise.
	Support from powerful groups/ legitimation	Public procurement and labelling to create legitimacy for new technologies, practices and visions, innovation platforms, foresight exercises
	Influence on direction of the search	Targeted R&D funding schemes, regulations, tax incentives, goals set and framing in strategies, foresight exercises, voluntary agreements
Destructive system functions	Control policies	Import restrictions, Banning certain technologies, Taxes
	Significant changes in regime rules	Structural reforms in legislation or significant new overarching laws. Historic examples of major rule changes include the privatisation and liberalisation of electricity markets in the 1990s which completely changed the selection environment within which utilities were operating.
	Reduced support for dominant regime technologies	Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport).
	Changes in social networks, replacement of key actors	Policy advisory councils with niche actors (as attempted in the Dutch energy transition programme through the transition platforms) (Kern and Smith, 2008); formation of new organisations or networks to take on tasks linked to system change.

Borras and Edquist applied a typology of policy instruments to innovation policy. They place policy instruments into three general categories: regulation, economic transfer, and soft policies (Borras & Edquist, 2013). They discuss the importance of policy mixes in shaping innovation systems, stating that it is critical to structure policy mixes in such a way as to comprehensively address lagging or problematic system functions.

Table 3: Typology of innovation policy instruments, and examples. (adapted from Borras and Edquist, 2013)

TYPE OF POLICY INSTRUMENT	Policy Instruments Examples
Regulatory (Laws, rules, directives)	Regulation of statutory nature of the organisations, and researchers' employment regulations, competition (anti-trust) policy regulations concerning R&D and innovative activities by firms in the market, specific industrial sector regulations with effects on innovative activities
Economic transfer (Demand and supply side incentives)	Cash transfers, cash grants, subsidies, reduced-interest loans, loan guarantees, competitive research funding (industrial or basic research), tax incentives, en-block support of R&D, support to technology transfer, venture and seed capital, public procurement
Soft policy (Voluntary)	Voluntary standardization, public-private partnerships, codes of conduct, voluntary agreements, campaigns and public communication instruments

Foresights Approaches

Foresights

Foresight refers to a system- and future-oriented field of practice in which pathways are approached interactively, with the aim of arriving at a better understanding of the present trends which may affect it, and to open participant's strategic scope to previously unconsidered contingencies (Daffara, 2011; Foxon, 2013; Inayatullah, 2006; Inayatullah & Song, 2014; Patterson et al., 2017; Valdivia et al., 2015). Systems-orientation, in this instance, means that a holistic knowledge of the various systems (societal, normative, technical, economic, political, etc.) and their respective dynamics are considered when reasoning (Hebinck et al., 2018). The term "futures-oriented" implies that present strategy development, action, and decision-making is informed by a perspective which takes the future in account (ibid). This approach does not claim predictive ability. Rather, in the midst of a present full of uncertainty and complexity, the future-oriented perspective central to foresights helps actors understand the possibilities of various futures and plan accordingly in the present (Constanzo & MacKay, 2009).

The impact of a foresight exercise can be determined based on two primary criteria (Øverland, & Karlsen, 2010, p. 60). First, the knowledge acquired during foresight is incorporated into future strategy, policy, and action plans. Second, the knowledge acquired during the foresight leads to a more comprehensive understanding of present drivers and trends. Within the innovation systems literature, foresights exercises are argued to support "learning processes and exploration at multiple dimensions" and are deemed a valid instrument for stimulating the system function "Guidance of the Search" (Hekkert et al., 2011; Kivimaa & Kern, 2016).

According to Eerola and Jørgensen, the foresights approach is defined as:

> ". . . a systematic, future-oriented, analytical and interactive process contributing to shared visions concerning long-term developments." (2002)

By participating in foresight exercises, actors are expected to better structure their understanding of the ways in which knowledge is created/distributed within and between systems, driving forces and developing trends, market structure, and normative/broader societal factors which play into their real-world system of interest (Eerola & Jorgensen, 2002). In addition, group foresight exercises are useful in establishing a shared knowledge base and a line of communication between actors (Daffara, 2011; Eerola & Jorgensen, 2002; Hebinck et al., 2018). This helps connect their versions of an ideal future, and the improved network can then move forward on strategy and decision-making in a more unified manner (Eerola & Jorgensen, 2002).

There is a wide variety of techniques which are employed in foresights, and preferences differ based on geographic region of practice. As of 2007, the five most popular methods within the European Union include (in order): literature review, scenario planning, expert panels, futures workshops, and brainstorming. (Popper, 2008). Others include visioning, driver mapping, and policy stress-testing. For this research, visioning, driver mapping, and scenario design, and policy stress-testing will be introduced below.

Visioning Interviews

In visioning interviews, insights are sought from relevant actors within the area of interest. This is a useful approach for collecting different conceptualization of success and the factors they deem most relevant in getting there (GOS, 2017). While exact questions vary, the objective to have respondents describe their vision of success, as richly as possible, then subsequently describe the processes and factors which contribute to it.

Driver Mapping

Driver mapping consists of collecting what respondents mention as factors which influence a successful outcome in the research scope, then sorting it according to pre-determined, or co-determined criteria (GOS, 2017). Some common examples include PEST or STEEP analysis. It is a useful way to understand which drivers are considered important in achieving a systems or policy future.

Scenario Design

A common scenario exercise consists of combining two drivers of change, assigning end state descriptors for both drivers, then combining them in a 2x2 matrix to generate four scenarios. A series of guiding questions are then posed to the group, which are meant to encourage them to think creatively and flesh out what the issue area looks like in the future, given the circumstances provided by the directions of the drivers of change. Activities range from writing a brief narrative describing the scenario, naming the scenario, imagining global and local context, to discussing policy implications. Metrics can also be incorporated into scenario activities. It is a useful approach to developing an understanding of the many different pathways in the future and can remove cognitive blind spots which are cast by assumptions based in the present (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006; Inayatullah & Song, 2014).

Policy Stress-testing

Policymaking is a capital-intensive process, therefore it is a priority by policy actors to focus on designing and implementing policy which can be expected to achieve its outcomes under a variety of circumstances. Policy stress-testing is a means to test this, in which a series of policies are presented, then individual outcomes are imagined and discussed under various scenarios. Robust policy is the aim, and this method facilitates their identification (GOS, 2017).

Empirical Mapping

Energy Systems

The physical and commercial layers of energy markets are *detached*, meaning that the electricity purchased from a supplier is not the same electricity produced by the compensated supplier (Hijgenaar, 2016).

Electricity travels from the point of generation to a household via transmission and distribution lines. Transmission grids deliver bulk electricity from generation to substations, at a high voltage. At substations, current is transformed from one form to another (direct current to alternating current, and vice versa). Distribution lines deliver electricity at a lower voltage, from the substations to individual clients, such as households, businesses, or other buildings.

In the mid-90's, the liberalization of the electricity market across the European Union occurred during the same period as the foundation for the Dutch energy transition, a multi-actor initiative to reduce dependence on fossil fuels (Arapostathis et al., 2013; Hijgenaar, 2016; Loorbach, 2010; R. P. J. M. Raven, 2006). Within the European Union, the Netherlands has one of the most liberalized electricity market structures (Edens, 2017; Rijksoverheid, 2017). Electricity is supplied to households in the Netherlands by private energy suppliers, who source it over the wholesale electricity market. There is both a spot and futures market, in which distributors, producers, traders, brokers, industrial end-users can exchange trading volumes. The difference between the spot and futures market is that cash is immediately transacted in the spot market, whereas the futures market is settled at a later date from the original transaction. Distribution grid operators (DGOs) are typically enforced monopolies for a given region. They are responsible to maintaining the grid and balancing load throughout. The transmission system is managed by a single party, and this role is regulated. There are day and night tariffs for electricity, and they are set in a competitive market by private energy suppliers, with oversight provided by the Dutch Authority for Consumers and Markets (ACM). The two prices exist to encourage end-users to consume less electricity during peak-demand hours (IEA, 2014; Rijksoverheid, 2017).

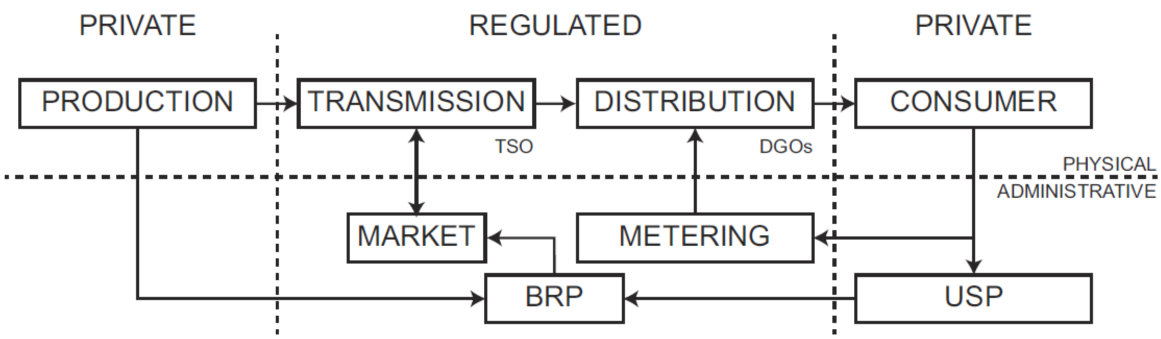

Figure 5: Schematic of Dutch electricity market structure, liberalised and regulated areas (from Hijgenaar, 2016)

In both government-run and liberalised energy markets, there are several key tasks: scheduling generation, balancing load, and settlement. A persistent issue is the opacity of costs, whether they reflect the truly optimized cost of doing business, or whether they are providing life support for inefficiencies and value extraction (Munsing et al., 2017; Neuteleers, Mulder, & Hindriks, 2017). These are conducted by trusted central authorities, with a host of conflicting interests. For instance, an investor-owned utility has an interest in reducing costs, improving upon and delivering reliable service, and providing value to shareholders (Edens, 2017; Munsing et al., 2017). Regulation exists to varying degrees across countries in checking and balancing these motivations.

Seeking to increase efficiency and better manage electricity grids, there has been an impetus towards "smart grids". Massoud defines the key capabilities of a smart grid as having the capacity to monitor and report energy usage data in real time, identify potential problems before they result in outages, and rapidly isolate outages or grid failure, so that it doesn't affect the broader network (Massoud, 2015).

To transform the electrical distribution system into a "smarter" grid, smart meters initiatives have been rolled out over the past decade. Smart meters are devices which collect energy consumption data at the household level and present it over time. Using data from smart meters, utilities can make more informed decisions for provision of capacity. The Dutch government has stated its plans to meet the smart metering requirements set out by the European Commission, of 80% penetration of smart meters in households by 2020 (EU Directive 2009/72/EC). Distribution grid operators are leading this effort. Other countries, such as Estonia, have already achieved 100% smart meter penetration, while many others are still further behind in achieving their objectives than the Netherlands.

Distributed Ledger Technology

Distributed ledger technology (DLT) is an umbrella term for record-keeping systems which maintain a decentralised consensus, and records added to the network are rendered immutable by means of encryption. Blockchain technology and directed acyclic graphs (DAGs) fall under this category, but blockchain is often used interchangeably with distributed ledger technology.

Blockchain technology emerged in the past decade, and is a distributed, decentralised, linear, and immutable ledger. It enables greater transparency and autonomy in transactions, removing the need for a trusted third party. It first came to public knowledge following the publishing of Satoshi Nakamoto's whitepaper, "Bitcoin - A Peer-to-peer Electronic Cash System" (2008). Transactions can be conducted directly between two individuals, without the need for a mediating third party. Once the authenticity of the contents and sender are confirmed by members of the network, the transaction is validated and cryptographically connected to previous confirmed transactions, referred to as a blockchain. When this occurs, all members of the ecosystem have their ledger, or record of transactions, updated to reflect the new addition.

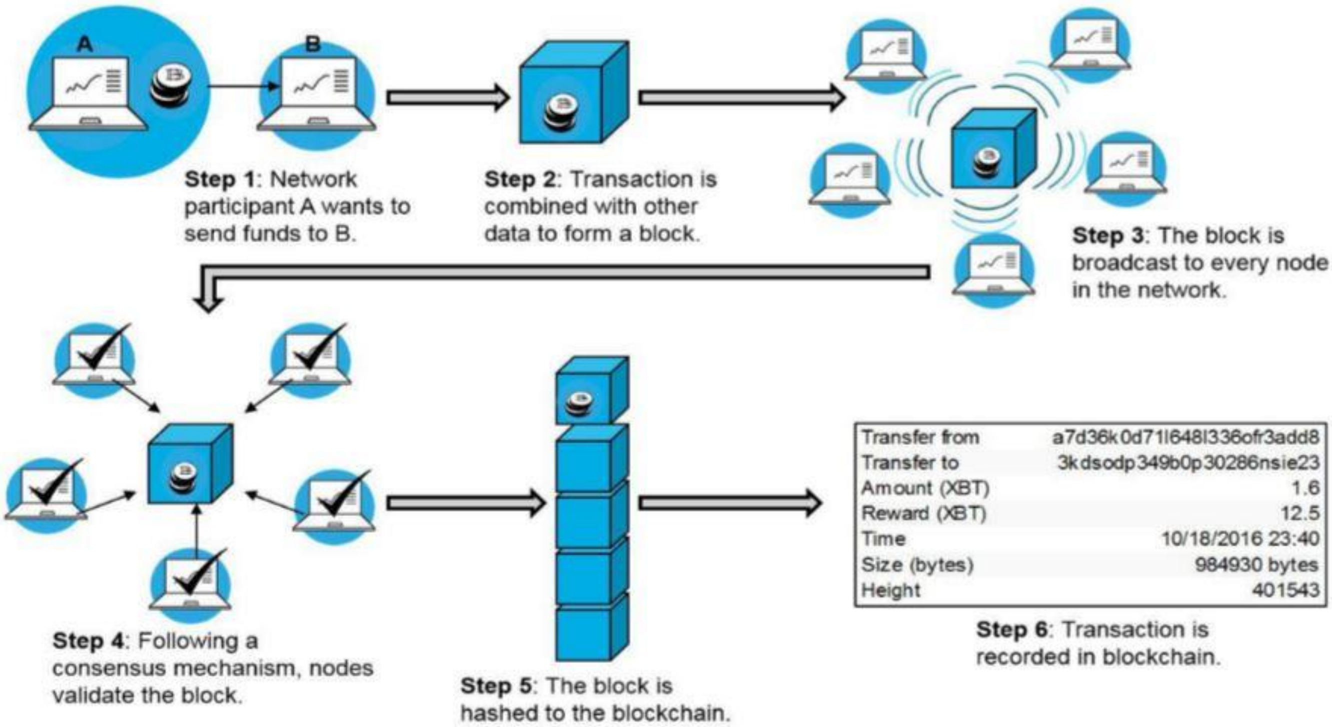

Figure 6: Schematic of how a transaction is processed in a blockchain network (Source: Bloomberg New Energy Finance, 2017)

Blockchain differs from a database[2] primarily in that a blockchain is immutable, meaning that once a block is added to a chain, it is extremely computationally intensive to decrypt and alter. It becomes exponentially more difficult with each block degree of separation in the chain. Each block in the chain is identified by a unique block header of a constant length. Part of this header consists of a hash referring to the previous block., connected by a unique hash identifier[3]. The contents of the previous block are used to create the hash connecting it to the next. A different input would result in a different hash. If somebody were to succeed in altering a transaction, it would cause a cascade of rehashes, leading to all the identifying headers of all subsequent blocks to be changed.

Consensus Mechanisms

For a transaction to be added to a block, and then for that block to be added to the chain, the computers within the network require a means of arriving at a consensus on the validity of the identity of the individual requesting the transaction and the contents of the transaction itself(Nakamoto, 2008). Definitively demonstrating the validity of the transaction involves authentication of the sender and of the transaction data. This is achievable in various ways, using what is known as a "consensus mechanism". There are three commonly explored means of confirming the validity of transactions in a blockchain:

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[2] There do exist append-only and read-only databases.
[3] A calculation which returns a unique string of characters of equal length, regardless of the input.

Proof of Work, Proof of Stake, Proof of Authority. There is another form of distributed ledger technology, known as *directed acyclic graphs* (DAGs).

Proof of Work

The principle at the core of PoW is that the more computation power you have, the more mining nodes are running, the higher the likelihood that you will arrive at the same hash (Nakamoto, 2008). There is no preferential method of selecting which node is responsible for confirming the transaction, but a more powerful processor will be able to proceed through a quicker succession of calculations. The most efficient mining unit currently available on the market averages approximately 0.25-0.3 Gigahashes/Watt (Gh/W). This is the consensus mechanism used in in the Bitcoin network. While currently considered the most secure and decentralised consensus mechanism, there has been a recent outcry over the energy consumption of these types of blockchains. To get a rough approximation of the energy consumption of the Bitcoin network, a brief calculation is performed below. If we assume that the average hash rate (measured in Terahashes per second – the amount of hash calculations which can be conducted within the span of one second) over the November 2017-2018 period is ~40 million Terahashes/second (source: blockchain.com), and all the mining units operate at 0.25 Gigahashes/Watt, then the total energy consumption would be 576 Terawatt-Hours (TwH). This is greater than the total EU generation of electricity from renewable sources in 2015 (EUROSTAT, 2016). Other factors, such as suboptimal processing capacity, energy consumed for climate control, and geographical region in which the mining takes place, could mean that the energy consumption is higher than this estimate. A new block is added to the longest chain once every ten minutes.

Proof of Stake

Like the notion of holding shares of stock, the key principle behind PoS is that the more ownership you have in the network (i.e. the more stake, in the form of tokens), the higher your probability of being assigned a block to verify (Hijgenaar, 2016). The average block time is fifteen seconds. This consensus mechanism consumes considerably less energy than Proof-of-Work but is not truly decentralised.

Proof of Authority

Consensus is not calculated but confirmed by designated nodes within the network (Li, Jiang, Chen, Luo, & Wen, 2017). There are authorized nodes which confirm the transactions to be added to the chain, while other users can still transact within the network. The authorities are not required to own stake in the network, but rather must have their real identities confirmed and notarized, effectively staking their identity. A majority confirmation is required from all the authority nodes in the network. The process of automated, and the sole requirement of the validator node is to maintain point security. As of writing this, average block time is five seconds. This consensus mechanism has also been proposed as a more energy-efficient alternative to Proof-of-Work. However, it is also not truly decentralised.

Directed Acyclic Graphs (AKA Tangles)

The validity of transactions in DAGs is maintained by having new transactions be cryptographically linked to two older transactions (Florea, 2018). These transactions don't have to necessarily both be the newest entries, so a new transaction can be linked to a recent entry in addition to an older one, hence the concept of the *tangle*. This is claimed to be the fastest transaction speed out of all consensus mechanisms, and lowest energy consumption (Florea, 2018).

Regardless of the consensus mechanism used, transactions are linked to each other in a unique way. If a malicious actor were to attempt to tamper with a block (for example, changing the designee of a particular transaction), they wouldn't only have to be able to change the contents of one ledger, but rather would have to change the records maintained by the majority of nodes in the network. Contrary to the widespread misconception of Bitcoin criminals operating in the shadows, blockchain technology is not anonymous. Previous transactions are searchable, with the identity of the individuals involved known insofar as the receiving address.

While the first implementation of blockchain was the cryptocurrency Bitcoin. Aside from currency, blockchain technology has applications across many industries, wherever a reliable record and peer-to-peer transaction are desired.

Technical Concerns

The Institute of Electric and Electronics Engineers, the world's largest association of engineering and technology professionals, recently published a position paper on the developmental priorities for blockchain technology, and their key security concerns include regulation compliance, security of consensus mechanisms, security of smart contracts, privacy of on-chain data, and fault tolerance of the hardware used to maintain blockchain networks (Zhang et al., 2018).

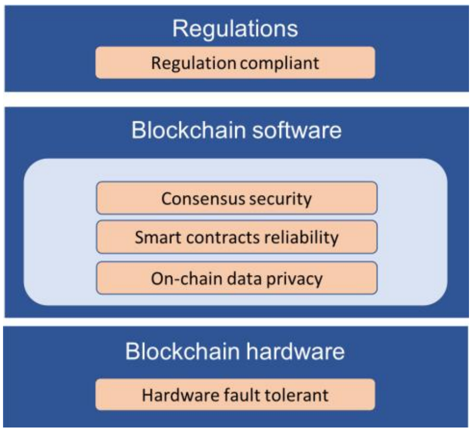


Figure 7: IEEE list of developmental priorities for blockchain technology (Zhang et al., 2018)

Societal Gap

The European Parliamentary Research Service published an exploratory report in February 2017 about how blockchain technology can change European life (Boucher et al., 2017). While there was no specific mention was made of applications to the energy sector, several strategic recommendations about the general applications of blockchain were made; namely to introduce regulatory certainty in order to facilitate product development, stating that:

> *"The key to smart regulation in such an environment of dynamic innovation is for the regulator to develop sufficient capacity…Pre-emptive and heavy-handed regulation that would stifle growth should and can be avoided. But such a* ***smart regulatory regime based on analytical excellence and proportionality must not be confused with light touch regulation****: rapid and forceful regulatory measures need to be part of the toolkit in order to address risks before they become systemic"* (Boucher et al., 2017)

For the first time in history, enough individuals are generating their own power that there now exists a demand for peer-to-peer trading, instead of purchasing power from traditional energy suppliers. The significance of blockchain to energy trading has been recently acknowledged by the European Commission (Ioannis et al., 2017; Kounelis et al., 2017); however, the Dutch government hasn't thus far taken any clear steps, with respect to blockchain and energy markets. The societal gap remains in understanding which factors are important to enabling a wider range of ways for individuals to engage and transact with their energy in ways that they want, without sacrificing reliability of supply or grid balance.

Research Gap

Several studies have investigated the potential of a blockchain-enabled energy system. From a technical standpoint, peer-to-peer energy trading models on a blockchain have been proven to work, on the scale of demonstration experiments and pilot projects ((Hijgenaar, 2016; Kounelis et al., 2017; Mengelkamp, Gärttner, Rock, et al., 2018; Mengelkamp, Gärttner, & Weinhardt, 2018). Meanwhile, three studies have approached blockchain energy solutions from a futures perspective. One scenario design study, via focus groups with industry experts, identified decentralisation/centralisation and technological innovation/technological stasis as the key trends affecting blockchain development (Voets, 2017). Hocjkova et al. conducted a literature review of energy market trends, identifying three idealised transition endpoints: off-grid future, highly decentralised and interconnected smart grid, and a massive, centralised "super-grid" (Hojčková, Sandén, & Ahlborg, 2018b). Another study called for a future vision of energy/blockchain regulation, and made general recommendations (NERA, 2018b). They all called for further research which contributes to an understanding of future policy and governance factors relevant to a low-carbon energy systems transformation.

Methodology & Analytical Approach

In developing the research strategy for this project, it was important to integrate the theoretical considerations of innovation science, various governance theories, and futures theory with the nature of the empirical context. Once more, the objective of this research is to investigate the governance and policy implications of distributed ledger technology on the energy transition. Given the amount of flux and the rush of energy system actors to meet their targets while safeguarding their respective priorities, the integration of this technology introduces further unknowns.

The primary question lies in understanding systems change. Rather than speculating narrowly into the future, a wide net, in which a broad range of factors are considered, ought to be cast. Previous studies have identified "rate of innovation" as an important driver in DLT-enabled energy futures, however, this research seeks a deeper understanding of precisely what that may entail (Voets, 2017). This requires a systemic lens, and knowledge from actors in distributed ledger technology and markets, technology, policy, and innovation within energy systems. For this reason, the multi-level perspective and creative/destructive functional dynamics of innovation systems are used to ground the research analytically, providing more granular information on innovation processes. Common methodological approaches in the innovation systems are literature reviews or semi-structured interviews in which industry actors are asked to share their observations and perspectives of development in their field (Bergek et al., 2008; Hellsmark & Söderholm, 2016). With a well-defined line of inquiry, it is possible to gain insights into the dynamics between and at the various levels.

Additionally, the importance of clear governance has become increasingly recognized. For this reason, this research aims to understand what form a governance arrangement in a DLT-enabled energy system might take. Institutional, actor, and content features all need to be known in order to identify a governance mode, therefore this needs to be sought out in data collection. We also want to conduct this in a participatory way, in order to directly understand how industry actors conceptualize change in governance arrangements.

At the suggestion of one the supervisors for this research, participatory foresight exercises were included in the research strategy. Government agencies and businesses alike have used these methods since the post-World War Two period in order to understand what the future may bring, and which contemporary forces may shape what is yet to come (GOS, 2017; Hebinck et al., 2018; Reed et al., 2013; Shell International B.V., 2008). Policy outcomes can differ when landscape variables shift (Borras & Edquist, 2013; Reichardt & Rogge, 2016). Therefore, it is of interest to identify policies which are robust across a multitude of futures. Moreover, it is important to identify policies and governance approaches which may enable desirable futures. This then elicits the question, what do system actors deem desirable futures?

Foresight workshops can be used as both as an expository and analytical tool. Drivers of change, collected from earlier stages of research, can be fed into the workshops as guidance material for futures ideation. Workshop participants can then create scenarios using those drivers, and then use the scenarios as an analytical lens through which to evaluate the strengths or weaknesses of various governance approaches and policy measures. Foresight methods are theory-agnostic, and frameworks from other disciplines (i.e. Technological Innovation Systems, Multi-level Perspective, Earth System Governance). Combination of foresight techniques has been found to contribute to a richer understanding of drivers or change and pathways to imagined futures (Keenan, n.d.; Milojević & Inayatullah, 2015; Pouru, Dufva, & Niinisalo, 2018).

When conceptualized within the domain of systems transformation, participatory foresight exercises are attested by scholars as both an investigation and an intervention (Hebinck et al., 2018). It can help system actors "get ahead" of the future. Imagining something which one would normally not consider (ex. a scenario in which the physical effects of climate change are catastrophic, yet people are willing and eager to sharing information between each other) forces consideration of factors which were previously deemed irrelevant. It also opens of channels of communication between previously disparate actors, helping to identify discontinuities in conceptual framings of a shared issue. Therefore, this research would serve a dual purpose, both collecting data from the participants, while inserting a designated space for futures-oriented thinking, minimally encumbered by the constraints of the present. Policy foresight exercises can support long-term planning efforts, in addition to facilitating design of innovative policy mixes. Since distributed ledger technology is relatively immature, a rare opportunity is presented- the guidance of the search may still be shaped, and new connections between energy and DLT professionals can be fostered.

Kramer emphasizes the need for venturing beyond technological and business conceptualizations of innovation in devising energy scenarios (2018). He also reiterates the breadth of the scenario space. For this reason, we decided to structure the foresights workshops in such a way as to maximize the diversity of energy scenarios created.

The Dutch electricity market presents a promising case study for understanding future energy systems governance, since the market is already extensively liberalized. Therefore, the policies proposed would be to advance the sector, rather than to catch up to other market examples. For foresight exercises, this is advantageous, enabling us to cast forward scenarios from a conceptual promontory point.

Summary of Methods

This research used a literature review, followed by semi-structured visioning interviews, driver mapping, scenario design, policy stress-testing, exit surveys, follow-up interviews, external expert interviews, and post-interview synthesis.

Eighteen visioning interviews were conducted, the majority of which were completed prior to the scenario workshops. Driver mapping was conducted by the researcher, to reconstruct drivers of change from the interviews. In mid-July, two independent scenario workshop sessions were run, with a total of eighteen participants (twelve in Utrecht, and six in Rotterdam, respectively). Following the workshops, ten follow-up interviews with participants were conducted, along with seven external consultation sessions with subject area experts. Additionally, seven unrecorded open interviews were conducted with blockchain, energy, and innovation experts.

Analytical Approach

Qualitative content analysis and open coding in NVIVO was used to identify blockchain use cases, drivers, visions, barriers and opportunities for change, potential regulatory steps and governance approaches. Administration of the project was conducted using Excel.

The foresights workshops themselves served both as a creative and analytical space. The scenarios were created in the workshop, and were subsequently used to analyze the policies gathered from Stage One. The follow-up interviews allowed participants to reflect on their decisions in the workshop, and to share any learning that may have occurred in the space between the workshop and interview. It also allowed individuals to more deeply outline their perspectives on regulation and transformation within the digital world and energy systems. The external consultations were used to provide further reflection on the output of the workshops, and provided a degree of validation on the perspectives shared by the workshop participants.

The overall research framework is as follows, and can been examined visually in the figure below (Figure 8). Visioning interviews were used to collected drivers of change and proposed policies for a sustainable energy future. The drivers of change were then sorted according to STEEPLE criteria and by the socio-technical system level as described in the Multi-level Perspective literature. These sorted drivers were then presented at the scenario exercise, where they were used to create scenario matrices and guide futures thinking. The scenario exercise generated descriptions of various energy futures, and DLT use cases identified within. Policies collected from the visioning interviews were presented following the creation of scenarios, and then run through stress-testing in selected DLT-present scenarios. This generated an understanding of which policies are expected to be robust or redundant under various circumstances. The policies identified as robust were categorized by policy instrument type, as described by Borras and Edquist in the innovation policy literature (2013). They were further categorized by creative/destructive innovation system functions as proposed by Kivimaa and Kern (2016). The scenarios which were selected for policy stress-testing and in follow-up and external interviews were analyzed for governance mode, based on descriptions of actor networks, policy instruments, policy levels, and institutional features (Driessen et al., 2012). Transition pathways were identified in these same scenarios, based on criteria established in the sustainability systems literature, namely pressure from landscape factors, regime tensions, and niche maturity and relation to the regime (Geels & Schot, 2007). Transformative potential of DLT use cases was assessed in follow-up and external interviews. The synthesis of these data streams led to collection of relevant DLT use cases, underlying drivers of change, policy mixes, and governance modes within a sustainable energy systems transformation.

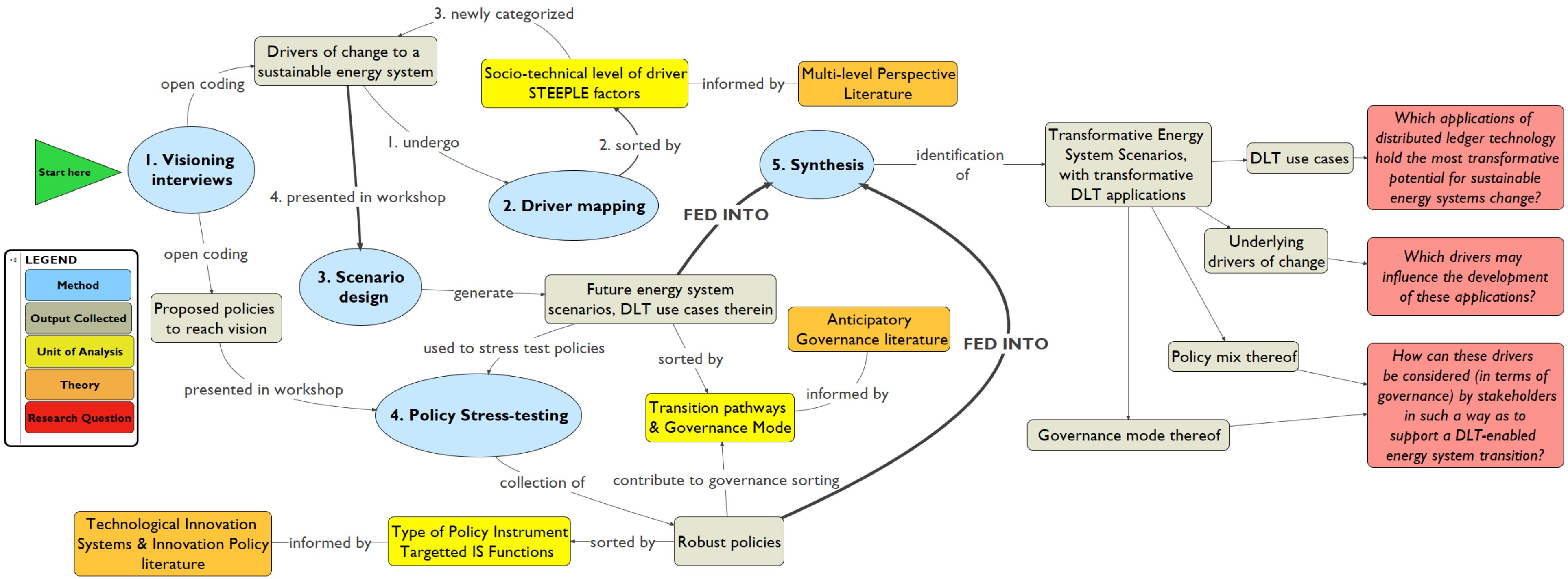


Figure 8: Research framework. Starting point is next to the green triangle. Blue: data collection method, Grey: data collected, Yellow: unit of analysis, Orange: supporting theory, Red: research questions.

For analyzing the proposed policies, we combined the analytical framework proposed by Kivimaa and Kern with the innovation policy instrument typology proposed by Borras and Edquist ((Borras & Edquist, 2013; Kivimaa & Kern, 2016).

Table 4: Analytical framework for creative and destructive systemic function, examples of policy instruments (and the type thereof) which target it.

	PROPOSED SYSTEM FUNCTION (adapted from (Kivimaa & Kern, 2016)	EXAMPLES OF POLICY INSTRUMENTS WHICH TARGET IT (adapted from (Kivimaa & Kern, 2016)	TYPE OF POLICY INSTRUMENT (adapted from (Borras & Edquist, 2013)
Creative system functions	Knowledge Creation, development and diffusion	Training schemes, coordination of intellectual property rights,	Regulatory
		R&D funding schemes; subsidies for demonstrations	Economic transfer
		Innovation platforms and other policies aiming to increase knowledge creation and diffusion through networks; reference guidelines for best available technology.	Soft policy
		Educational policies	Flexible
	Establishing market niches/ market formation	*Not characterized.*	Regulatory
		tax exemptions, certificate trading, feed-in tariffs, public procurement, deployment subsidies, labelling.	Economic transfer
		Not characterized.	Soft policy
	Price-performance Improvements	*Not characterized.*	Regulatory
		Deployment and demonstration subsidies enabling learning-by-doing; R&D support (cost reductions through learning).	Economic transfer
		Not characterized.	Soft policy
	Entrepreneurial Experimentation	Policies stimulating entrepreneurship and diversification of existing firms, relaxed regulatory conditions for experimenting.	Regulatory
		Low-interest company loans, venture capital	Economic transfer
		Advice systems for SMEs, incubators	Soft policy
	Resource mobilization	Labour-market policies	Regulatory
		R&D funding, deployment subsidies, low-interest loans, venture capital.	Economic transfer

		Secondment of expertise.	Soft policy
	Support from powerful groups/ legitimation	*Not characterized.*	Regulatory
		public procurement and labelling to create legitimacy for new technologies, practices and visions	Economic transfer
		Innovation platforms, foresight exercises	Soft policy
	Influence on direction of the search	*Not characterized.*	Regulatory
		Targeted R&D funding schemes, regulations, tax incentives	Economic transfer
		Goals set and framing in strategies, foresight exercises, voluntary agreements.	Soft policy
Destructive system functions	Control policies	Import restrictions, Banning certain technologies	Regulatory
		Taxes,	Economic transfer
		Not characterized.	Soft policy
	Significant changes in regime rules	Structural reforms in legislation or significant new overarching laws. Historic examples of major rule changes include the privatisation and liberalisation of electricity markets in the 1990s which completely changed the selection environment within which utilities were operating.	Regulatory
		Not characterized.	Economic transfer
		Not characterized.	Soft policy
	Reduced support for dominant regime technologies	*Not characterized.*	Regulatory
		Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport).	Economic transfer
		Not characterized.	Soft policy
		Not characterized.	Regulatory
		Not characterized.	Economic transfer

	Changes in social networks, replacement of key actors	policy advisory councils with niche actors (as attempted in the Dutch energy transition programme through the transition platforms) (Kern and Smith, 2008); formation of new organisations or networks to take on tasks linked to system change.	Soft policy

Visioning interviews

Recruitment

Approximately eighty people were contacted for an hour-long semi-structured interview, with fifteen agreeing to participate, and ultimately contributing. Representation was sought from the following sectors:

- Venture capital/Finance
- Utilities
- Energy service providers
- Energy regulation
- Academia
- Blockchain energy companies
- Blockchain solution providers

Participants were found through online investigation and snowball technique from earlier interviews:

- Event speakers:
    - Event Horizon 2017 & 2018, a blockchain energy conference
    - Grid Edge Innovation Summit
    - Women in Cleantech & Sustainability event
- LinkedIn
- Literature review
- Snowball technique, referral from earlier interviewees

Individuals were selected based on satisfying one or more of the following criteria

- Has been an invited speaker at a conference or seminar on the topic of DLT and energy
- Has published a peer-reviewed article on DLT and energy
- Actively contributing to a DLT energy project
- Part of a company or research group which is investigating DLT
- Part of a company or research group which is investigating disruptive energy system models

Interviews were semi-structured, and typically lasted one hour. Responses were written in shorthand, and then transcribed later. The transcriptions were later stored and coded using NVivo software.

7 Questions Interviews

In order to gather visions of a 2050 low-carbon future, a modified version of the "Seven Questions" interview from the "Futures Toolkit" was used (GOS, 2017):

The original “7 Questions” interview format is aimed at gaining strategic insights from a wide range of stakeholders into the following areas (GOS, 2017; Shell International B.V., 2008):

- The critical issues for the policy or strategy area being considered
- What a favourable outcome is
- What an unfavourable outcome is
- The key operational, structural and cultural changes that need to be made to deliver the favourable outcome
- Lessons from the past
- Decisions which must be prioritized
- What the interviewee would do if (s)he had absolute authority

Four questions were added to this format, in the “System Position and Journey” section, which were aimed at understanding the respondents’ position within industry networks, and their involvement in blockchain/DLT. From a multi-level perspective, any connections the interviewees may have between incumbent organisations, innovation niches, and the exogenous landscape are also of interest as a source of systems insight. Interviewee perspectives on blockchain development in the energy sector might be partially influenced by the subject’s placement and affiliations within the socio-technical system, so this information was collected. In addition, the timeline of initial introduction to the topic and deeper involvement is of interest. This is since the factors motivating the interviewees to proceed from a subject awareness to research and development may provide further insights into the stakeholder journey in the blockchain space. Understanding what drives individuals from different points within the overall energy socio-technical system to get more deeply involved in blockchain in the energy sector may help inform future engagement strategy or policy decisions.

Interview Structure

Table 5: Visioning Interview structure

System Position and Journey 1. State any affiliation you have in the energy and/or blockchain industry (speaking roles, business associations, non-profits, etc.), aside from your primary function 2. When and how did you find out about blockchain technology? 3. When did you begin actively researching and/or contributing to it? 4. What motivated this greater engagement? **Futures Questions** 5. Describe to me your ideal vision of a sustainable energy system in the year 2050. You may describe specific locational contexts or in a more general global context. a. What is the energy mix? b. What kind of technologies are in use? c. Who is responsible for generation, distribution, balancing? d. How (generation, distribution, and balancing) is this done? e. Does blockchain have a role to play here? If so, what and why? If not, why? 6. If you had the opportunity to travel to that 2050 future previously described, and to ask a fully-informed, completely objective individual about the energy system, what would you ask them? 7. What some uncertainties you identify in the transition from the current state of the energy system to the 2050 vision previously described? 8. What have been some false starts in the past which you believe have hindered progress towards a desirable energy future? 9. What are some shifts in normative, regulatory, and market factors that, if made, would facilitate this transition? 10. What are some actions relating to those same factors which could be made now or in the near future? 11. If you were able to develop the energy system in exactly the way you wanted to, without resource or institutional constraints, what would you do?

Creation of Prototypical Pathway

Drivers, uncertainties, and emerging trends were selected which were implied to be important to increasing the share of RES in the energy mix, optimizing distributed energy resources, reducing GHG emissions, end-user satisfaction, market/government player buy-in, blockchain development, blockchain integration into the energy sector. They were then sorted according to STEEPLE criteria, consisting of the following dimensions:

- Social
- Technological
- Environmental
- Economic
- Political
- Legal
- Ethical

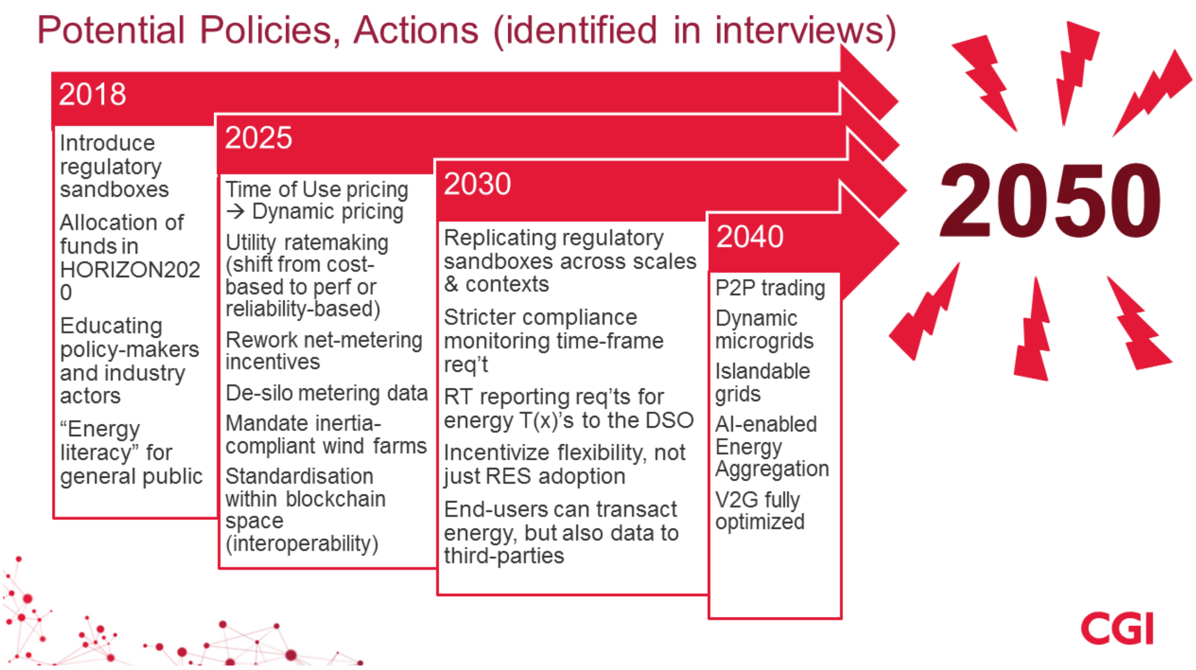
Typically, STEEP criteria are more commonplace in coding forces which may affect a given organisation. The "Legal" and "Ethical" dimensions were included for several reasons. The legal aspect of a blockchain-integrated energy system is a relevant dimension to include in this research due to the abundance of legal ambiguity and flux currently within the blockchain space. Countries differ greatly in their legal approach to blockchain technology, and even the purview within the blockchain realm. For example, cryptocurrencies are an aspect of blockchain which experience the most legal scrutiny, with some nations recognizing them as a security, while others ban them altogether. However, the legal dimension relevant to blockchain in the energy sector is contingent on legal action related to use cases (ex. Legally-recognized energy traders on the market). Since the legality of explicit blockchain applications or use cases which would be potentially transformed by blockchain, is continuously changing, this was included as a relevant dimension for drivers of change. Inclusion of an ethical dimension was also included in order to reflect the recent public and governmental concern over user data and privacy.

Drawing upon the Multi-level perspective of sociotechnical change, the drivers were also categorized by systems level: niche, regime, and landscape.

Specific policy proposals and technological developments, along with more generally described regulatory or market shifts, were collected. Also collected were any explicit mentions of timepoints (ex. '…by 2030, we expect that….', 'assuming we meet the 2050 goals, there will be…') and connection made by the interviewee with a policy or an organisational action. Following policy selection in the workshops, those policies were categorized by the specific innovation system functions they are intended to target. The policies were also categorized in three policy instrument categories laid out by Borras and Edquist: regulatory, economic transfer, and soft policy.

For the first iteration, policies were included which were either mentioned by at least three respondents. The period between 2018 and 2050 was divided into four periods: 2018-2025, 2025-2030, 2030-2040, 2040-2050.

Table 6: The policy pathway presented to workshop participants.



Workshops

Workshop Recruitment

The participatory foresight workshops simultaneously served as a level of analysis for the data collected during the visioning expert interviews, in addition to generating new knowledge for the follow-up interviews and external expert consultations which followed.

Participants for the workshops were recruited by the following means:

- Posts on LinkedIn, both on the researcher's personal accounts and the company page
- Creation of a landing page on the CGI Group website with an invitation
- Email

Knowledge of blockchain was not a prerequisite. The primary prerequisite was knowledge of the energy sector. The reason this was done was because it was deemed more important that participants know the types of use case blockchain or other DLTs might enable, rather than the technical details. Members from diverse stakeholder groups were invited to the workshops: energy cooperatives, transmission system operators, distribution system operators, energy suppliers, consultancies, academia, and start-ups.

Participant Intake

During the week preceding the workshop, intake interviews were conducted with each participant. Participants were informed in greater detail about the workshops and the research aim and given the option to continue with the interview or decline further involvement. If they remained interested in participating, then they were run through a series of rapid-fire questions aimed at establishing their area of knowledge.

A concept, such as "Balance Responsible Party", was stated by the interviewer. If the prospective participant felt comfortable enough to be able to define and briefly explain the concept to another individual, then they were asked to respond with "Yes". If they were not familiar enough with the concept to explain it to another person, or if they wished to receive further information, they were asked to respond with "No". Subjects covered included the energy sector (various industry players, technologies, and energy transition concepts), blockchain, and sustainable development agreements. In the blockchain section, prospective attendees were also run through several True/False questions centered around common misconceptions of blockchain.

Table 7: Pre-workshop Screening interview structure. Workshop participants were placed into groups of three with complementary subject-area knowledge, as determined based on these questions.

Pre-Workshop Screening Interview Structure
1. Please answer (Yes) or (No) at the mention of each concept or entity. A "Yes" answer should only be given if you feel absolutely comfortable explaining this concept to anybody. Any "Maybe" or "It Depends" answers will be counted as "No".

a. Energy
    i. Distribution System Operator
    ii. Transmission System Operator
    iii. Balance Responsible Party
    iv. Energy Aggregation
    v. Energy Supplier
    vi. Frequency Control
    vii. Smart Meter
    viii. Internet of Things
    ix. Energy Storage
    x. Smart Storage
    xi. Electric Vehicle as Storage
    xii. Prosumer
    xiii. Curtailment/ Negative Energy Prices
    xiv. Net Metering
    xv. Demand Response
    xvi. Load-balancing
    xvii. Peak-shaving
b. Blockchain/Information Technology
    i. Trustlessness
    ii. The difference between Bitcoin and blockchain
    iii. Token
    iv. Ethereum
    v. Smart Contract
    vi. Consensus Mechanism
    vii. Proof of Work
    viii. Proof of Stake
    ix. Proof of Authority
    x. Off-chain Transaction
    xi. Typical meta-contents of a block
    xii. Fork
    xiii. Zero-knowledge proof

xiv. Self-sovereign Identity Management xv. Cloud Computing c. Sustainable Development i. Paris Agreement ii. Energy Transition iii. HORIZON2020 (this is specific for the EU context) iv. United Nations Sustainable Development Goals
2. Please answer "True" or "False" to the following statements a. All blockchain records are decentralised b. The contents of a blockchain are Mutable c. There is only one blockchain in the world d. A blockchain can be public or private e. A blockchain can be permissioned or non-permissioned

The results of the intake interviews served two purposes. First, it enabled the researcher to compile a customized information packet for each attendee, to ensure that they received minimally redundant information in preparation for the workshop. This information packet consisted of a combination of brief paragraph definitions of some of the concepts or technologies covered, links to gray literature (industry/governmental organisation web pages covering the topic), and online video tutorials about certain aspects of the energy system and/or blockchain. The customized nature of the packet was emphasized to participants, in the hopes of increasing the chance that they will read through all the information provided to them. The second purpose of collecting these data was in order to create complementary group assignments, in which each group member brought a different area of expertise to the table. Six groups (four for the Utrecht Workshop, two for the Rotterdam workshop) consisting of three people each were created.

Workshop Structure

The workshop began with participants introducing themselves to the rest of the group. It was followed by an introduction to blockchain use cases within the energy sector, and mention of organisations and projects currently operating within the space. The objective of the research and accompanying research questions were reiterated at this point, followed by an overview of the workshop structure. It was repeatedly emphasized that the workshops are about co-creating knowledge, and that participants should feel welcome to voice their thoughts whenever they so choose.

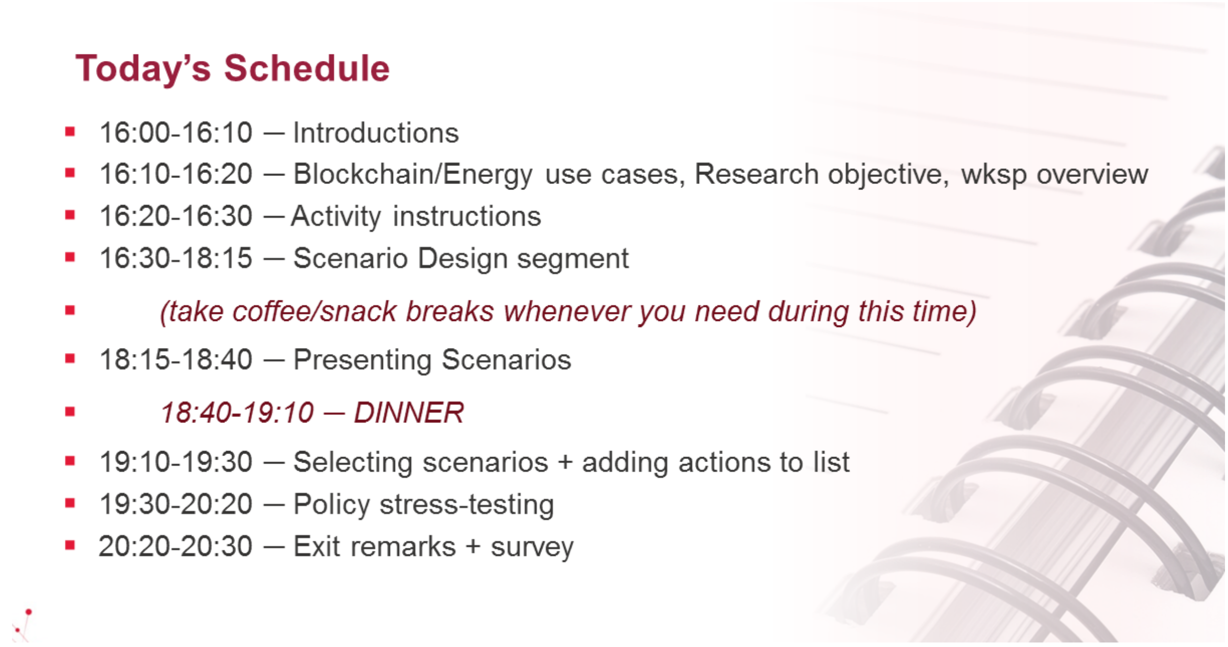


Figure 9: Schedule for both foresight workshops.

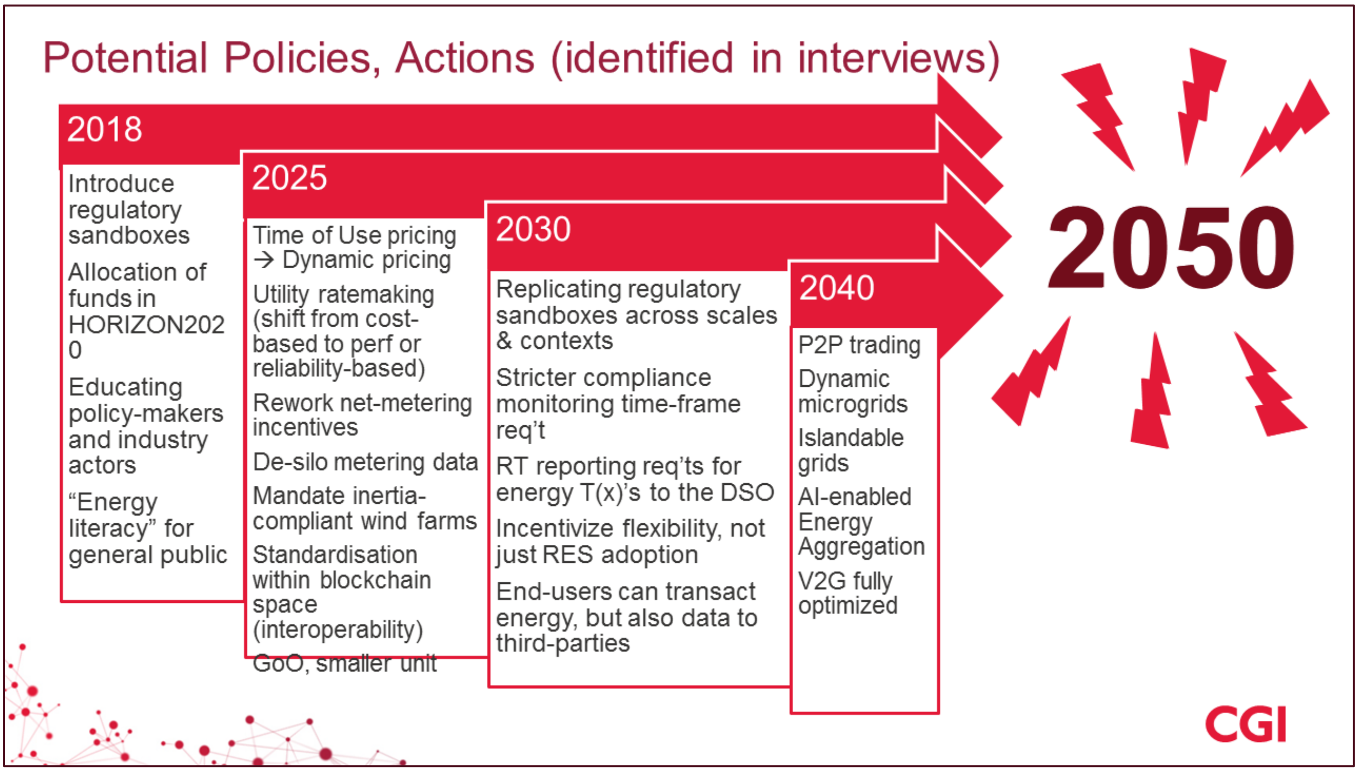
The drivers collected from the pre-workshop interviews were then presented to the group, in addition to a brief overview of the prototypical policy pathway. At this point, a feedback period was included to allow for participants to comment on or propose new drivers. Group assignments were announced, then each group was asked to indicate their two preferred drivers. Workshop materials, namely a scenario matrix, a Porter's 5 Forces chart for each scenario, and a sheet to describe the global/Dutch contexts under each scenario, were distributed and each group proceeded to flesh out their scenarios over the course of a ninety-minute period. The researcher circulated regularly around the groups, listening to their thought process, offering clarifications or making suggestions when needed. Once complete, the groups returned to the common room and presented their scenarios in plenary fashion. Each presentation consisted of a brief summary, identified potential blockchain use cases, and recommended actions or considerations for each scenario.

Figure 10: One of the main slides presented to workshop attendees for the scenario design exercise.

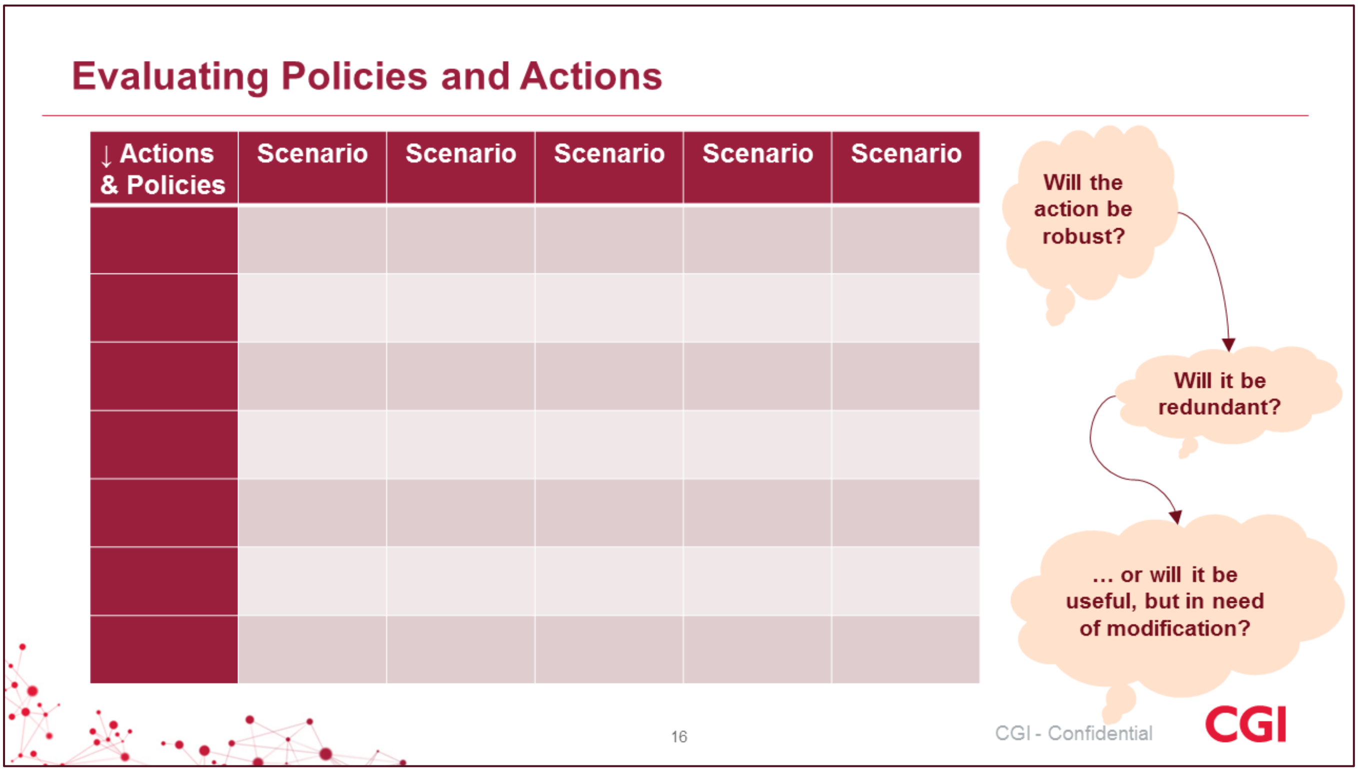
A group dinner immediately followed the presentations. During the dinner, the researcher collected all the scenarios in which blockchain use cases were identified. When participants returned, these scenarios were displayed to the group. Each participant had two votes which they used to select scenarios for the policy-stress testing component of the workshop.

A similar selection process then took place for the policy pathway. With over twenty proposed actions collected from the interview process, it was necessary to reduce the number of policies for the sake of time. The pathway consisted of policy instruments for the first two decades, then ended in the 2040-2050-time range with technological developments described in the majority of interviewee's visions of a 2050 energy future in which there was an identifiable blockchain use case. Policy selection proceeded as follows:

- One near-future policy from the 2018-2025 period
- Three policies relevant to blockchain development within the 2025-2040 period
- Three technologies deemed relevant to blockchain integration



A matrix was created on a flipchart, with the scenarios as column headers, and policies/technologies in the rows. Within each scenario, a show of hands and brief discussion was conducted around each policy or technology. Guiding questions inquired as to the robustness/relevance of such a policy, or technological development within each scenario. Responses included: Robust (Thumbs-up), Redundant (Thumbs-down), or Uncertain (Hand extended straight, with palm facing ground). For technological developments, such as Peer-to-Peer Energy Trading, the same gestures were used to indicate the following response: Likely to materialize within the timeframe (2018-2050) under this particular scenario, Unlikely to materialize, Uncertain.



The workshop was concluded with an exit survey and announcement of the research timeline.

Follow-up Interviews

Workshop participants were contacted via email one week following the sessions. They were provided with a debrief document summarizing the findings of the workshop, with the exception of the competition analysis (which remains for CGI internal use only).

The interviews were semi-structured, and typically lasted one hour. They were audio-recorded, and later transcribed and coded in NVivo. A typical interview structure can be seen below, however the order varied depending on the pacing and the responses:

Table 8: Follow-up Interview structure

Follow-up Interview Structure
3. DRIVERS - Present the drivers selected by the participants groups
a. If you could choose again, which drivers would you select? (Choose 2-3)
b. What from your experience (either personal or professional) informs this decision?
4. SCENARIOS - Select two scenarios (from the nine scenarios to more deeply explore
a. Asked to describe energy system, generation, distribution, society (same scenario-provoking questions as in workshops)

b. Where in the world would you want to live under such a scenario? 5. USE CASES - Discussion of blockchain use cases a. Open discussion of blockchain's potential role in the energy transition b. Ordering of the use cases identified in the investigation 6. POLICES AND GOVERNANCE - Discussion of policies and organisational actions a. Open discussion of the policies/actions b. Ordering/evaluation of the policies, proposing additional considerations associated with individual policies/actions 7. WORKSHOP PROCESS - Inquire into workshop dynamics (did you feel like your voice was heard, how did you establish consensus?)

External Consultation

Recruitment

In this particular phase of the research, blockchain knowledge was a prerequisite. Researchers at sustainability institutes were contacted, in addition to individuals within governmental agencies. This was limited within the scope of the Dutch energy context. Interviews were conducted during August and September 2018.

Consultation Structure

The interviews were semi-structured, and typically lasted one hour. They were audio-recorded, and later transcribed and coded in NVivo. Within this time frame, subjects were presented with the blockchain use cases identified in the literature review and pre-workshop interviews. They were then asked to order the use cases in order of likelihood to enter the market soonest. There was a period for brief discussion as to the reasoning behind their choices.

Table 9: External consultation structure

External Consultation Structure
1. Present the drivers selected by the participants groups a. Which drivers would you select? (Choose 2-3) b. What from your experience (either personal or professional) informs this decision? 2. Discussion of blockchain use cases a. Open discussion of blockchain's potential role in the energy transition b. Ordering of the use cases identified in the investigation

3. Discussion of policies and organisational actions
    a. Open discussion of the policies/actions
    b. Ordering/evaluation of the policies, proposing additional considerations associated with individual policies/actions

Results

In this section, results are presented from the visioning interviews, foresight workshop, and post-workshop periods during which participant follow-up interviews and external expert consultations took place.

Visioning Interviews

Respondent Composition

A total of eighteen respondents were interviewed during this research stage. All were actively involved in the energy sector, in various capacities ranging from start-up, venture capital, law practice, academic research, independent consultants, to energy companies. Fourteen interviewees (78%) had direct experience in distributed ledger technology. Six (33%) of respondents had professional knowledge in finance. Twelve (67%) had energy policy expertise. Five (28%) had software expertise. Fourteen (78%) participants had directly experience leading and implementing projects within the energy sector. With respect to gender distribution, six (~33%) of the participants were female, and the remaining twelve (~66%) were male.

Table 10: Visioning interview respondent composition

Title	Subject Area Knowledge
Electrical engineer, Public research university	blockchain
Energy department, Technical University	finance, blockchain, policy, project development
Energy research institute	project development, blockchain, policy
Privately-held utility	project development, blockchain, policy
Government-associated university research center	blockchain, general software
Venture capital firm	blockchain, finance, project development
Former director of government agency, independent consultant	policy, project development
Independent consultant	blockchain, general software, policy, project development
Energy industry-oriented venture capital firm	finance, blockchain, policy, project development
C-level executive, Energy Supplier & Services provider	project development
Analyst, Media publication	blockchain, policy
C-level executive, blockchain/energy startup	blockchain, finance, policy, project development
Co-founder, Microgrid services provider	general software, policy, project development
Partner, Law Firm	policy, blockchain
C-level executive, blockchain startup	finance, blockchain, project development
Independent consultant, IT & Utilities	general software, blockchain, policy, project development

Energy expert, independent consultant	general software, project development
Founder, Energy supplier	project development, policy, blockchain

DLT USE CASES

Five general areas of DLT applications were collected from the interviews. They are presented below:

- Certificate/Guarantee of Origin
- Data management
  - Billing and settlements
  - Data reconciliation in auditing processes
  - Monitoring/Compliance
- Self-sovereign identity management
- Enhanced Demand Response Management
- Peer-to-Peer Trading

GUARANTEE OF ORIGIN

Description

A guarantee of origin (GoO) is a certificate scheme created to authenticate the source of an energy stream. The objective is to distinguish renewable generation from non-renewable, and aid national governments in collecting energy generation data in assessing progress to energy goals. Commercial and private power plants are issued the certificate (in one Megawatt-hour increments), then these are issued to energy traders. These are traded electronically, identifiable by a unique number. Certifying bodies within EU Member States are required to issue a guarantee of origin, per Article 15(2) of Directive 2009/28/EC. There is no specification as to nature of the digital platform used for such trading.

DATA MANAGEMENT AND ADMINISTRATIVE PROCESSES

Description

This category covers a variety of data and administrative applications. These range from billing, settlements, data reconciliation, clearing, monitoring, compliance.

<u>Billing, Settlements</u>

Billing and settlements refer to the exchange of funds or data in an accounting process. Billing is defined as the process of creating and sending invoices. Settlement is the process of payment in exchange for an agreed-upon product. It signifies the end of the contractual obligation.

Reconciliation Processes

Data reconciliation refers to the process of verifying that all relevant parties in a transaction are operating with the same information. The application of DLT in this instance was described as useful. It is not a duplicate system, in which records are compared and reconciled. Relevant parties not only see the same information, they all have the same ledger.

Monitoring/Compliance

This refers to monitoring of data or physical flows and storing data in a distributed ledger. Compliance assessment is a process by which the monitored flows are examined to determine whether they fall within pre-established bounds (e.g. emissions tracking)

Clearing

Clearance is the process by which the information at the sending and receiving ends of the transaction are collected and evaluating to determine definitively how much is owed to whom.

SELF-SOVEREIGN IDENTITY MANAGEMENT

Description

Christopher Allen, a software architect at Blockstream (a private company focused on cryptocurrency network infrastructure), popularized the concept of self-sovereign identity in 2016. In a markup file on GitHub, he published a list of what he deemed were the integral dimensions of self-sovereign identity management. Self-sovereign identity management is described by Christopher Allen by ten main principles (Allen, 2016).

1. The user being identified must have an existence outside of digital form.
2. The user must have ultimate control over their identity, able to "refer, update, or even hide it.", even though others are able to make claims on it.
3. The user must be able to readily access information regarding all claims on their identity.
4. Identity administration systems must be as open, transparent, and free as possible.
5. The identity must be able to be rendered independent of the claims made on it, and last transitions between old and new identity systems.
6. The identity must never be held at the whims of a single party which is not comprised of the individual.
7. The identity must be interoperable, recognized in a wide series of networks.
8. The individual must offer consent to all claims made on their identity.

9. The minimum amount of information needed to process a claim should be divulged.
10. The identity network should favor the needs of the individual rather than the identity network itself, decentralised, censorship-resistant algorithms.

Respondents saw this extending beyond human individuals, explaining that a distributed ledger could also be used by machines and devices to authenticate themselves.

ENHANCED DEMAND RESPONSE MANAGEMENT

Description

As DLT enables a trustless record of data, it can be used to share open data that multiple parties use. An ownerless records of grid congestion data and household energy consumption can facilitate decentralised demand response. Smart contracts can automatically execution control functions on IoT-enabled devices when certain load conditions or customer behavioral patterns are observed (ex. Smart charging of electric vehicles).

PEER-TO-PEER TRADING

Description

Peer-to-peer was envisioned by different respondents at two different levels. First, within the existing energy market structure, they described peer-to-peer energy trading on the wholesale market. Other described what this report will hereafter refer to as "true peer-to-peer", in which households could directly trade energy with each other, or with an energy supplier. Another application would be in machine-to-machine transaction, in which smart devices can balance amongst themselves.

Governance

Individual households are not legally allowed to act as energy traders.

Peer-to-peer is technically possible without DLT, which is only described as enhancing the value proposition thereof.

Tangential Mention of Other Industry Energy Transition Priorities

One respondent noted the need for policy reform of the international shipping industry. The majority of cargo ships are powered by fossil fuels, and a small portion of the military ships, icebreakers, and freighters operate off nuclear power. This policy area which was beyond the scope of this research, but worth noting as an important and underrepresented consideration for the energy transition.

Drivers

Twenty-two recurring drivers of change were identified from the interviews, meaning that each driver had been mentioned at least in two separate interviews (Table 9).

Four social drivers were mentioned, and covered end-user engagement, social cohesion, climate towards information sharing, and trust in institutions. End-user engagement was most commonly described as the involvement of end-users/households in the energy transition, beyond following price signals. There is a minimum degree of awareness regarding energy consumption practices, and a willingness to engage with energy market actors in co-creating or testing innovations. Social cohesion refers to the degree to which people within the bounds of their in-group boundaries (which can, admittedly, be numerous, and mutually exclusive or overlapping) are open and able to cooperate with each other on initiatives which are deemed beneficial to the overall group. Climate towards information-sharing is described as the willingness of people within a society to share their data, regardless of the formalized rules which structure it. Trust in institutions was most commonly described as the degree to which civil society actors approve of and deem proper the goals set by the institutions which guide their activities, and the means by which these institutions go about achieving those ends[4].

There were nine technological drivers identified. These include degree of Internet of Things (IoT) enablement, electrification of transportation and/or rural areas, data siloing practices, telecommunications development, blockchain scalability, blockchain security, blockchain/GDPR-compliance, the legal status of a smart contract, and blockchain interoperability.

Two economic drivers were gathered, and they included the design of end-user financial incentives and utility rate-making. Two environmental drivers included the extent of effects of climate change on society, and orientation of environmental solutions (adaptive vs. optimization-oriented). During the foresight workshops, this became rephrased to "Radical/Incremental Innovation" and was used interchangeably with the original phrasing. The two political drivers were degree of centralisation in government, and the state of democracy in a given political system. One legal driver was identified- the legal status of a smart contract. Two ethical drivers were collected, the degree to which individuals owned their own data, and the effects of financial transparency on different class groups in society.

[4] "Trust in institutions" might have been better defined as "legitimacy", but this is a retroactive observation.

Identified Policies

Sixteen potentially facilitating policies were identified in the visioning interviews. Prior to more detailed description of the policies the figure below is a graphical representation thereof, with policies sorted into time ranges which were determined by explicit mention by respondents, or by inference using the timeline to 2050 laid out in the Dutch Energy Agenda (Rijksoverheid, 2017).

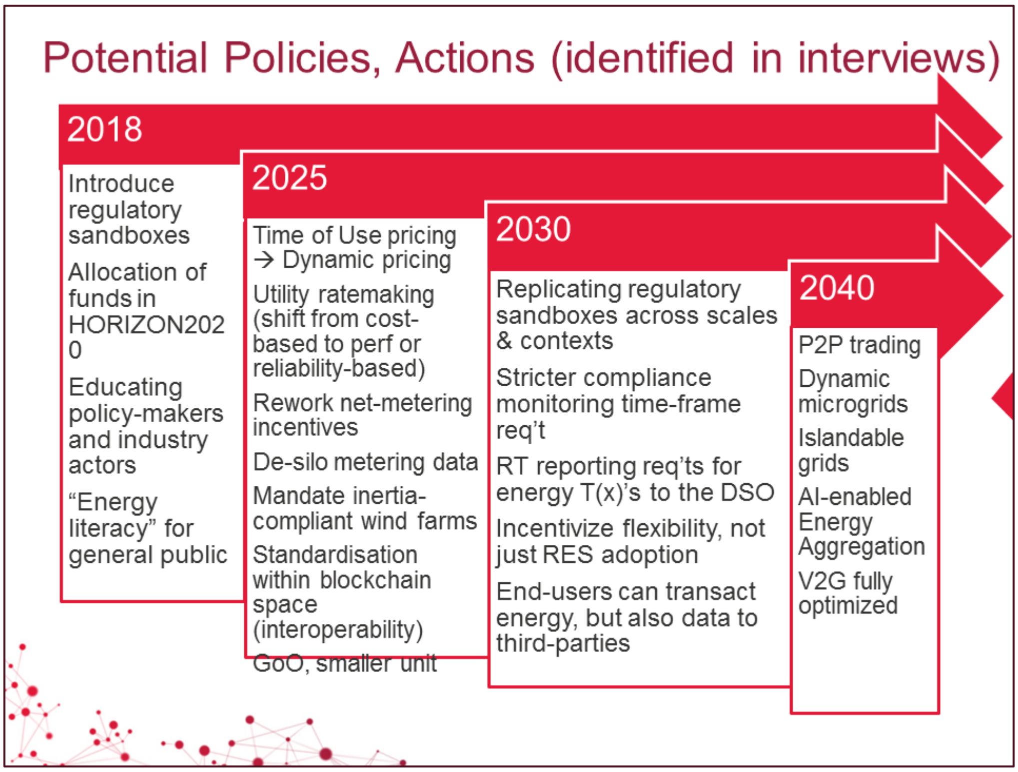


Figure 11: Collection of policies which were identified from pre-workshop visioning interviews, clustered into time periods. Frequently mentioned technological outcomes which would be facilitated by these policies are in the "2040" box.

2018-2025

INTRODUCTION OF REGULATORY SANDBOXES

Regulatory sandboxes were mentioned by four interviewees as a useful policy measure to test innovative business models and technologies relevant to the energy transition. However, several important caveats were mentioned. First, there is a high amount of cross-actor coordination and paperwork needed to get it off the ground. Typically, an idea which is demonstrated to work within a regulatory sandbox may get scaled out into mainstream markets. For this reason, it is critical that the conditions within the sandbox reflect realistic conditions. In addition to being realistic, the type of decision-making made in sandboxes is less risk-averse than in typical conditions, which is a double-edged sword. It can allow for demonstration of proof-of-concept; however, it is difficult to know whether the outcomes will be replicated in a larger, more complex network.

ALLOCATION OF FUNDS IN HORIZON2020

This particular proposal aims at the allocation of HORIZON2020 funds for projects specifically related to modernization and transformation of energy systems infrastructure. There are currently discussions within the European Union regarding the potential of distributed ledger technology. In February of 2018, a "Blockchain Observatory" was created following issuance of a call for tenders by the European Parliament. ConsenSys, a global atelier of blockchain-based applications, was selected to guide the search. Thus far, 80 million EUR has been invested by the European Commission in research oriented at social and technical applications of blockchain. Approximately 300 million EUR in funds are expected to be allocated by 2020. The two main projects supported by these funds include privacy and health applications (DECODE and MHDMD, respectively). No projects or funds are specifically allocated to investigating applications to smart energy systems.

EDUCATING POLICY-MAKERS AND INDUSTRY ACTORS

Three respondents emphasized the importance of continued outreach to those who create policy, and those who are responsible for its implementation. This was described as including both policymakers and industrial actors. A campaign for both to become familiar not only with the standalone capabilities of a technology, but also of what affects its development, and how it can transform or disrupt markets.

ENERGY LITERACY FOR THE GENERAL PUBLIC

This policy proposal hits on a similar note as the aforementioned proposal. Two respondents stated that if substantive long-term momentum towards a successful energy transition was to be maintained, it would be necessary to educate children in schools about how their energy system works. One respondent mentioned that it is easier to educate younger generations, before they have to discard unsustainable habits.

2025-2030

SHIFTING FROM TIME-OF-USE PRICING TO DYNAMIC PRICING

Two respondents suggested that an important policy step would be to transition away from time-of-use pricing or flat electricity rates, to dynamic pricing. This means that instead of a single flat tariff on electricity, or peak/off-peak prices, the prices change over shorter time intervals (e.g. a 1-hr slots) and are related to the amount of coincident grid congestion. The primary claim made by respondents is that this will contribute to clearer price signals for end-users to respond to.

The association with "surge pricing" was mentioned as a source of potential resistance. One respondent mentioned that most end-users are not comfortable with the unpredictability posed by dynamic pricing, and they favor the convenience of being able to use electricity whenever they want over marginal savings. Contracts in which end-users could lock in a specific electricity price for a given period of time was cited as a facilitatory co-policy which would aid in acceptance.

UTILITY RATEMAKING

One respondent noted the importance of reforming the process by which utilities decide which price to charge for their service. In the United States (the respondent's area of expertise), the majority of utilities set prices based on the costs which they incur in maintaining the services they provide to their customers. This provides a poor incentive for utilities to innovate, optimize, and improve the overall deftness of their operations, because that would mean reduced costs. An example of a ratemaking reform includes shifting to performance-based or reliability-based rate. Performance-based ratemaking, such as the RIIO (Revenue = Incentive + Innovation + Outputs) model of network regulation recently adopted in the United Kingdom, means that the utility rates depend on how well the utility manages to deliver power in an efficient way which balances consumer needs and profit motive of the utilities. Reliability-based ratemaking would mean that the utility rates depend on how the utility provider is able to deliver within pre-defined boundary conditions (usually using phase angle and voltage amplitude).

REWORK NET-METERING INCENTIVES

Three respondents identified a need to reform the net-metering policies in place, which currently allow small scale electricity producers to feed into the grid, with energy taxes applied only to their net electricity consumption. This can include a provision for *telepanels*, so that people without their own rooftop can still economically benefit from adopting renewable energy sources and placing it at a site separate from their home. Another proposed version of this includes cessation of net-metering policies altogether or siphoning some of the net-metering benefits from PV adoption alone to also include storage technologies. While the types of reforms suggested differed, the common consensus was that current end-user incentives to adopt fewer consumptive behaviors, flexibility technologies, or PV panels.

DE-SILO METERING DATA

Six respondents pointed to de-siloing of metering data as a policy initiative which would open up new innovation possibilities within the energy sector. Several highlighted the importance of access to data for teaching machine learning models. Access to a wider dataset was described as a progressive step toward improved artificial intelligence applications.

MANDATE INERTIA-COMPLIANT TECHNOLOGIES

One respondent mentioned that a regulation which mandates inertia-compliance in energy storage units and wind farms could facilitate frequency control within an increasingly decentralised and variable supply.

This is corroborated by recent developments in the Quebec province, in which all new wind farms are required to be inertia-compliant, to favorable results thus far.

STANDARDISATION WITHIN BLOCKCHAIN SPACE

Three respondents, who all specifically work on blockchain projects in the energy sector, stated that interoperability, security protocols, and some form of standardization within the community. The key objective behind any community guidelines should be oriented around how to provide secure, trustless transaction.

INTRODUCE GUARANTEE OF ORIGIN, SMALLER UNIT OF TRANSFER

Two respondents noted that Certificates of Origin were a step in the right direction. However, they stated that an important step towards more distributed energy generation is to allow for smaller-scale generation sites to have some means of attesting to the renewable source of the energy they provide. This would include a Guarantee-of-Origin (GoO), which would account for generation at the kilowatt level, rather than the Megawatt level.

2030-2050

REPLICATING REGULATORY SANDBOXES ACROSS SCALES AND CONTEXTS

This is proposed as a way of improving the applicability of findings and developments from regulatory sandboxes. A positive result in a regulatory sandbox is promising for innovation within energy systems. However, as previously mentioned, if scaled-up before adequate validation takes place, then holes in the system which were not observable in that particular context or scale might exact unforeseen consequences on a large scale.

STRICTER COMPLIANCE MONITORING TIME-FRAME REQUIREMENTS

Compliance monitoring refers to the practice of designated parties by which they evaluate whether the targets of a particular regulation are operating in accordance with the specifications of that regulation. Two respondents stated that most cycles of monitoring compliance with an environmental policy, reporting the results thereof, and the target body modifying its behavior in response, takes too much time and will hinder progress towards emissions targets. They highlight administrative burden as a factor behind this lag and propose that enacting stricter time requirements for compliance monitoring and response would force monitoring bodies to pursue efficiency-saving measures. Blockchain, as a means of data reconciliation, was described as being useful in this situation, with respect to accelerating progress towards sustainability goalposts.

REAL-TIME REPORTING REQUIREMENTS FOR ENERGY TRANSACTIONS TO GRID OPERATOR AND/OR BALANCE RESPONSIBLE PARTIES

This policy applies to microgrids in which energy can be distributed in a decentralised manner, off the distribution grid. While the distribution grid is not being use, the amount of load within the microgrid and areas of congestion on the periphery, are relevant to the interest of balancing the grid on a larger scale. For this reason, knowledge of energy transactions and volumes within microgrids provide useful information to both grid operators and balance responsible parties. A real-time reporting requirement for these transactions is described as a policy measure which can facilitate a transition towards a more nimble, "smart" grid.

INCENTIVIZE FLEXIBILITY, NOT JUST DISTRIBUTED ENERGY TECHNOLOGY ADOPTION

Flexibility is described as the capacity for energy production to match energy consumption. One aspect of energy flexibility could be to reduce demand in response to high grid load. One respondent highlighted that a significant portion people with access to the electrical grid might not be financially able to acquire the most efficient devices, or to adopt a renewable energy generation or storage technologies, despite the presence of subsidies. End-user engagement could be fostered in another way, the respondent proposed, by means of incentivizing device flexibility. This policy was described as offering financial or other compensation for agreeing to flexible use of household device (ex. washing machine, or dishwasher). They did not specify who should be responsible for disbursing this compensation. Overall, they envision a swath of people, without the capability of adopting new technologies to also gain value from the energy transition. They stated that smart contracts could be used to automatically compensate the participants, in addition to a distributed ledger gathering data from substations or households for monitoring local grid load.

END-USERS CAN TRANSACT ENERGY, BUT ALSO DATA TO THIRD-PARTIES

Two respondents stated that in the future, transacting energy will no longer occupy the lion's share of the energy sector. Data has increasing value, especially with respect to training machine, deep, and meta learning models. The two interviewees proposed a policy which leads to development of a data market, in which people own and sell/lease/rent access to their various data streams.

Driver Mapping

The drivers collected from the visioning interviews were categorized by STEEPLE criteria and the sociotechnical system level to which they most closely corresponded, as characterized by the criteria in the Theory section of this report. Most social factors corresponded to the landscape level, with one at the regime (end-user engagement). Technological factors were equally distributed between regime and niche levels. Environmental factors were at the landscape or regime level. Economic and political factors were exclusively at the regime level. The sole legal factor corresponded to the regime. Ethical factors were at the regime and landscape level.

Table 11: Drivers of change, collected from visioning interviews

SOCIAL	System Level
End-user engagement	Regime
Social cohesion	Landscape
Climate towards information sharing	Landscape
Trust in institutions	Landscape
TECHNOLOGY	
IoT Enablement	Regime
Electrification of transportation and/or rural area	Regime
Data siloing	Regime
Telecommunications development	Regime
Blockchain Scalability	Niche
Blockchain Security	Niche
Blockchain/GDPR-compliance	Niche
Blockchain interoperability	Niche
ENVIRONMENTAL	
Effects of climate change on society	Landscape
Solutions Orientation (adaptive vs. optimisation-oriented) (During workshop, became rephrased to “Radical/Incremental Innovation”)	Regime
ECONOMIC	
End-user financial incentives	Regime
Utility-rate making	Regime
Wholesale pricing model	Regime
POLITICAL	
Democracy of political system	Regime
Degree of centralisation in government	Regime
LEGAL	
Legal status of a smart contract	Regime
ETHICAL	
Ownership of data	Regime
Effect of transparency on different subgroups of society (ex. Prices)	Landscape

Workshops

Participant Composition

All participants are involved in the energy sector in some capacity, from interns, independent consultants, software engineers, project managers, policy advisors, to company founders. Five (31%) participants had expertise in energy policy. Six (37.5%) participants had direct experience in the blockchain sector, from research to project development. Four (25%) of participants had software expertise. Two participants had subject area expertise in the financial/banking sector. Thirteen (81%) participants had directly experience leading and implementing projects within the energy sector. With respect to gender distribution, twenty-five percent of workshop participants were female, and seventy-five percent were male.

Table 12: Workshop participant composition and subject area expertise

Title	Subject Area Expertise
Master's student (blockchain-focused research), Dutch university	Technical, Project Development, Energy
Master's student (blockchain-focused research), Dutch university	Technical, Energy
Dutch DSO	Technical, Project Development, Energy
Independent consultant	Project Development, Energy
Banking	Finance, Energy
Dutch DSO	Project Development, Energy
Independent consultant, blockchain and energy specialist	Technical, Project Development, Energy
French utility	Technical, Energy
Dutch DSO	Policy, Project Development, Energy
Independent consultant	Policy, Innovation, Project Development, Energy
Independent Consultant	Technical, Project Development, Energy
Dutch DSO	Technical, Project Development, Energy
Investment banking, Renewables portfolio specialist	Finance, Project Development, Energy
Dutch market actor platform	Policy, Project Development, Energy
Dutch consultancy	Policy, Project Development, Energy
Dutch consultancy	Policy, Project Development, Energy

Selected Drivers

Table 13: Definition of driver boundaries

Definition of Driver Boundaries	(-) Low end	(+) High end
Social Cohesion	(-) Individualistic society, every individual seeks to maximize their own personal benefit	(+) High social cohesion, people think collectively and are cooperative
Degree of Innovation / Temporal Orientation of Solutions	(-) Incremental Innovation, technical solutions are designed with adaptation in mind (just surviving)	(+) Radical Innovation in the Energy Transition, technical solutions are designed with optimisation in mind
Democracy of Political System	(-) Authoritarian dictatorship	(+) Highly democratic society, full voting rights and transparency in government
Degree of Internet of Things (IoT) Enablement	(-) Low IoT enablement, IoT devices exist but are not interconnected enough to realise the envisioned seamless device future	(+) High IoT enablement, IoT devices are cheap, plentiful, and can communicate seamlessly with each other
Improvement of behind-meter end user incentives	(-) Continue with current net-metering policy (i.e. PV owners can sell their energy back to the grid, with certain restrictions)	(+) Improvement of current net-metering policy (i.e. PV owners are not only incentivised to sell their energy back to the energy supply but are also incentivised to self-consume.)
Blockchain Scalability	(-) Business-as-usual, state of blockchain remains where it is now	(+) The trilemma is overcome (i.e. decentralisation, security, scalability)
Societal Openness towards Information-sharing	(-) Society only share data on a need-to-know basis, and never volunteer it	(+) Society as a whole is generally well-disposed towards sharing data openly and anonymously
Impacts of Climate Change on Society	(-) Catastrophic effects on society, mass migration, economic displacement	(+) No major effects, society continues as it has
Ownership of Data	(-) Centralised, siloed	(+) Decentralised, either the data is open, or the generators of the data own it

Scenarios

All the initial scenarios are included below for reference. First, a schematic of the scenario matrix is depicted below in order clarify the structure. The top right corner of the quadrant indicate that both drivers selected are imagined in their high-setting (however defined for that specific driver). In the bottom right corner, one driver is high, and the other is low, et cetera.

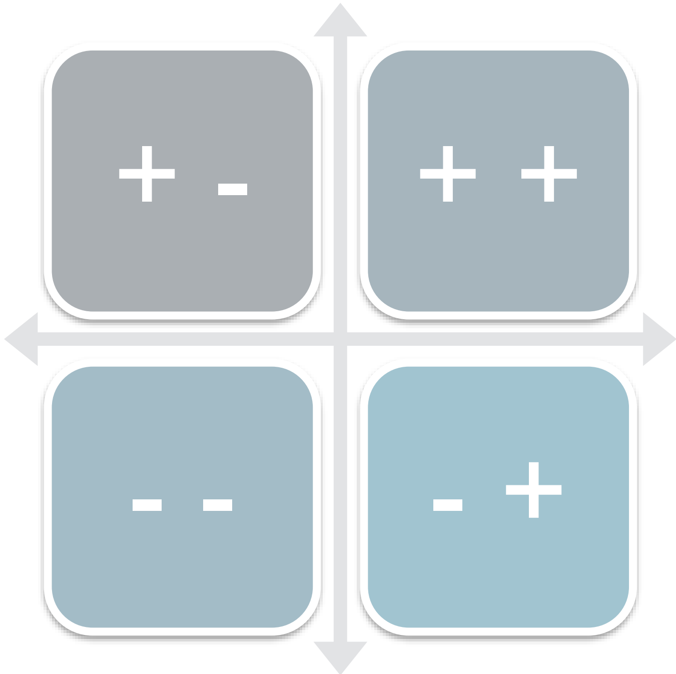


Figure 12: Schematic illustrating the logical structure of the selected drivers within a scenario matrix. Clockwise from the Top Right quadrant: High/high end of Driver 1 & 2, Low/High of Driver 1 & 2, Low/Low of Driver 1 & 2, High/Low of Driver 1& 2

UTRECHT

In the Utrecht workshop, sixteen scenarios were created, using the following drivers:

- Social Cohesion & Orientation of Environmental Solutions (Also referred to as "Innovation")
- Design of End-User Incentives & Blockchain Scalability
- Democracy of Political System & IoT Enablement
- Societal climate towards Information-sharing & Effects of Climate Change on Society

Their names and corresponding driver directions can be accessed in the tables below (Table 13 & 14).

Table 14: Scenario names and matrices from Utrecht workshops

GROUP 1		
United Front	Social Cohesion +	Innovation +
No Guarantees	Social Cohesion -	Innovation +
Tortoise in the Shell	Social Cohesion -	Innovation -
Climate disbelief	Social Cohesion +	Innovation –
GROUP 2		

Within and About	End-User Incentives +	Blockchain Scalability +
Sell Yourself	End-User Incentives -	Blockchain Scalability +
Stuck in Place	End-User Incentives -	Blockchain Scalability -
Party of One	End-User Incentives +	Blockchain Scalability -
GROUP 3		
Bitcoin	Democracy of Political System +	IoT Enablement +
The Matrix	Democracy of Political System -	IoT Enablement +
1984	Democracy of Political System -	IoT Enablement -
Old Greek	Democracy of Political System +	IoT Enablement –
GROUP 4		
Utopia	Climate towards Info Sharing +	Climate Change Impacts +
Central Energy System	Climate towards Info Sharing -	Climate Change Impacts +
Mad Max	Climate towards Info Sharing -	Climate Change Impacts -
Transition Towns	Climate towards Info Sharing +	Climate Change Impacts -

ROTTERDAM

In the Rotterdam workshop, eight scenarios were created, using the following drivers:

- Societal climate towards Information-sharing & Blockchain Scalability
- Ownership of Data & IoT Enablement

Their names and corresponding driver directions can be accessed in the tables below (Table 13). The scenario matrices from both workshops are presented on the following page (Figure 13).

Table 15: Scenario names and driver directions collected from the Rotterdam foresights workshop.

GROUP 5		
Paradise	Climate towards Info Sharing +	Blockchain Scalability +
Lockchain	Climate towards Info Sharing -	Blockchain Scalability +
Duct Tape	Climate towards Info Sharing -	Blockchain Scalability -
Siloed	Climate towards Info Sharing +	Blockchain Scalability -
GROUP 6		
Digital Freedom	Ownership of Data +	IoT Enablement +
Battle of the Titans	Ownership of Data -	IoT Enablement +
Gladiators	Ownership of Data -	IoT Enablement -
Back to the Future	Ownership of Data +	IoT Enablement -

Figure 13: Scenario Matrices from Utrecht (blue) and Rotterdam (orange) Foresights workshops. Red outline indicates scenarios which were selected for policy-stress testing.

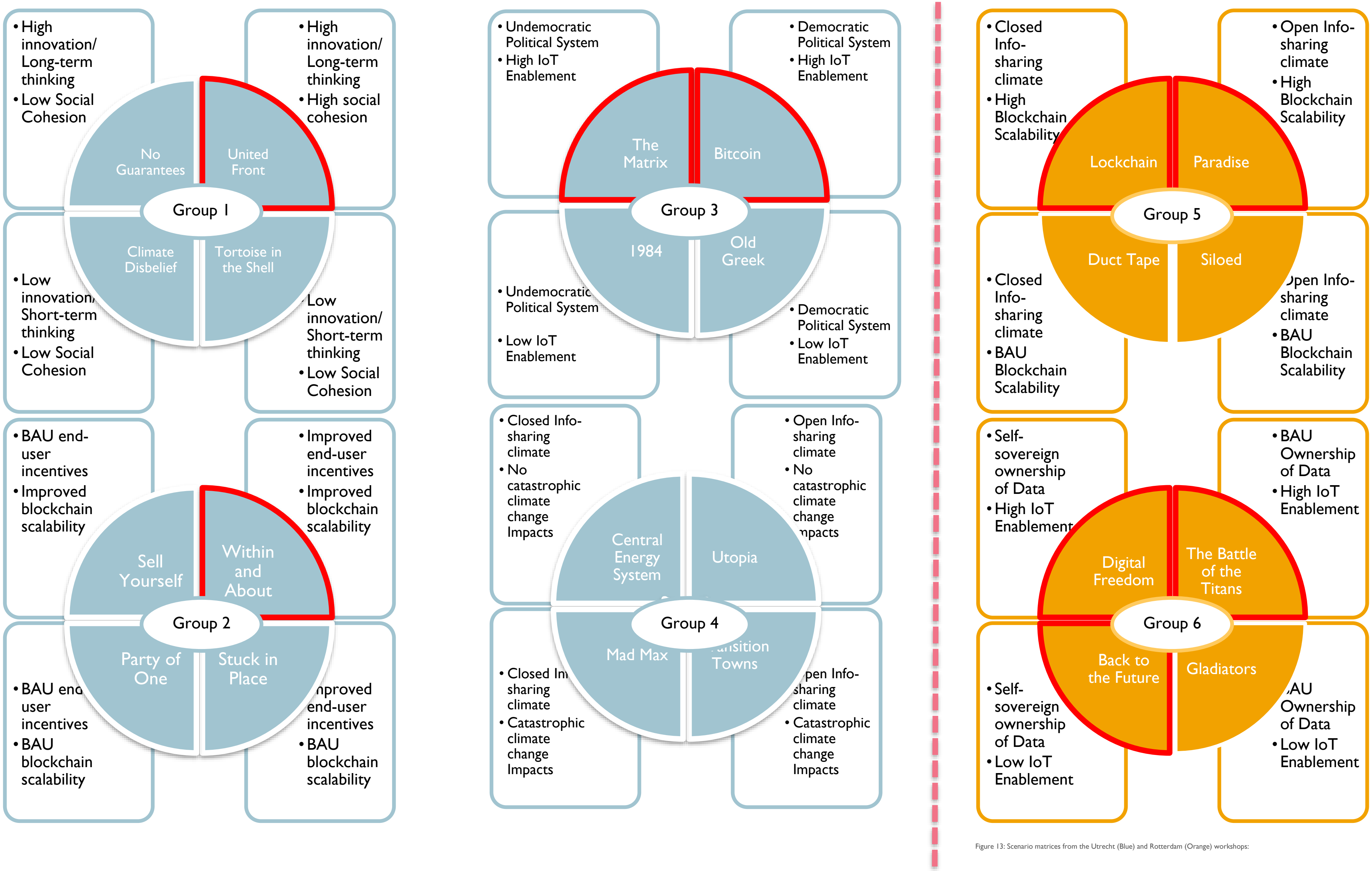


Figure 13: Scenario matrices from the Utrecht (Blue) and Rotterdam (Orange) workshops.

Selected Scenarios

Scenarios with identified DLT use cases were collected. These were then presented to all participants, who selected four and five scenarios to apply to the policies, for a total of nine selected scenarios. These scenarios were then used to stress-test the selected policies. They are presented below (Table 14). More detailed descriptions immediately follow.

Table 16: Selected scenarios with identified DLT use cases, which were used for policy stress-testing.

	DRIVERS	
UNITED FRONT	Social Cohesion +	Innovation +
BITCOIN	Democracy of Political System +	IoT Enablement +
WITHIN AND ABOUT	End-User Incentives +	Blockchain Scalability +
THE MATRIX	Democracy of Political System -	IoT Enablement +
LOCKCHAIN	Climate towards Info Sharing -	Blockchain Scalability +
PARADISE	Climate towards Info Sharing +	Blockchain Scalability +
BATTLE OF THE TITANS	Ownership of Data -	IoT Enablement +
DIGITAL FREEDOM	Ownership of Data +	IoT Enablement +
BACK TO THE FUTURE	Ownership of Data +	IoT Enablement –

Selected Scenario Descriptions

In this next section, the selected scenario narratives, types of DLT use cases, competitive analysis, results from policy stress-testing, and additional comments from the workshops are collected and presented per scenario.

UNITED FRONT

SELECTED DIRECTIONS

Social Cohesion (HIGH) & Orientation of Solutions/Innovation (HIGH)

In a world where people think beyond themselves when making energy-related decisions, and in which the direction of technical innovation is towards long-term sustainability rather than stopgap measures, the energy transition is expected to accelerate in the Netherlands.

There is high government-driven innovation, and one dominant technology is used for each particular aspect of the energy market. The government takes care of vulnerable groups, and there is a mandatory grid connection. Taxes are more accepted in this scenario, since people think about the collective good. Trust is high, so people do not use blockchain to buck the existing system, but rather the existing system incorporates some blockchain tools into their daily operations. Blockchain may have some use cases, particularly for administrative solutions or cross-scale emissions trading schemes. Getting actor buy-in is not necessary.

While the threat of disintermediation is low, existing firms will compete to provide better services and products to their clients. Progress will be made towards the energy transition, renewables proliferation will increase, and blockchain's impact on sustainable development outcomes are expected to be incremental.

IDENTIFIED BLOCKCHAIN USE CASES

- Emissions trading
- Certificates/Guarantee of Origin
- Data management
    - Billing and settlements
    - Reconciliation in auditing processes

POLICIES

(presented in decreasing order of perceived robustness)

- Establishment of blockchain interoperability standards is expected to be highly robust under this scenario, since societal attitudes are geared towards open collaboration and trust. (highly robust)
- Shifting from Time-of-Use to Dynamic pricing (moderately robust)
- De-siloing metering data (moderately robust)
- Real-time reporting requirements of energy transactions to grid operators (slightly robust)

BITCOIN

SELECTED DIRECTIONS

Democracy of Political System (HIGH), IoT Enablement (HIGH)

In this scenario, the energy future is decentralised, with mostly off-grid power distribution. Technology is used to both assist people and increase the efficiency of the energy supply. People use Bitcoin, or some other cryptocurrency to conduct energy transactions. Risk of disintermediation is low for incumbent players in the distribution and transmission spaces, as the data deluge brought on by the greater IoT enablement expands the market. Incumbent and emerging players alike develop business models based on providing energy services, rather than delivering energy. This is expected to be a highly transformative scenario, both technologically and societally, but not necessarily because of blockchain.

IDENTIFIED BLOCKCHAIN USE CASES

- Cryptocurrency[5]

POLICIES

(presented in decreasing order of perceived robustness)

- De-siloing metering data (moderately robust)
- Establishment of blockchain interoperability standards is expected to be highly robust under this scenario, since societal attitudes are geared towards open collaboration and trust. (slightly robust)
- Shifting from Time-of-Use to Dynamic pricing (slightly robust)
- Real-time reporting requirements of energy transactions to grid operators (slightly robust)

[5] The irony is not lost on us that this scenario is named "Bitcoin", yet distributed ledger technology is not deemed a key transformative factor.

WITHIN AND ABOUT

SELECTED DIRECTIONS

End-User Incentives (HIGH), Blockchain Scalability (HIGH)

In this future energy systems scenario, the scaling issues associated with blockchain are resolved, and incentives are in place which stimulate consumption of electricity "behind the meter". Households and industry actors are encouraged to continue adopting renewable energy sources, and the incentive to self-consume is greater than that of feeding in electricity back to the distribution grid. In the long term, this results in the disintermediation of the DSOs and BRPs, with decentralised distribution and balancing. Local energy communities enrich their connectivity, both within their own boundaries and producing, consuming, and exchanging energy with neighbors. Net-metering subsidies as they currently exist are eliminated, removing the perverse incentives to feed-in rather than self-consume. This also encourages people to look beyond renewables generation and explore storage options. Rather than providing net-metering subsidies, the government maintains an important role in consumer protection by ensuring that electricity remains affordable. There is a potential use case for blockchain or other DLT within this scenario, primarily including demand response management in a decentralised energy network, facilitated by blockchain identity management and smart contracts.

IDENTIFIED BLOCKCHAIN USE CASES

- Guarantee of Origin
- Identity/Data Management
- Enhanced Demand Response Management

POLICIES

(Presented in decreasing order of perceived robustness)

- De-siloing metering data (moderately robust)
- Shifting from Time-of-Use to Dynamic pricing (moderately robust)
- *Establishment of blockchain interoperability standards is expected to be highly robust under this scenario, since societal attitudes are geared towards open collaboration and trust. (dubious)*
- *Real-time reporting requirements of energy transactions to grid operators (dubious)*

THE MATRIX

SELECTED DIRECTIONS

Democracy of Political System (LOW), IoT Enablement (LOW)

This is a centralised energy system, with no customer choice regarding devices, demand response, or other services. Energy efficiency is optimised and grid load is balanced by automated software, without opportunity for human intervention. Artificial intelligence plays a role in energy aggregation, potentially making energy aggregators redundant. Technologies will be state-of-the-art but will support the powers that be. Risk of disintermediation is low for incumbent players in the distribution and transmission spaces, while buyer power decreases. Competition between existing actors is also expected to decrease, turning into electricity cartels, as they continue to operate behind the curtain of public perception. This is a technologically transformative scenario, but not societally. As machines increasingly reduce human choice, this leads to an important question - will people know what they want or what they are missing?

IDENTIFIED BLOCKCHAIN USE CASES

- Data management
  - Billing and settlements
  - Reconciliation in auditing processes
- Trustless record for machine-to-machine communication

POLICIES

(Presented in decreasing order of perceived robustness)

- Real-time reporting requirements of energy transactions to grid operators (Moderately robust)
- Shifting from Time-of-Use to Dynamic pricing (slightly robust)
- Establishment of blockchain interoperability standards is expected to be highly robust under this scenario, since societal attitudes are geared towards open collaboration and trust. (slightly robust)
- *De-siloing metering data (Highly Redundant)*

LOCKCHAIN

SELECTED DIRECTIONS

Climate towards Info Sharing (LOW), Blockchain Scalability (HIGH)

"Lack of understanding of might foster a hostility towards the technology." – Workshop participant

Blockchain scales, but people do not feel inclined to share information beyond what is needed for service providers. Information becomes more "intelligent", but there is a disconnection of technology and society. Trust has remained an issue, despite blockchain being technically capable of trustless, scalable transaction. Public skepticism permeates the debate surrounding token-based economies. Communities will be open to energy aggregation, but data sharing is minimal. Public blockchains have the potential to mitigate the risks of information sharing, as a layer of personal data services, but face adopter apprehension. In the European Union, a new, improved General Data Practices and Regulation is introduced. For this reason, it becomes especially importantly for governments to establish a strong legal definition of "need-to-know" information. There is a potential use case for blockchain within this scenario, but most of it ends up being within private enterprise-scale applications, or for self-sovereign identity management. In this scenario, achievement of neither climate change objectives nor blockchain-facilitated systems transformation are expected.

IDENTIFIED BLOCKCHAIN USE CASES

- Self-sovereign identity management
- Enterprise-scale private blockchains focused on data management
    - Billing and settlements
    - Data reconciliation in auditing processes

POLICIES

(presented in decreasing order of perceived robustness)

- Energy & Data Literacy, Educational campaign (Slightly robust)
- Incentivisation of flexibility (to help lower-economic status end-users gain value from the energy transition) (Slightly robust, slightly uncertain)
- *Shifting from Time-of-Use to Dynamic pricing (dubious)*
- *End-users own and can transact their own data with third parties (Moderately Redundant)*

PARADISE

SELECTED DIRECTIONS

Climate towards Info Sharing (HIGH), Blockchain Scalability (HIGH)

This is a true global copperplate scenario. There is greater urbanisation, with most people living in urban centers. Energy flows freely, with African border countries becoming key energy players from massive Saharan solar arrays (allowing for local Saharan economies to economically leverage their position). High voltage direct current will transmit energy from large-scale renewable generation sites to end-users. We expect a free market in its purest form, enabled by open data and unlimited means for exchange. Big polluters are held accountable with blockchain-based public emissions auditing tools, automatically billing them for greenhouse gas emissions. Small companies can participate in the market, and we expect to see many more energy suppliers. The lines between the buyer and the supplier blur, and more customer choices results in a strong market position for the buyer. People are the masters of their data and decide what they want to do with it. The full spectrum of use cases for blockchain is enabled within this scenario, ranging from incremental applications such as billing/settlement to transformational applications like peer-to-peer energy trading. The energy mix will be nearly entirely renewable, with natural gas eventually phased out. In Europe, the Netherlands has traditionally functioned as a hub for the European continent. Under this scenario, this role is expected to grow. There is also greater organisation at the local level, and an accompanying rise in energy cooperatives. Wars are no longer waged over energy. As a result, global standard of living rises, and there is a freer flow of people across borders, migration is dynamic and easier than ever before. However, geopolitical shifts are an important consideration. Some nations acting as large-scale HVDC hubs will gain power from their position, will we see an OPEC for transmission hubs, or will this be distributed into redundancy? In a world in which nations can no longer strive to be energy independent, energy interdependence is the new norm.

IDENTIFIED BLOCKCHAIN USE CASES	**POLICIES** (presented in decreasing order of perceived robustness)

• Guarantee of Origin
• Monitoring/Compliance
• Enhanced Demand Response Management
• Self-sovereign identity management
• Data management
  ◦ Billing and settlements
  ◦ Data reconciliation in auditing processes
• Peer-to-Peer Trading
	• Shifting from Time-of-Use to Dynamic pricing (Highly robust)
	• Incentivisation of flexibility (to help lower-economic status end-users gain value from the energy transition) (Highly robust)
	• *Energy & Data Literacy, Educational campaign (Slightly redundant)*
	• *End-users own and can transact their own data with third parties (Slightly Redundant)*

BATTLE OF THE TITANS

SELECTED DIRECTIONS

Ownership of Data (LOW), IoT Enablement (HIGH)

Under this scenario, there is a proliferation of connected devices, with an oligopoly of energy suppliers, distribution systems operators, and service providers. There will be a culling period, in which the existing incumbents compete amongst each other to become one of a few prevailing vertically integrated energy supplier and service provider. In both the developed and developing world, most countries will have energy generated from renewables, but it is controlled by corporations. There is the "illusion" of democracy. Corporations will have power over the government, through extensive lobbying. and push for regulations which suit them. There will be a high share of renewables within the energy mix, but people will not own the solar panels on their respective roof. Energy resources will be distributed, but control will be centralised. Almost all data belongs to the corporations, and citizens have little to no control over it. With centralised corporate control in this scenario, there is less motivation to explore societally transformative blockchain use cases.

IDENTIFIED BLOCKCHAIN USE CASES

- Guarantee of Origin
- Enterprise-scale private blockchains focused on data management
    - Billing and settlements
    - Data reconciliation in auditing processes

POLICIES

(presented in decreasing order of perceived robustness)

- End-users own and can transact their own data with third parties (Highly robust)
- Incentivisation of flexibility (to help lower-economic status end-users gain value from the energy transition) (Slightly robust)
- *Shifting from Time-of-Use to Dynamic pricing (Moderately redundant)*
- *Energy & Data Literacy, Educational campaign (Highly redundant)*

DIGITAL FREEDOM

SELECTED DIRECTIONS

Ownership of Data (HIGH), IoT Enablement (LOW)

In this scenario, IoT integration is cheap, and people have greater control over both their data and electricity. Almost 100% of the energy mix consists of distributed renewables. We expect to see "digital utilities" emerging, with virtual power plants and AI-enabled energy aggregation and load balancing. There is less corporate control, and continued growth in household-owned PV and community storage. This should also be reflected in the global context. There will be a blockchain use case for many processes, even including peer-to-peer energy trading. This is expected to be a highly transformative scenario, changing physical and digital infrastructure, and societal norms around energy use. Energy will become increasingly abundant without sacrificing progress towards other Sustainable Development Goals. The business of energy supply will no longer be profitable. Societies come to value non-financial acts or services, weakening the strength of corporate lobbying and monetary systems. By averting a climate planetary disaster, a foundation is laid for long-term capability development across current and future generations.

IDENTIFIED BLOCKCHAIN USE CASES

- Guarantee of Origin
- Monitoring/Compliance
- Enhanced Demand Response Management
- Self-sovereign identity management
- Data management
    - Billing and settlements
    - Data reconciliation in auditing processes
- Peer-to-Peer Trading

POLICIES

(presented in decreasing order of perceived robustness)

- Energy & Data Literacy, Educational campaign (Highly robust)
- Shifting from Time-of-Use to Dynamic pricing (Highly robust)
- Incentivisation of flexibility (to help lower-economic status end-users gain value from the energy transition) (Highly robust)
- End-users own and can transact their own data with third parties (Highly robust)

BACK TO THE FUTURE

SELECTED DIRECTIONS

(Ownership of Data +, IoT Enablement –)

This scenario might resemble conventional life during the 90's. Corporations will have more centralised control over power generation, albeit from majority renewables. There is little motivation on the part of the incumbent organisations to innovate, since the threat of disintermediation is low. Less data is generated on-site (i.e. households) and thus most data are controlled by corporations, despite it being owned by individuals. This is also expected within the global context. It is unclear as to whether there is a blockchain use case here. A potential entry point could be in the aftermath of a series of data breaches by the corporations. This might lead to public outrage, leading to a call for distributed control. Overall, since IoT penetration fails to develop as previously hoped for, there aren't new markets created from the hypothesized data streams thereof. This is a technologically and societally incremental scenario.

IDENTIFIED BLOCKCHAIN USE CASES

- N/A beyond what currently exists

POLICIES

(presented in decreasing order of perceived robustness)

- Energy & Data Literacy, Educational campaign (Highly robust)
- *Shifting from Time-of-Use to Dynamic pricing (Moderately redundant)*
- *Incentivisation of flexibility (to help lower-economic status end-users gain value from the energy transition) (Moderately redundant)*
- *End-users own and can transact their own data with third parties (Highly redundant)*

Policy Selections

One policy was selected in both workshops, a **Shift from Time-of-Use to Dynamic pricing models** for end-user electricity pricing. The policies selected in the Utrecht workshop were a shift to dynamic pricing, de-siloing of metering data, community blockchain interoperability guidelines and standardization efforts, and real-time reporting requirements for P2P trading. In the Rotterdam workshop, shift to dynamic pricing, energy literacy, policies which incentivize flexibility (to help lower-economic status end-users gain value from energy transition), and policies will enable end-users to own and transact their own data were selected. More detailed information about the type of policy instrument and their targeted innovation system functions can be found in the table below (Table 15).

Table 17: Policies selected for stress-testing, instrument type, and innovation system functions associated with it.

POLICY	INSTRUMENT TYPE	TECHNOLOGICAL INNOVATION SYSTEM FUNCTION
Energy Literacy	Regulation and/or Soft Instrument	Knowledge creation, development, and diffusion (C1), Resource mobilization (C5)
Shift from Time-of-Use to Dynamic pricing models for end-user electricity pricing	Regulation	Significant changes in regime rules (D2), Reduced support for dominant regime technologies (D3)
De-silo metering data. Make it available for 3rd parties	Regulation	Knowledge creation, development, and diffusion (C1), Entrepreneurial Experimentation (C4)
Community guidelines, standardization efforts within blockchain community	Soft instrument	Knowledge creation, development, and diffusion (C1), Establishing market niches/market formation (C2)
Real-time reporting requirements for P2P trading	Regulation	Significant changes in regime rules (D2)
Policies which incentivize flexibility (to help lower-economic status end-users gain value from energy transition)	Economic transfer	Establishing market niches/market formation (C2), Significant changes in regime rules (D2)
End Users own and can transact their own data, to third parties	Regulation	Changes in social networks, replacement of key actors (D4)

Policy Stress-testing

The objective of this exercise is to determine which policies are robust under which scenario. This was guided by the underlying questions:

- Can we expect the policies going to be fully implemented by whatever predominant drivers are influencing this scenario?
- Will the policies have an impact in the intended target area (i.e. facilitating the energy transition in a way which leaves open an entry point for blockchain/DLT)?
- Would the desired impact (low-carbon, decentralised energy transition) be unlikely to occur if the policy is not introduced under a scenario?

Two dimensions were used to evaluate the policies under each scenario: Robustness/Redundancy & Uncertainty.

Robust votes were given a positive value, and "redundant" votes were given a negative value. The number of votes was summed up, and categorized by the following criteria:

- Unanimous Negative – Highly Redundant, Weak Policy
- Negative value between half and all participants – Moderately Redundant
- Negative Value less than half of number of participants – Slightly Redundant
- Positive Value less than half of number of participants – Slightly Robust
- Positive value between half and all participants – Moderately Robust
- Unanimous Positive – Highly Robust

A second dimension is Uncertainty, and the following criteria were used to categorize it and denoted by the following formatting:

- *Slightly Uncertain* – Less than half of participants express uncertainty
- **Moderately Uncertain** – Between half and less than total number of participants
- **<u>Highly Uncertain</u>** – Unanimous group expression of uncertainty, or the number of Robust and Redundant votes cancel each other out.

On the following page, the voting results are presented. Robust policies are readily identifiable (Table 16).

Table 18: Policy Stress-testing Matrix (Columns: Scenarios, Rows: Policies)

	United Front	*Bitcoin*	*Within and About*	*The Matrix*	*Lockchain*	*Paradise*	*Battle of the Titans*	*Digital Freedom*	*Back to the Future*
Energy Literacy + Education Campaign					Slightly Robust	**Slightly redundant**	Highly redundant	Highly Robust	Highly Robust
Shift from Time of Use to Dynamic Pricing	Moderately Robust	*Slightly Robust*	Moderately Robust	*Slightly Robust*	**0**	Highly Robust	Moderately Redundant	Highly Robust	*Moderately Redundant*
De-silo Metering Data	Moderately Robust	Moderately Robust	Moderately Robust	Highly Redundant					
Standardisation within blockchain space (interoperability)	Highly Robust	Slightly Robust	**0**	Slightly Robust					
Real-time reporting requirements for Energy transactions to grid operators	Slightly Robust	Slightly Robust	**0**	Moderately Robust					
Policies which incentivise flexibility (to help lower-economic status end-users gain value from energy transition)					*Slightly Robust*	Highly Robust	Slightly Robust	Highly Robust	**Moderately Redundant**
End Users own and can transact their own data, to third parties					*Moderately Redundant*	**Slightly Redundant**	Highly Robust	Highly Robust	Highly Redundant

We will start with dynamic pricing, since it was the only policy to be selected in both scenarios. Sixty-six percent, six out of nine of participants voted dynamic pricing to be robust. Next, we proceed to summarizing the voting outcomes of policies in separate workshops. Flexibility incentives was voted robust by eighty percent, four out of five participants. De-siloing of metering data, community interoperability standardization, and real-time reporting requirements were voted robust by three out of four participants. Energy literacy was voted robust by three out of five participants. Lastly, a policy which enabled end-users to own and transact their own data was voted robust by two of three participants, with the rest abstaining. The voting results can be seen in Table 17 below, and then the following section will include more in-depth descriptions of the voting results for each individual policy.

Table 19: Voting results from policy stress-testing, robustness of policies.

	Robust	Uncertain	Redundant	DEGREE OF ROBUSTNESS (# robust votes / total # votes)
Energy Literacy	3	0	2	3/5 (60%)
Shift from Time-of-Use to Dynamic pricing models for end-user electricity pricing	6	1	2	6/9 (66%)
De-silo metering data. Make it available for 3rd parties	3	0	1	3/4 (75%)
Community guidelines, standardisation efforts within blockchain community	3	1	0	3/4 (75%)
Real-time reporting requirements for P2P trading	3	1	0	3/4 (75%)
Policies which incentivize flexibility (to help lower-economic status end-users gain value from energy transition)	4	0	1	4/5 (80%)
End Users own and can transact their own data, to third parties	2	0	3	2/3 (66%)

ENERGY LITERACY & EDUCATION CAMPAIGNS

Time Period: 2018-2025

Workshop session: Rotterdam

Robust	• **Lockchain** (Society Openness to Info Sharing LOW / Blockchain Scalability HIGH) • **Digital Freedom** (Self-ownership of data HIGH / IoT Enablement HIGH) • **Back to the Future** (Self-ownership of data HIGH / IoT Enablement LOW)
Redundant	• **Battle of the Titans** (Self-ownership of data LOW / IoT Enablement HIGH)
Uncertain	• **Paradise** (Society Openness to Info Sharing HIGH / Blockchain Scalability HIGH)

OBSERVATIONS

This policy was deemed robust under two key circumstances:

- End-users own their data, so they will need to be taught what they can do with it
- The technology exists to share data in a scalable way, but society is not yet open to the prospect of sharing. Encouraging energy and data literacy is then thought to help facilitate openness to data-sharing, which is a key driver to a more decentralised and efficient electricity distribution system.

Energy literacy is deemed a redundant or weak policy under Battle of the Titans, in which data is centrally owned and controlled and there is a high degree of IoT enablement. There was moderate uncertainty surrounding the relevance of such a policy in a scenario such as Paradise, since the desired impact is already achieved.

SHIFT FROM TIME-OF-USE TO DYNAMIC PRICING

This policy was the only tool selected in both workshops.

Robust	• **United Front** (Social Cohesion HIGH / Innovation HIGH) • **Within and About** (Behind-meter incentive design HIGH / Blockchain Scalability HIGH) • **Bitcoin** (Democracy of Political System HIGH / IoT Enablement HIGH) • **The Matrix** (Democracy of Political System LOW / IoT Enablement HIGH) • **Paradise** (Society Openness to Info Sharing HIGH / Blockchain Scalability HIGH) • **Digital Freedom** (Self-ownership of data HIGH / IoT Enablement HIGH)
Redundant	• **Battle of the Titans** (Self-ownership of data LOW / IoT Enablement HIGH) • **Back to the Future** (Self-ownership of data HIGH / IoT Enablement LOW)
Uncertain	• **Lockchain** (Society Openness to Info Sharing LOW / Blockchain Scalability HIGH)

OBSERVATIONS

High degrees of IoT enablement and blockchain scalability alone are not deciding factors in whether a more flexible pricing policy will be enacted. Dynamic pricing policies were deemed robust by sixty-six percent of workshop participants under scenarios with high social cohesion and improved design of behind-the meter incentives, with fifty percent responding the same for scenarios in which there was high societal openness to information-sharing and decentralised data ownership. The degree to which a government is democratic was not described as a deciding factor in adoption of dynamic pricing policy. Over seventy-five percent of Rotterdam workshop participants expressed uncertainty as to the robustness of a dynamic pricing policy under the Lockchain scenario (Society Openness to Info Sharing LOW / Blockchain Scalability HIGH).

DE-SILO METERING DATA

This policy was selected as important in the Utrecht workshop.

Robust	• **United Front** (Social Cohesion HIGH / Innovation HIGH) • **Within and About** (Behind-meter incentive design HIGH / Blockchain Scalability HIGH) • **Bitcoin** (Democracy of Political System HIGH / IoT Enablement HIGH)
Redundant	• **The Matrix** (Democracy of Political System LOW / IoT Enablement HIGH)
Uncertain	• 5 voters abstained from voting under the **Within & About scenario** (Behind-meter incentive design HIGH / Blockchain Scalability HIGH)

OBSERVATIONS

A high degree of IoT enablement was not the deciding factors in whether or not de-siloing was likely to be introduced under multiple scenarios. Democracy was deemed an important factor, with seventy-five percent of workshop participants stating that de-siloing was likely under democratic conditions, while the participants unanimously agreed that de-siloing was unlikely to occur in undemocratic political contexts. Fifty-eight percent of participants agreed that de-siloing of metering data was likely to be enacted under a scenario in which blockchain scalability issues are resolved, and behind-meter incentives are improved, with one participant disagreeing, and five abstaining.

STANDARDISATION WITHIN THE BLOCKCHAIN COMMUNITY (INTEROPERABILITY)

This policy was selected in the Utrecht workshop.

Robust	•**United Front** (Social Cohesion HIGH / Innovation HIGH) •**Bitcoin** (Democracy of Political System HIGH / IoT Enablement HIGH) •**The Matrix** (Democracy of Political System LOW / IoT Enablement HIGH)
Redundant	•N/A
Uncertain	•**Within and About** (Behind-meter incentive design HIGH / Blockchain Scalability HIGH), with ten abstentions from voting, and two countering votes

OBSERVATIONS

Seventy-five percent of participants agreed that a standardization effort would be a robust policy under the United Front scenario, in which there was both high social cohesion and innovation. To a lesser degree, IoT enablement, regardless of the democratic political context, was deemed an important factor. This was indicated by "robust" votes from twenty-five and forty-two percent of participants, in the undemocratic and democratic contexts, respectively. Half of participants abstained from voting, and ten and seventeen percent voted that standardization would be redundant or irrelevant in the undemocratic and democratic contexts, respectively.

REAL-TIME REPORTING REQUIREMENTS FOR ENERGY TRANSACTIONS TO GRID OPERATORS

This policy was selected during the Utrecht workshop.

Robust	• **United Front** (Social Cohesion HIGH / Innovation HIGH) • **Bitcoin** (Democracy of Political System HIGH / IoT Enablement HIGH) • **The Matrix** (Democracy of Political System LOW / IoT Enablement HIGH)
Redundant	• N/A
Uncertain	• **Within and About** (Behind-meter incentive design HIGH / Blockchain Scalability HIGH), with eight abstentions from voting, and four countering votes.

OBSERVATIONS

The only scenario under which a real-time reporting requirement for energy transactions among energy aggregators to grid operators is deemed robust is The Matrix (Democracy of Political System LOW / IoT Enablement HIGH), with seventy-five percent of participants voting it robust, with twenty-five percent dissenting, and no abstentions. The United Front and Bitcoin scenarios were also voted as conducive environments, with seventeen percent of participants voting "robust", with ten percent dissenting in the case of United Front, and over seventy-five percent abstention.

POLICIES WHICH INCENTIVIZE FLEXIBILITY

(To help lower-economic status end-users gain value from energy transition)

This policy was selected by the Rotterdam workshop participants.

Robust	• **Paradise** (Society Openness to Info Sharing HIGH / Blockchain Scalability HIGH) • **Digital Freedom** (Self-ownership of data HIGH / IoT Enablement HIGH) • **Battle of the Titans** (Self-ownership of data LOW / IoT Enablement HIGH)
Redundant	• Back to the Future (Self-ownership of data HIGH / IoT Enablement LOW)
Uncertain	• **Lockchain** (Society Openness to Info Sharing LOW / Blockchain Scalability HIGH)

OBSERVATIONS

Societal openness towards information sharing, and a high degree of IoT enablement were unanimously decided to be an important driver in a scenario in which a policy aimed at incentivizing flexibility would be expected to be robust. Self-ownership of data was also voted as important, however, high IoT enablement was a more significant factor. This can be seen in that both high IoT enablement contexts were deemed relevant contexts for a flexibility incentive policy, regardless of the exact structure of data ownership. Societal openness to information sharing was deemed a more significant factor in the relevance of a flexibility incentive policy, rather than high blockchain scalability. This can be seen in two scenarios: Paradise (Society Openness to Info Sharing HIGH / Blockchain Scalability HIGH), and Lockchain (Society Openness to Info Sharing LOW / Blockchain Scalability HIGH). The flexibility incentive was unanimously voted as robust under Paradise, but in a societal context where end-users are not willing to sharing their information beyond a need-to-know basis, the policy was expected to be redundant or weak. Under the Lockchain scenario, half of participants voted "robust", while half voted either "redundant" or "uncertain".

END USERS OWN AND CAN TRANSACT THEIR OWN DATA, TO THIRD PARTIES

This policy was selected for stress-testing during the Rotterdam workshop.

Robust

- **Digital Freedom** (Self-ownership of data HIGH / IoT Enablement HIGH). Unanimous robust
- **Battle of the Titans** (Self-ownership of data LOW / IoT Enablement HIGH)**.** Unanimous robust

Redundant

- **Back to the Future** (Self-ownership of data HIGH / IoT Enablement LOW). Unanimous redundant
- **Lockchain** (Society Openness to Info Sharing LOW / Blockchain Scalability HIGH) Eighty-three percent redundant, seventeen percent uncertain.

Uncertain

- **Paradise** (Society Openness to Info Sharing HIGH / Blockchain Scalability HIGH). Fifty percent uncertain, thirty-three percent redundant, seventeen percent robust.

OBSERVATIONS

End-user data ownership and transaction to third parties is unanimously deemed robust under the Digital Freedom and Battle of the Titans scenarios. Both scenarios feature high IoT enablement, but different in the structure of data ownership. Workshop participants accounted for this by stating that in a decentralised data space, an open market will be created between end-users and third-party service providers. In the Battle of the Titans scenario, in which data ownership is centralised, participants envisioned a scenario in which large oligopolies compete with each other to offer end-users better services. The ability to transact data may become a deciding factor in customer retention, and these "titans" will shift their business models to remain competitive. In the Back to the Future scenario, in which data ownership is decentralised but IoT is poorly enabled, a unanimous "redundant" vote was made, with participants stating that there will not be enough data available for a scalable decentralised market in a low-IoT environment. The Lockchain scenario, in which society is not open to sharing data outside of a need-to-know basis but blockchain scalability issues are resolved, was deemed a redundant or weak setting for a data self-ownership and transaction policy. An explanation for this in the workshops was that if there is abundant data, but people are not willing to share it, then the policy does not facilitate anything. Under the Paradise scenario, in which these is a high degree of societal openness to information sharing, and blockchain is scalable, fifty percent of participants were uncertain as to the relevance of the self-ownership/transaction policy, thirty-three percent deemed it redundant, and seventeen percent voted "robust". During the ensuing discussion, participants who described the policy as either uncertain or redundant defended their statement by explaining that people who are already socially willing and technically able to transact their own data do not need support from a specific policy. On the other hand, those who voted "robust" stated that an official policy would further bolster the market and discourage regression to a previous market model.

Competitive Analysis[6]

"Companies, by default, traditionally have always kept their cards close to their chest, and they win whenever they can create a monopoly. And what you see with some companies trying to tackle a blockchain use case, they are trying to create a monopoly using blockchain. Blockchain is about cutting out the middleman, power to the people, but some companies are really trying to create a blockchain on a platform which they control.

And it's technically possible- that's the scary part*."* – Interviewee

This section will remain brief, since the specific contents will remain for internal use within CGI Group.

For each scenario, participants were asked to assess how the general competitive landscape would be expected to shift in the energy sector.

Four Porter's Five Forces diagram were distributed to each scenario group. Participants were asked to fill out a diagram for each scenario, in which they assess the following dimensions:

1. Rivalry among Existing Firms
2. Threat of New Market Entrants
3. Buyer Power
4. Threat of Substitution or Disintermediation
5. Supplier Power

They were instructed to respond with "Much less, slightly less, neutral/unsure, slightly more, much more than the present" for each dimension under each scenario.

In no selected DLT/energy scenario was it expected that buyer/end user power would increase while simultaneously protecting incumbents from the threat of disintermediation or substitution. A common refrain among the workshop participants was that they didn't yet know who among the energy incumbents would be flexible enough to shift their value proposition to a world of decentralised data ownership, without going under.

[6] A more detailed version of this competitive analysis was developed and provided to CGI for internal use.

Workshop Follow-up and External Expert Interviews

Follow-up respondent composition

A total of ten respondents were interviewed during this research stage. All were actively involved in the energy sector, in capacities ranging from academic research, energy suppliers, grid operators, market actor platforms, and independent consultants. Four interviewees (40%) had direct experience in distributed ledger technology. Four (40%) had energy policy expertise. Two (20%) had software expertise. Nine (90%) participants had directly experience leading and implementing projects within the energy sector. With respect to gender distribution, two (~20%) of the participants were female and remaining eight (80%) were male.

Table 20: Participant composition of follow up interviews.

TITLE	SUBJECT AREA KNOWLEDGE
Master's student (blockchain-focused research), Dutch university	General software, blockchain, Project Development
Master's student (blockchain-focused research), Dutch university	blockchain
Dutch DSO	Project Development
Energy supplier	blockchain, Project Development
Independent consultant	Project Development
Energy supplier	Policy, Project Development
Independent consultant	Policy, Project Development
Dutch consultancy	Policy, Project Development
Independent Consultant	general software, blockchain, Project Development
Dutch market actor platform	Policy, Project Development

External Expert Consultations

A total of seven respondents were interviewed during this research stage. All were actively involved in the energy sector, in capacities ranging from academic research, energy suppliers, grid operators, energy market facilitator, central government, and consultancy. Five interviewees (71) had direct experience or knowledge of distributed ledger technology. One (14%) of respondents had professional knowledge in marketing. One (14%) had energy policy expertise. Two (28%) had innovation policy expertise. Three (42%) had software expertise. Six (86%) participants had directly experience leading and implementing projects within the energy sector. With respect to gender distribution, two (~28%) of the participants were female and remaining five (72%) were male.

Table 21: Participant composition of external consultations

TITLE	SUBJECT AREA KNOWLEDGE

Dutch DSO	General software, blockchain, project development
Dutch DSO	Marketing, project development, blockchain
Energy science department, Dutch public research university	General software, blockchain, project development
Innovation consultancy start-up	Innovation policy, project development
Dutch energy market facilitator	Policy, project development
Dutch DSO	General software, blockchain, project development
Rijksoverheid	Innovation policy, blockchain, regulation

Scenarios selected for exploration

Table 22: Scenarios selected for follow-up

Scenarios Selected	# times selected	Driver	
Lockchain	4	Society Openness to Info Sharing (-)	Blockchain Scalability (+)
Paradise	3	Society Openness to Info Sharing (+)	Blockchain Scalability (+)
Central Energy Systems	2	Society Openness to Info Sharing (-)	Climate Change Impacts (+)
Siloed	1	Society Openness to Info Sharing (+)	Blockchain Scalability (-)
Tortoise in the Shell	1	Social Cohesion (-)	Orientation of Solutions (-)
No Guarantees	1	Social Cohesion (-)	Blockchain Scalability (+)
Bitcoin	1	Democracy of Political System (+)	IoT Enablement (+)
Within and About	1	End-User Incentive design (+)	Blockchain Scalability (+)
Utopia	1	Society Openness to Info Sharing (+)	Climate Change Impacts (+)
United Front	1	Social Cohesion (+)	Orientation of Solutions (+)

Five scenarios which were used for policy stress-testing were revisited, Lockchain, Paradise, Bitcoin, Within and About, and United Front. The five selected scenarios which were not selected for policy stress-testing in the workshops were Central Energy Systems, Siloed, Tortoise in the Shell, Tortoise in the Shell, No Guarantees.

Lockchain and Paradise, the two most frequently selected scenarios in follow-up and external interviews were also selected in the workshops. Central Energy Systems, which was not selected for policy stress-testing, was selected by two follow-up respondents. The scenarios Siloed, Tortoise in the Shell, No Guarantees, Bitcoin, Within and About, Utopia, and United Front were all selected once for review.

Lockchain was commonly described by respondents as a "plausible" scenario, citing that it more likely for blockchain scalability issues to be resolved rather than to expect an improvement in the societal climate towards information-sharing. Paradise, which was created using the same drivers as Lockchain, was described as a desirable future, but contingent on transforming current information-sharing practices.

In Central Energy Systems, there is a low willingness by societal actors to share information where not required, and the society of interest does not experience catastrophic impacts of climate change. Both respondents who selected this scenario stated that they felt that climate change impacts are unlikely to be avoided, therefore rendering this scenario unlikely, but non-transformative in any case. In Siloed, a successful transition to a low-carbon society was envisioned. Blockchain failed to scale in this scenario, but greater openness to information sharing enabled existing energy market actors to develop more advanced services to end-users while simultaneously increasing the share of renewables. Tortoise in the Shell had no blockchain use cases, described by a respondent as an "East Germany" of the future, in which short-term environmental solutions prevail, and social cohesion is lacking. The energy transition was not envisioned to succeed nor progress very far in that scenario. No Guarantees was described as an "Ayn Rand"-like future, in which social cohesion is low but blockchain, in addition to a myriad of advanced technologies mature and are integrated into the energy sector. Application areas include self-sovereign identity management, administrative processes, and certificate trading. This scenario was described as hypercapitalist, with price signals driving most user activity, and the energy transition was only seen to succeed if end-users were able to gain value from it individually. Peer-to-peer trading wasn't of interest here. People were described as more inclined towards feeding in their electricity, since the "community spirit" doesn't exist to motivate people to take on reduced convenience in order to trade with each other. Finally, in Utopia, societal attitudes towards information-sharing are open, and catastrophic impacts of climate change are not felt. This avoidance of a climate disaster means that existing institutions are less likely to be pushed to their breaking point, their legitimacy remains intact, and civil society actors are generally less likely to feel the impetus to explore decentralised technologies such as DLT, self-sovereign identity management, and peer-to-peer. Therefore, the current order of energy actors is envisioned to remain in the field, only using the increase in information to provide. In this scenario, an energy transition is successful, and while individual households have increasingly adopted rooftop panels or energy storage, service providers or balance responsible parties have control over the appliances, serving as a distributed "fleet".

Synthesis

In this section, the most frequently drivers, expected order of emergence and transformative potential of DLT use cases are collected. Scenarios which were selected for further discussion the follow-up and external interviews, in addition to those which were used in policy stress-testing, were sorted by transformative potential, transition pathway, governance mode. Policy instruments and mixes deemed most robust in a transformative scenario are also presented.

Emergence and Transformative Potential of DLT use cases

The array of DLT applications were described to vary in their transformative potential (Figure 13). For example, Guarantee of Origins on a distributed ledger do not shift any market models, and can readily be co-opted into an existing scheme. Administrative processes and data management can also be incremental, depending on whether the efficiency gains of the organisation are used to further extract profit, or to optimise operational costs.

Three use cases were deemed transformational, with respect to changes in information-sharing practices, social institutions, and market models: self-sovereign identity management, enhanced demand response, and peer-to-peer energy trading at the household level. The rationale is as follows. Self-sovereign identity management, that is, a system in which identification is centered around the user, and owned by them, can erode the power of monopolies which previously exploited their ability to delete a user as means of erasure. Several respondents stated that DLT-enabled demand response could improve the business case for further decentralisation of generation and control. Respondents argued that energy aggregation is more efficient at higher levels of organisation, but that a distributed ledger could facilitate bottom-up aggregation without compromising the need-to-know at higher levels. Such a system could facilitate development of interconnected microgrid infrastructure. Peer-to-peer energy trading between households was deemed highly transformative, since it involves a shift in societal practices, regulations, physical infrastructure, and market models.

With respect the order of expected emergence of these use cases, Guarantee of Origins/certificate-trading were unanimously the first use cases expected to mature, followed by data exchange/administrative processes, self-sovereign identity management, enhanced demand response, and peer-to-peer energy trading (Figure 15).

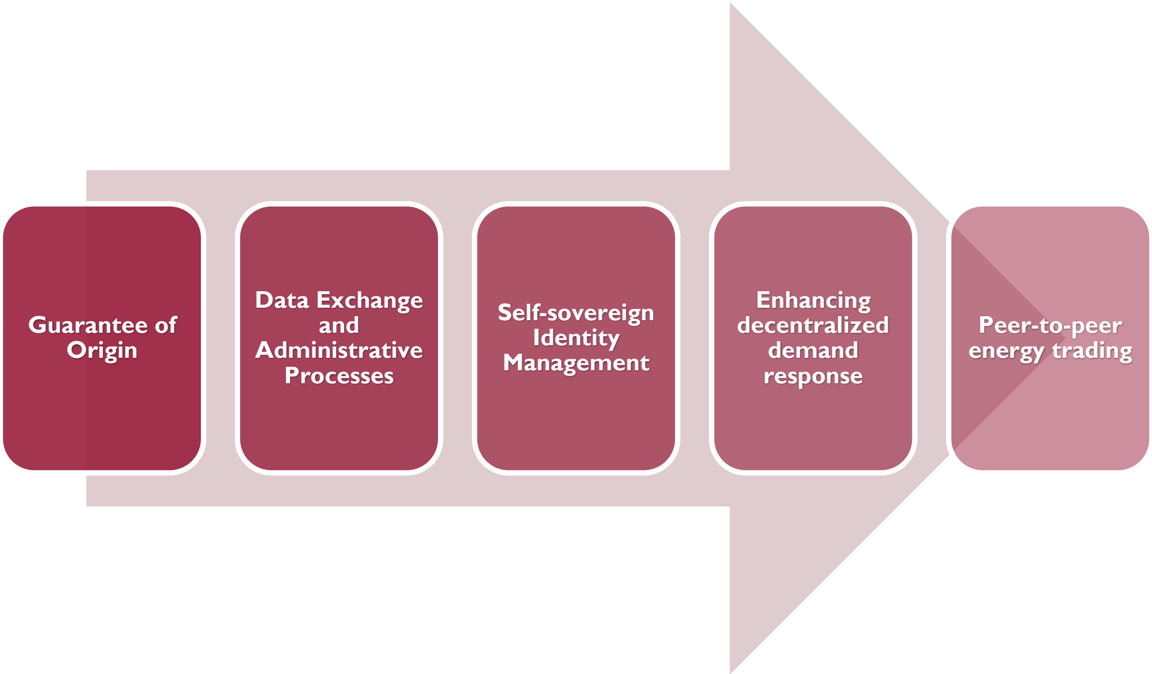


Figure 14: Respondent defined transformational potential of distributed ledger technology use cases within the energy sector (in order of increasing transformational potential, and expected emergence)

Systems Transformation – With or Regardless Of DLT?

Following the foresight workshops and subsequent interviews, the scenario narratives were coded for transformative potential by five dimensions (on a categorical scale of Low, Moderate, and Radical).

- Societal (ex. mention of revolutions, shifts in political systems, urbanizations, social cohesion, social norms and practices)
- Economic transformative potential (determined by the Porter's 5 Forces diagrams drawn for each scenario, mention of moving away from capitalist systems, novel value systems)
- Information/Data institutions transformative potential (ex. mention of self-sovereign identity, open data practices, metering data de-siloed)
- Digital Energy Infrastructure (ex. Mention of non-DLT cases, i.e. artificial intelligence applications, predictive analytics, big data, cloud and/or fog computing, telecommunications networks development)
- Physical Energy Infrastructure (ex. number of generation units, distribution thereof, intensification of an energy source requiring more installation of physical infrastructure)

The values of the social, economic, and information dimensions for each scenario were aggregated, then weighted to have the same value as those of combined digital and physical energy infrastructure, hereafter referred to as the Info-socioeconomic and Energy Infrastructure transformative potential pillars. The pillar value of each scenario was then plotted on a quadrant against the types of DLT use cases identified (ex. Energy Infrastructure pillar for "Tortoise in the Shell", plotted against zero DLT use cases).

The x-axis indicates transformative potential of a scenario, as determined from respondent descriptions. Low was taken to mean business as usual, "moderate" indicated a slight level of change which is beyond what is expected from business-as-usual but not as much at the highest end, and "Radical" indicated what the majority of respondents deemed either a massive deviation or acceleration from the current trend.

The y-axis was designated by the number of DLT use cases identified in each scenario. Criteria for which use cases were deemed transformative was determined by respondent feedback during the follow-up and external interviews. Respondents were asked to order the previously discussed use cases in order of increasing transformative potential (Figure 15). In increasing order of hypothesized transformative potential, these were guarantee of origin, data exchange and administrative processes, self-sovereign identity management, enhanced decentralised demand response, and peer-to-peer energy trading.

What is apparent from the figures below is that appearance of transformative DLT use cases is not expected in scenarios where there is little to no sociotechnical transformation.

Comparing Energy Infrastructure and DLT Transformative Potential

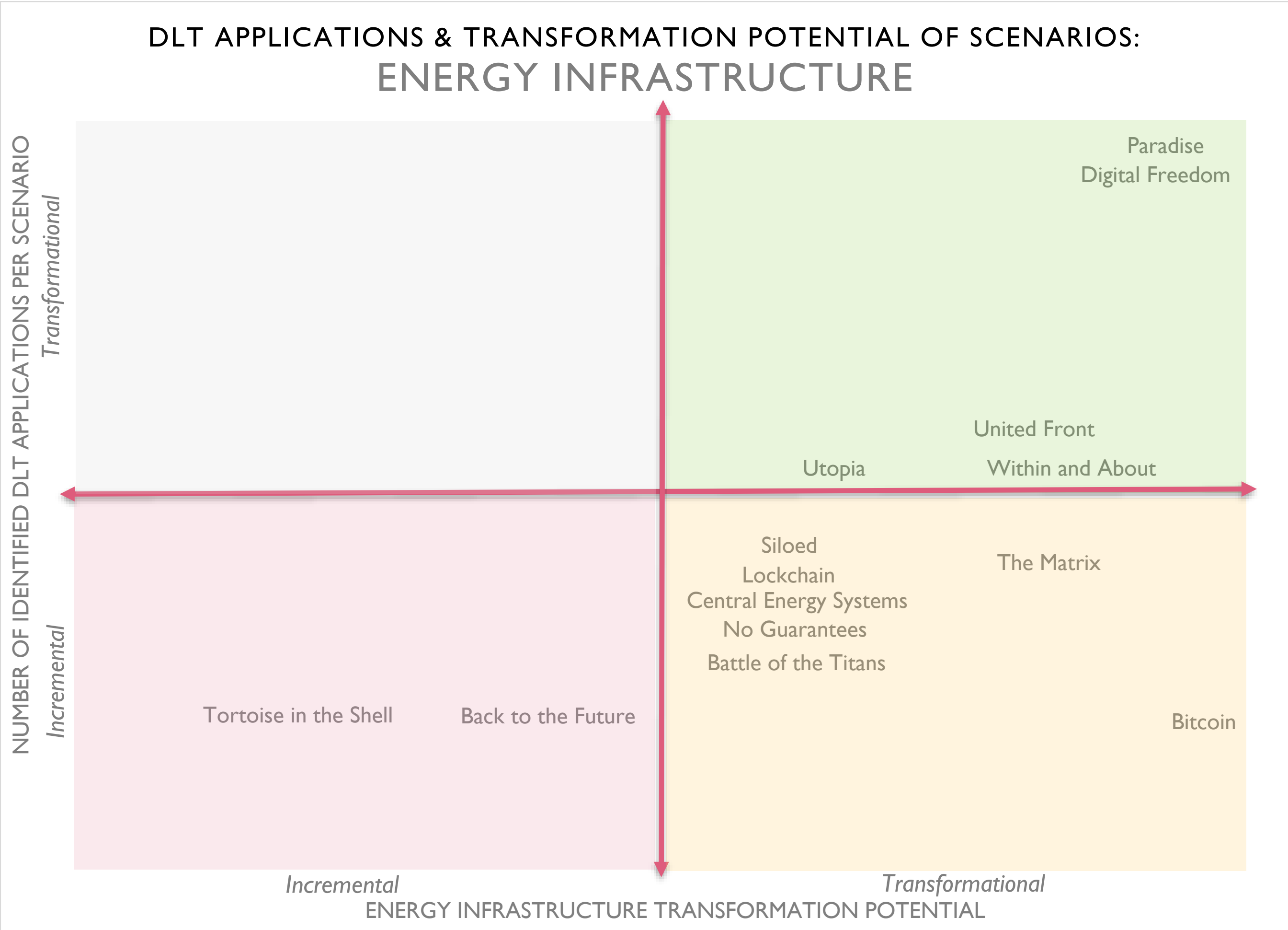


Figure 15: Quadrant graph comparing transformational potential of blockchain use cases identified in scenarios versus the digital and physical energy infrastructure transformation potential of the scenarios selected in policy stress-testing and follow-ups.

Five scenarios were deemed transformative with respect to both DLT applications and development of digital and physical energy infrastructure: Paradise, Digital Freedom, United Front, Within and About, and Utopia. Seven scenarios were deemed transformative in energy system infrastructure, both digital and physical: Bitcoin, The Matrix, Siloed, Lockchain, Central Energy Systems, No Guarantees, and Battles of the Titans. There were two incremental/incremental scenarios, in which neither transformative DLT use cases nor energy infrastructure transformation was expected: Back to the Future, and Tortoise in the Shell.

Comparing Info-socioeconomic and DLT Transformative Potential

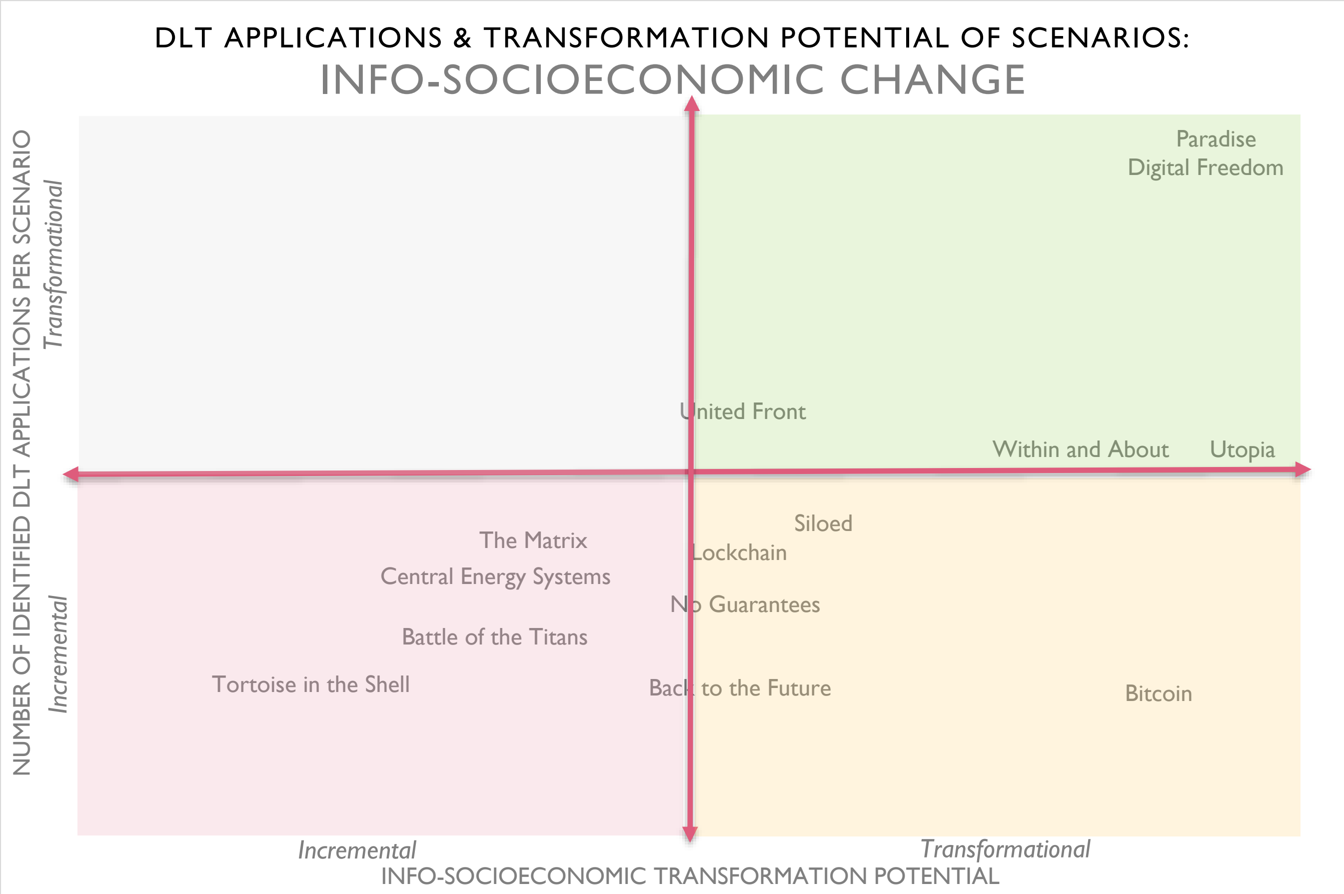


Figure 16: Quadrant graph comparing transformational potential of blockchain use cases identified in scenarios versus the info-socioeconomic transformational potential of the scenarios selected in policy stress-testing and follow-ups

Five scenarios were deemed transformative with respect to both DLT applications and info-socioeconomic change: Paradise, Digital Freedom, United Front, Within and About, and Utopia. Five scenarios were deemed transformative in info-socioeconomic change: Bitcoin, Siloed, Lockchain, No Guarantees, and Back to the Futures. There were four incremental/incremental scenarios, in which neither transformative DLT use cases nor info-socioeconomic transformation was expected: The Matrix, Central Energy Systems, Battle of the Titans, and Tortoise in the Shell.

Comparing Comprehensive Factors and DLT Transformative Potential

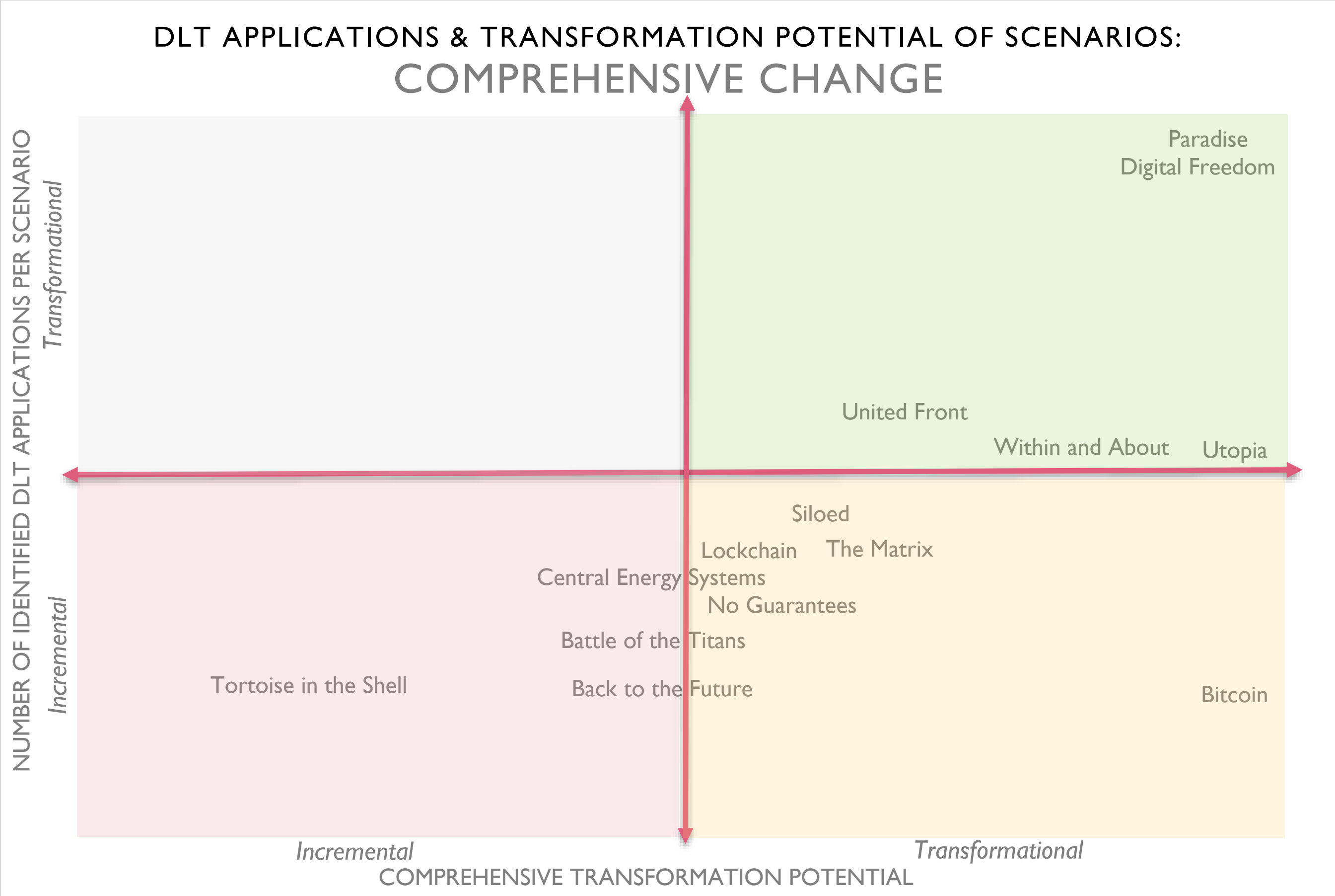


Figure 17: Quadrant graph comparing transformational potential of DLT use cases identified in the scenarios versus the comprehensive (energy technology + info-socioeconomic change) transformational potential of each scenario.

Five scenarios were deemed transformative with respect to both DLT applications and overall change: Paradise, Digital Freedom, United Front, Within and About, and Utopia. Five scenarios were deemed com transformative in overall change: Bitcoin, The Matrix, Siloed, Lockchain, and No Guarantees. There were four incremental/incremental scenarios, in which neither transformative DLT use cases nor overall transformation was expected: Central Energy Systems, Battle of the Titans, Back to the Future, and Tortoise in the Shell.

Drivers Underpinning Sociotechnical and DLT Transformative Scenarios

Five scenarios fall consistently into the upper right quadrant of the matrix (Transformational DLT applications, Transformational comprehensive energy systems development): United Front, Utopia, Within and About, Paradise, and Digital Freedom. Drivers which underpinned these scenarios include:

- high societal openness to information sharing
- improvement in blockchain scalability
- improvement of end-user incentives
- avoidance of catastrophic climate change impacts
- self-sovereignty over data
- high IoT enablement
- high social cohesion
- long-term orientation towards solution development

Across all the scenarios which were selected either in the workshops or in the post-workshop interviews, the most frequently drivers which underpinned them were (in decreasing order): blockchain scalability, societal openness to information-sharing, orientation of solutions, end-user financial incentives, IoT enablement, trust in institutions, social cohesion, data ownership, and degree of effects of climate change on society (Figure 18).

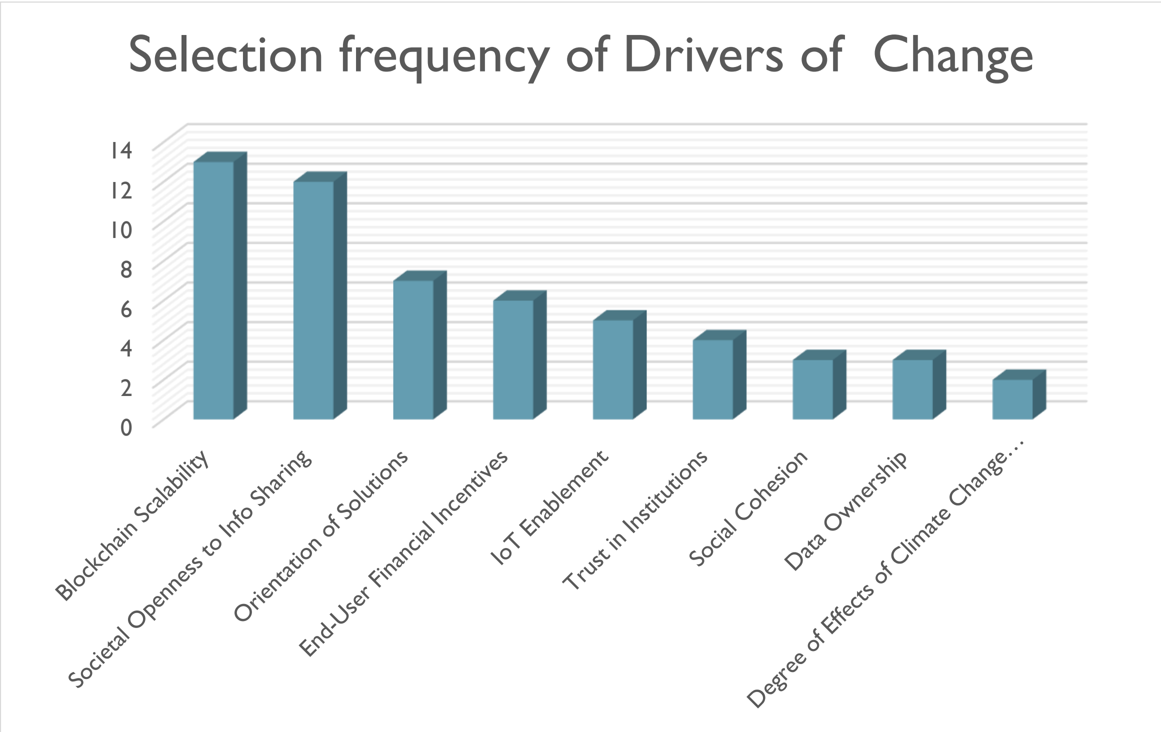


Figure 18: Selection frequency of drivers of change in the selected scenarios

Governance Modes of Selected Scenarios

The governance modes corresponding to each of the scenarios used in policy stress-testing and in post-workshop interviews were determined in the synthesis (Table 18). This was assessed by reading the scenario descriptions and policy stress-testing results, and noting how closely the institutional, actor, and content features of the narrative and robust policy instrument types matched to individual governance mode within the typology provided by Driessen et al. (2012).

Tortoise in the Shell most closely matched a market-led mode of governance. In Back to the Future, the governance mode could not be determined because of respondent disagreement over visions of the market and state relationship dynamic. Battle of the Titans, in which an oligopoly of energy actors emerges, and their power may come to rival the state's, we identified self-governance. Central Energy Systems, despite having the word "Central" name, was convergently found to most closely fit a centralised mode of governance. Lockchain, information-starved high-tech future, and No Guarantees, our "Ayn Rand" energy future, were both characterized by self-governance.

Siloed resembled a public-private governance mode, while The Matrix and United Front, strikingly different scenarios, were both centralised. Utopia was decentralised. Within and About, Bitcoin, Digital Freedom, and Paradise most closely matched an interactive mode of governance.

Table 23: Scenarios discussed in workshops and follow-up interviews, and their corresponding governance mode

SCENARIO	DRIVERS SELECTED	VENUE SELECTED	GOVERNANCE MODE	SUPPORTING DESCRIPTIONS (actors, relations, policy instruments, see Fig. 17))
Tortoise in the Shell	Low social cohesion Short-term orientation of environmental solutions	Follow-up	Market-led	State loses legitimacy, lack of civil organisation, global markets will shape consumer behavior
Back to the Future	High ownership of data Low IoT enablement	Workshop	N/A	Robust policies: Policy instruments oriented towards knowledge creation, development, and diffusion (C1) Redundant policies: **Regulation** oriented towards establishing market niches/market formation (C2), significant changes in regime rules (D2), Reduced support for dominant regime technologies (D3), and Changes in social networks, replacement of key actors (D4)
Battle of the Titans	Low ownership of data	Workshop	Self-governance	Incumbent market actors remain dominant, but begin to compete more fiercely with increasingly advanced technology, platforms, and innovative business models

	High IoT enablement			Consolidation trend, picking each other off in bid for hegemony Robust policies: **Economic transfer** and **regulation** which promote establishing market niches/market formation (C2), Changes in social networks, replacement of key actors (D4) Redundant policies: Policy instruments oriented towards knowledge creation, development, and diffusion (C1), Reduced support for dominant regime technologies (D3)
Central Energy Systems	Low societal openness to information-sharing High impact climate change effects	Follow-up	Centralised	State actors **regulate** and control, no civil society engagement. Market actors are contracted to work for the state.
No Guarantees[7]	Low social cohesion High blockchain scalability	BOTH	Self-governance	Highly individualistic society, high innovation Market driven, driven by **economic transfer policies** aimed at innovation.
Lockchain	Low societal openness to information-sharing High blockchain scalability	BOTH	Self-governance	Robust policies: **Economic transfer** policies which are oriented towards knowledge creation, development, and diffusion (C1), establishing market niches/market formation (C2), resource mobilization (C5) Redundant policies: **Regulations** oriented toward reduced support for dominant regime technologies (D3), Changes in social networks, replacement of key actors (D4)
Siloed	High societal openness to information-sharing Low blockchain scalability	BOTH	Public-private	Trust is not an issue, but DLT is not technically at the point where it can enable peer-to-peer transaction in energy communities. Market actors still play a major role, in collaboration with state actors, and devise solutions with the wealth of solutions available to them. However, people do not have autonomy over their data, they are not equal actors in this architecture.

[7] Along with *Lockchain*, *No Guarantees* was described by six follow-up respondents as the "most likely" scenarios in Europe and North America. They share a context in which social cohesion is low, trust in information-sharing is low, and distributed ledger technology scales. Both are highly individualistic societies.

The Matrix	Low democracy High IoT enablement	Workshop	Centralised	Robust policies: **Regulation** which is oriented towards significant changes in regime rules (D2), reduced support for dominant regime technologies (D3). **Soft instruments** which promote establishing market niches/market formation (C2) Redundant policies: **Regulation** which is oriented towards entrepreneurial experimentation (C4)
United Front	High social cohesion Long-term orientation of environmental solutions	BOTH	Centralised	Non-individualistic behavior, state actors able to make sweeping reforms and use their authority to shape direction of market innovation in direction of long-term solutions Robust policies: **Regulation** geared toward significant changes in regime rules (D2), Reduced support for dominant regime technologies (D3), Knowledge creation, development, and diffusion (C1), Establishing market niches/market formation (C2), and **Soft instruments** promoting knowledge creation, development, and diffusion (C1), Entrepreneurial Experimentation (C4)
Utopia	High societal openness to information sharing Low impact climate change effects	Follow-up	Decentralised	Due to non-catastrophic climate change impacts, no sharp pull on society towards extreme centralisation by state nor market actors.
Within and About	Improved end-user incentives High blockchain scalability	BOTH	Interactive	Robust policies: **Regulation** geared toward entrepreneurial experimentation (C4), reduced support for dominant regime technologies (D3) Uncertain policies: **Soft instruments** which promote establishing market niches/market formation (C2)
Bitcoin	Highly democratic High IoT enablement	BOTH	Interactive	Policy enacted at many different levels, bottom-up engagement and transnational policies. Strong policy integration, sustainable energy and human development considered in policy design across sectors and levels. Robust policies: (See *United Front*)
Digital Freedom	High ownership of data High IoT enablement	Workshop	Interactive	Rich local knowledge and agency. Decentralised grid balancing will be possible. Robust policies: Policy instruments which promote knowledge creation, development, and diffusion (C1), resource mobilization (C5). **Regulation** which enables significant changes in regime rules (D2), reduced support for dominant regime

				technologies (D3), and changes in social networks, replacement of key actors (D4). **Economic transfer policies** which are oriented toward establishing market niches/market formation (C2), and significant changes in regime rules (D2)
Paradise	High societal openness to information-sharing High blockchain scalability	BOTH	Interactive	Bottom-up community organisation and increased free global movement. Massive infrastructure changes, state and market actor collaborate, civil society co-design solutions which best suit their particular contexts while taking connected systems into account.

Identifying Sustainability Transition Pathways

Following evaluation of transformative potential and identification of governance modes, the scenarios were then assessed for transition pathways as described in the sociotechnical systems literature. The drivers underpinning each scenario corresponded either to landscape, regime, or niche levels. The following questions guided assignment scenarios to transition pathways:

1. Is the landscape exerting pressure on the regime? (ex. Catastrophic climate change impacts)
2. Is there considerable internal regime tension? This was determined based on the results of the competitive analysis.
3. Is the niche mature at the temporal endpoint of interest, 2050?
4. Is the niche technology competitive or symbiotic with the regime?

The driver directions of the scenarios informed categorization about level-specific criteria. This was further elaborated through revisiting the scenario narratives from the workshops, and follow-up and external interviews. Precise criteria for each scenario can be found in the table below (Table 19).

Tortoise in the Shell most closely matched a de/re-alignment pathway. In Back to the Future, Battle of the Titans, and Central Energy Systems, we were unable to clearly distinguish a transition pathway. No Guarantees and Lockchain were categorized as technological substitution pathways. Siloed, systems descriptions did not correspond to any of the transition pathways. United Front also did not fit neatly into a specific pathway but had several characteristics of a reconfiguration pathway. The Matrix was a reconfiguration pathway. Utopia, Bitcoin, and Digital Freedom fit into a reconfiguration pathway. Within and About, and Paradise were characterized as transformation pathways.

Table 24: Transition pathways identified in selected scenarios

SCENARIO	DRIVERS SELECTED	Levels selected	Landscape Exerting Pressure on Regime	Internal Regime tension: Low or High	Maturity of Niche	Niche x Regime: Competitive or Symbiotic	TRANSITION PATHWAY

Tortoise in the Shell	Low social cohesion Short-term orientation of environmental solutions	Landscape, regime	Yes	Low	Immature	Competitive	De/re-alignment
Back to the Future	High ownership of data Low IoT enablement	Regime, regime	No	Low	Immature	Symbiotic	N/A
Battle of the Titans	Low ownership of data High IoT enablement	Regime, regime	No	Low	Immature	Symbiotic	N/A
Central Energy Systems	Low societal openness to information-sharing High impact climate change effects	Landscape, landscape	Yes	Low	Immature	Competitive	N/A
No Guarantees[8]	Low social cohesion High blockchain scalability	Landscape, Niche	Yes	High	Mature	Competitive	Technological Substitution
Lockchain	Low societal openness to information-sharing High blockchain scalability	Landscape, Niche	Yes	Moderate	Mature	Symbiotic	Technological Substitution
Siloed	High societal openness to information-sharing Low blockchain scalability	Landscape, Niche	No	High	Immature	Symbiotic	N/A

[8] Along with *Lockchain*, *No Guarantees* was described by six follow-up respondents as the "most likely" scenarios in Europe and North America. They share a context in which social cohesion is low, trust in information-sharing is low, and distributed ledger technology scales. Both are highly individualistic societies.

The Matrix	Low democracy High IoT enablement	Regime, regime	Yes	Low	Mature	Symbiotic	Reconfiguration
United Front	High social cohesion Long-term orientation of environmental solutions	Landscape, Regime	No	Moderate	Mature	Symbiotic	N/A, possibly Reconfiguration
Utopia	High societal openness to information sharing Low impact climate change effects	Landscape, landscape	Moderate	Low	Immature	Symbiotic	Transformation
Within and About	Improved end-user incentives High blockchain scalability	Regime, Niche	No	High	Mature	Symbiotic	Reconfiguration
Bitcoin	Highly democratic High IoT enablement	Landscape, regime	High	Low	Immature	Symbiotic	Transformation
Digital Freedom	High ownership of data High IoT enablement	Regime, regime	Moderate	High	Immature	Symbiotic	Transformation
Paradise	High societal openness to information-sharing High blockchain scalability	Landscape, niche	High	High	Mature	Symbiotic	Reconfiguration

Integrating Governance Mode, Transition Pathways, and Transformative Potential

Lastly, the governance mode, transition pathway, and transformative potential of the scenarios are presented in an integrated table below (Table 20).

In non-DLT and non-sociotechnically transformative scenarios (Tortoise in the Shell, Back to the Future, Battle of the Titans, Central Energy Systems), governance modes ranged from market-led, centralised, and self-governance. The only identifiable transition pathway was of de/re-alignment.

Scenarios in which DLT applications were incremental, but transformative of the overall energy system (No Guarantees, Lockchain, Siloed, The Matrix, United Front), self-governance, public-private, and centralised governance were identified. Transition pathways were reconfiguration or technological substitution.

Comprehensively transformative scenarios (Utopia, Within and About, Digital Freedom, Paradise) and one DLT-incremental/energy systems-transformative scenario (Bitcoin) corresponded to either decentralised or interactive modes of governance. Reconfiguration or transformation were the only transition pathways identified.

Table 25: Selected scenarios, and their governance mode, transition pathway, and transformation potential/DLT relationship

SCENARIO	DRIVERS SELECTED	GOVERNANCE MODE	TRANSITION PATHWAY	TRANSFORMATION (see Fig. 15)
Tortoise in the Shell	Low social cohesion Short-term orientation of environmental solutions	Market-led	De/re-alignment	No transformative DLT use cases, nor sociotechnical transformation
Back to the Future	High ownership of data Low IoT enablement	N/A	N/A	
Battle of the Titans	Low ownership of data High IoT enablement	Self-governance	N/A	
Central Energy Systems	Low societal openness to information-sharing High impact climate change effects	Centralised	N/A	
No Guarantees[9]	Low social cohesion High blockchain scalability	Self-governance	Technological Substitution	Transformative with respect to overall sociotechnical system. Incremental DLT applications
Lockchain	Low societal openness to information-sharing	Self-governance	Technological Substitution	

[9] Along with *Lockchain*, *No Guarantees* was described by six follow-up respondents as the "most likely" scenarios in Europe and North America. They share a context in which social cohesion is low, trust in information-sharing is low, and distributed ledger technology scales. Both are highly individualistic societies.

	High blockchain scalability			
Siloed	High societal openness to information-sharing Low blockchain scalability	Public-private	N/A	
The Matrix	Low democracy High IoT enablement	Centralised	Reconfiguration	
United Front	High social cohesion Long-term orientation of environmental solutions	Centralised	N/A, possibly Reconfiguration	
Utopia	High societal openness to information sharing Low impact climate change effects	Decentralised	Transformation	Transformative DLT use cases, and transformation of overall sociotechnical system
Within and About	Improved end-user incentives High blockchain scalability	Interactive	Reconfiguration	
Bitcoin	Highly democratic High IoT enablement	Interactive	Transformation	
Digital Freedom	High ownership of data High IoT enablement	Interactive	Transformation	
Paradise	High societal openness to information-sharing High blockchain scalability	Interactive	Reconfiguration	

Robust Policy Mixes and Instruments in Comprehensively Transformative Scenarios

In this section, the specific innovation system functions targeted by policies which were deemed robust in the scenarios corresponding to "comprehensively transformative potential" (the green rows in Table 20) are synthesized. The type of policy instrument is also shared. The policies will be separated into creative and destructive categories:

Creative (Niche support)

Policies instruments which support niche development are recommended to target the following system functions. Regulatory instruments which target knowledge creation, development, and diffusion (C1), establishing market niches/market formation (C2), and entrepreneurial experimentation (C4). Economic transfer policies are deemed robust when they are oriented toward establishing market niches/market formation (C2). Robust soft policy instruments were commonly found to promote knowledge creation, development, and diffusion (C1), and entrepreneurial experimentation (C4). Overall, any type of policy instrument which fosters knowledge creation, development, and diffusion (C1) and resource mobilization (C5) was voted robust.

Destructive (Regime destabilization)

Fewer destructive policy instruments were deemed robust, only regulatory and economic transfer instruments. Regulatory instruments which were thought robust contributed to significant changes in regime rules (D2), reduced support for dominant regime technologies (D3), and replacement of key actors (D4). Robust economic transfer policies were oriented toward significant changes in regime rules (D2).

Comments on the Gas Transition

The cost of the Dutch gas transition was cited by six respondents in post-workshop interviews as a bottleneck to state and energy actor investment in development of DLT use cases. Several went further, arguing that the state focus on household actors needs to be more evenly distributed to also include industrial actors. One claimed that the government is ignoring the "big fish" in the gas transition because the industrial lobby is exerting influence over policy decisions.

Discussion and Recommendations

In this section, the results from the project are discussed in the broader context of transformative change, anticipatory governance of emerging technologies. Next, the research questions will be revisited and addressed. Policy recommendations are then made to state, market, and civil society actors regarding a DLT and sustainable energy systems transformation. Following discussion of the results is a reflection on the limitations of the methods and theories employed in this investigation. The section is concluded with proposals for future research.

Discussion of Results

Visioning

A variety of DLT application areas were identified as having a potential role in a sustainable energy system change. These include certificate trading/Guarantee of Origin, to allow for procurement of renewably sources electricity without relying on a third certifying body, payment layers and administrative processes, identity management, enhancing demand response, and peer-to-peer trading.

Many respondents stated that they could imagine DLT having an incremental role in the energy transition. Transformative roles were either deemed contingent on other technical developments, such as telecommunications, rate of electrification, and advances in artificial intelligence.

The backgrounds of the respondents appeared to shape the types of visions. Most interviews with participants with deeper blockchain knowledge yielded more transformative visions, along with more pointed concerns about centralisation concerns within the energy service provider space. More socially-oriented scenarios were described by the more technically-focused interview subjects, while interviews with non-technical respondents erred toward the financially-focused side, and unearthed greater concerns for end-user incentives in the energy transition.

In discussing applications of distributed ledger technology to the energy sector, two refrains were commonly heard: that of the true value of the proposed use case, and of what constitutes "true decentralisation".

The Spirit of Decentralisation

Respondents from all stages of the research stated that they felt that most blockchain/DLT projects were operating on promises to transform processes/increase efficiency, rather than empirical evidence. However, one respondent who was part of a team which developed a blockchain billing/settlements layer for a municipal utility attributed the success of their project to the ability to use real user data to model the savings on the proposed solution. Giving users the option to compare price and performance, and ultimately decide for themselves was a key factor.

Another common point made by respondents is that of reconciling the capabilities of distributed ledger technology with the principles behind it. First was the claim that the value proposition of most DLT projects in the energy sector were not as efficient as existing approaches or did not provide significant value-added beyond what a conventional database would. Second, in application areas where DLT was deemed to be a valuable solution (such as Guarantee of Origin), a common lament was that a DLT solution may be created but was not true to the spirit of the technology itself, which is to enable peer-to-peer, without centralisation. Consensus mechanisms such as Proof-of-Stake and Proof-of-Authority were highlighted as examples. While they consume significantly less electricity, they are not truly decentralised. However, some also argued that Bitcoin itself is not truly decentralised, because of the centralisation of mining pools which validate transactions in the network. Lines were drawn in the sand over the following concepts:

- DECENTRALISATION OF ELECTRICITY GENERATION
- DECENTRALISATION OF METERING DATA
- DECENTRALISATION OF ADMINISTRATIVE/FINANCIAL PROCESSES
- DECENTRALISATION OF DISTRIBUTION CONTROL
- DECENTRALISATION OF TRANSACTION VALIDATORS
- DECENTRALISATION OF MINING NODES

Overall, the greatest divergence is observed in those who envision decentralisation of generation, and those who also envision decentralisation of control. While observed in passing, this difference merits future research.

Driver Mapping and Selection

Mapping of the drivers by STEEPLE criteria and sociotechnical system level shed light on some patterns which may have otherwise gone unnoticed. For instance, most drivers were technological and economic, and were categorized in the regime level. The reasoning behind this is not clear.

Given that neither the quantity of drivers identified in each category nor the system level of the driver appeared to relate to the perceived importance of the drivers themselves by the respondents, the number of drivers identified in the technological and economic categories are likely due to respondent professional familiarity. It is probable that if respondents spend the most time studying these domains, they can therefore be expected to have a richer awareness of the dynamics of change processes therein.

The rationale behind selection of non-technical and non-economic factors was frequently grounded in anecdotal reasoning, with respondents mentioning books they had recently read, philosophies, and personal experience. This differed significantly from the rationale for selection of technical and economic factors, in which respondents typically directed attributed their choice to their professional experience.

The driver "Impacts of Climate Change on Society" was a frequent conversation point across the visioning interviews, workshops, and subsequent interviews. All respondents who mentioned it stated that they felt that the driver direction is already set, towards "Catastrophic impacts", citing extinction and extreme weather event in recent years.

Scenario Design

Both workshops were initiated with an introduction of the research objective and round of participants introductions. An overview of blockchain technology and identified use cases from the visioning interviews were shared. Participants were assigned into groups, at which point the drivers of changes were then presented. Each group then selected two drivers from different categories, then used these drivers to guide the scenario design process.

Requiring the selection of different STEEPLE category drivers demonstrated promise in creation of diverse and transdisciplinary scenarios. The drivers selected for use in the scenario design activity were social cohesion, degree of innovation/orientation of environmental solutions, democracy of political system, degree of internet of things (IoT) enablement, improvement of behind-the-meter end-user incentives, blockchain scalability, societal openness towards information-sharing, impacts of climate change on society, and ownership of data.

Participants from the workshops noted that they learned a lot and connected with useful and interesting individuals. Most expressed enthusiasm for the systemic approach. Structuration of selection/voting processes and background on foresights methods were mentioned as areas of improvement. Overall, these remarks affirm the intention that the workshop itself had served as a form of intervention, in addition to providing useful feedback for improvement of future events.

Policy Pathways and Mixes

While this research began with the intention to generate a clear and actionable policy pathway, it illuminated the importance of governance arrangement and policymaking process over the specifics of the policies themselves. Most respondents saw most of the proposed policies as inevitable, so the key differentiator is then execution. An important point was made – *What does it matter how soon a policy is enacted if it is not well-thought out?* Do stakeholders have an opportunity to participate in policy design, implementation, and what are their avenues for feedback? These are all important considerations which were not immediately apparent at the outset of this investigation, that it's not just *what* policymakers do, it's also how they do it.

Key Points from Follow-up and External Interviews

While end-user engagement was selected as an important driver of change in the scenario design process, it was considerably more emphasized in individual interviews. End-user engagement was a polarizing topic, in all phases of the research. Some respondents argued that all the end-user needs to see is a price signal, whereas other cited it as a critical factor in community-based energy transformations. This divide is significant, and as seen in the synthesis of this report, energy infrastructure transformation may yet be possible without democratic end-user engagement. The importance of education, of younger generations, policymakers, and industry leaders of general energy principles and our "digital footprint", was highlighted as useful in shaping societal norms and increasing end-user engagement.

Dynamic pricing emerged as a key policy, in the eyes of workshop participants. In follow-up and external interviews, several qualifiers were attached to its implementation. In short, it is possible for dynamic pricing to be used for value extraction, but there are other scenarios in which it enables value creation (in the form of reduced grid load, price contracts, options markets, and reduced energy bills), but most of the follow-up interviews did not include a discussion of how to mitigate the potential economic impacts on individual households. In an external consultation with a blockchain expert who worked for a long time at an energy utility, the tension between the current system and a decentralised future is strung over the human desire for convenience and reliability. True dynamic pricing might be attractive to an economist but would come off as repressive to the general population. For this reason, one respondent emphasized the need for some type of energy performance contract to be introduced, in order to allow general users to benefit from stability for a specified and known interval of time.

The importance of information-sharing was explained in further detail during several external interviews, some of which are participating in cross-competitor initiatives to open certain data silos within the Dutch distribution system. Access to data was highlighted as important in training machine learning models. These models could then be leveraged into highly sensitive grid-balancing algorithms, allowing for efficient management of decentralised generation.

In synthesizing the results, we found that futures which are transformative with respect to sustainable energy systems and distributed ledger technology, are primarily characterized by interactive modes of governance. This highlights the role of end-user engagement, despite the previous debates.

Incremental DLT applications (i.e.. Certificates of Origin, and open data initiatives between market actors) might be able to proceed without much government intervention. However, more salient applications (such as peer-to-peer energy trading) will require a strong, explicit stance from the government. The private sector will not be able to push this alone. An increase in the pressure from landscape factors can be reasonably expected, given recent climate models, political trends towards authoritarian figures and populism, and public outcry in response to illegal data collection, recent data breaches, and manipulation by algorithm. What remains unclear on the time horizon is the expected maturity of distributed ledger technology.

Research Questions Revisited

The findings of this research are reframed within the original research questions.

WHICH APPLICATIONS OF DISTRIBUTED LEDGER TECHNOLOGY HOLD THE MOST TRANSFORMATIVE POTENTIAL FOR SUSTAINABLE ENERGY SYSTEMS CHANGE?

The application areas outlined in the scenario narratives include certificate trading (such as Guarantee of Origin), cryptocurrency, billing, settlement, data reconciliation, monitoring, compliance, enhancing demand response, self-sovereign identity management, and peer-to-peer energy trading.

Two other use cases were identified in external consultations. The first was facilitation of bottom-up energy market clearing. The second proposed use case was the creation of a building identity on a blockchain record, the perceived benefit of which is the distribution the cost of renewables adoption and efficiency measures over the building's lifetime, rather than the duration of the adopter's residence.

WHICH DRIVERS MAY INFLUENCE THE DEVELOPMENT OF THESE APPLICATIONS?

Driver identification went beyond normative, market, and regulatory dimensions, to include social, technological, environmental, economic, political, legal, and ethical drivers. Additionally, these drivers were categorized based on the sociotechnical system level to which they corresponded (i.e. niche, regime, or landscape).

At the niche level, three key drivers were identified, all of which were technical. They include DLT scalability, ledger security, and interoperability between other types of ledgers or data structures.

At the regime level, selected drivers spanned across all STEEPLE criteria. These are end-user engagement, design of end-user financial incentives, type of utility-rate making, structure of wholesale pricing model, the level of democracy of political system, the degree of centralisation in government, rate of IoT Enablement, rate of electrification of transportation and/or rural areas, degree to which metering data is siloed, extent of telecommunications development, the legal status of a smart contract, the orientation of environmental solutions (adaptive/short-term, optimising/long-term), and the state of data ownership.

At the landscape level, identified drivers covered social, environmental, and ethical dimensions. These are social cohesion, societal climate towards information sharing, degree of trust in institutions, level of severity of climate change effects on society, and the effect of transparency on different subgroups of society.

Taking into account the results of the foresight workshops and post-workshop interviews, recurring drivers of change (and directions) in holistically transformative scenarios were found to be improvement in blockchain scalability, high societal openness to information sharing, long-term orientation towards development of environmental solution, improvement of end-user incentives, high IoT enablement, high social cohesion, self-sovereignty over data, and avoidance of catastrophic climate change impacts.

HOW CAN THESE DRIVERS BE CONSIDERED (IN TERMS OF GOVERNANCE) BY STAKEHOLDERS IN SUCH A WAY AS TO SUPPORT A DLT-ENABLED ENERGY SYSTEM TRANSITION?

Interactive governance was the predominant mode identified in transformative energy system scenarios. This is predicated on involvement of market and civil society actors at all government levels of policy design, implementation, and evaluation (Edelenbos et al., 2009). The policies deemed robust for facilitating energy systems change did not differ significantly between the DLT and non-DLT scenarios, but rather the design process did. Interactive policy-making is expected to maintain good working relationships between civil, market, and state actors, facilitating further decentralisation and experimentation.

Policy Recommendations

> *"I think the energy transition is an evolutionary process that we should try to enjoy. And if you want to enjoy navigating all these possibilities and uncertainties, then you have to have good relationships."*
>
> *- Respondent*

We recommend creation of policies which support an interactive governance arrangement. That is, policies which are integrated across sectors and levels, while maintaining a tailored approach to local contexts. Instruments are neither uniformly commanding, economically cajoling, nor voluntarily undertaken in good faith. Rather, they are typically negotiated between equal actors. A mix of various types of policy instruments is envisioned to be robust, if attention is paid to the system function they are individually meant to stimulate.

Policies which support niche development are recommended to target the following system functions:

- **Regulation** aimed at knowledge creation, development, and diffusion (C1), establishing market niches/market formation (C2), and entrepreneurial experimentation (C4).
- **Economic transfer policies** which are oriented toward establishing market niches/market formation (C2).
- **Soft policy instruments** promoting knowledge creation, development, and diffusion (C1), and entrepreneurial experimentation (C4).
- Regardless of instrument type, policies which promote knowledge creation, development, and diffusion (C1) and resource mobilization (C5) were voted robust.

Complementary destructive system functions and corresponding policy instruments:

- **Regulation** geared toward significant changes in regime rules (D2), reduced support for dominant regime technologies (D3), and replacement of key actors (D4).
- **Economic transfer policies** which are oriented toward significant changes in regime rules (D2).
- Soft policy instruments are not considered robust for regime destabilization in this case.

Examples of specific policy instrument examples corresponding to these system functions can be found in the Methodology section of this report (Table 4).

The specific policies proposed are:

- Shift from Time-of-Use to Dynamic pricing models for end-user electricity pricing
- De-silo metering data. Make it available for 3rd parties
- Community guidelines, standardization efforts within blockchain community
- Policies which incentivize flexibility (to help lower-economic status end-users gain value from energy transition)
- Energy Literacy
- Real-time reporting requirements for P2P trading
- End Users own and can transact their own data, to third parties

Again, we emphasize the importance of interactive engagement in design of these policies, especially prior to the implementation and roll-out. Otherwise, policymakers risk a backlash for neglecting externalities, compromising legitimacy in future policy endeavours.

Limitations of the Research

This work was a reconnaissance mission, and marks an initial foray into an empirical field which has very recently emerged. Therefore, we sought a general overview of the system, in order to identify areas for future research. This broad approach has many drawbacks, but we feel them to be outweighed by the newfound understanding of system actors, processes, and relations. Key limitations are described below. Much has been learned which will enrich the robustness of future research.

Theory

It is apparent that the theoretical foundation is the weaker point of this research. The researcher devoted the most time studying the subject matter and the methodology, rather than relevant theories which may have contributed to a more structured understanding of the empirical context.

Time was a limitation. Key breakthroughs regarding the theoretical relevance and analytical framework (i.e. sorting the scenarios by governance mode, and transition pathways, the drivers by sociotechnical system level, and policies by innovation system function and instrument type) were made in the final weeks of the project. The various components of the analytical framework (of creative/destructive innovation system function, policy instrument type, etc.) were known from the outset of this research; however, the potential for integrating them did not "click" until the final two weeks. Given that there are certain hard boundaries soon which prohibit the possibility of extending this investigation, the researcher attempted to consolidate the key contributions as functionally as possible.

The analytical framework proposed by Kivimaa and Kern was an insightful tool for understanding future innovation policies. However, when integrated with Borras and Edquist's policy instrument typology, as was done in this investigation, gaps in the framework become apparent. Further characterization of innovation policies would be handy in fleshing out a promising framework.

While it was possible to identify mention of various innovation system functions in the interviews, it would have better served the TIS literature if more care was taken to shape the interview questions in a way to more precisely assess actor perceptions regarding the system functions.

The proposed policy pathway shared in the results section was not as useful nor robust as hoped, as the research veered to focus more on the scenarios themselves, and the sorting of the policies into time periods lacked significant validation. In the future, more attention will be focused more on the construction of the policy pathway. Backcasting would be an intriguing foresights method to apply to this inquiry.

Operationalizing "transformative potential" was done rather subjectively, and would have benefitted from deeper empirical grounding, rather than intuition.

Methods

Foresights methods are a very stimulating approach, and a pleasure to apply. However, there were several limitations in their execution for this research.

The importance of clarifying foresights concepts at the beginning of the workshop was learned. While participants reported learning a lot from the workshops, a common critique of workshop was a lack of clarity in explaining the scenario design process and what a driver specifically is. An excessive focus on the subject matter, rather than the process, led to participant confusion in later stages.

Another limitation lies in the execution of group assignments. In the first workshop, when assigning groups, we didn't give them a period to re-situate themselves, get acquainted with each other, and to discuss amongst themselves which drivers they would like to include in their scenario matrix. In the Rotterdam workshops, we followed the group assignments and presentation of drivers with a short break. During this time, participants were able to more cohesively arrive at their group's driver selection. This poses a limitation to the validity of the drivers selected in the Utrecht workshop.

Driver definition was also a limitation. Within groups, participants disagreed on what they deemed to be the two directions of a driver. Requiring a group consensus and detailed definition of the drivers and driver directions would have improved the foundation for scenario design.

Another limitation was unclear guidance of criteria for scenario selection. The only criteria mentioned were that scenario had an identifiable DLT use case. Further specification would have helped reduce uncertainties in understanding participant selections. On that note, clarity in explaining and guiding the policy stress-testing voting was also not as smooth as it could have been, limiting the validity of the results.

In both workshops, it would have been informative to spend more time in discussion of the specific policies after the stress-testing. While the workshop did not feel stressful or extremely rushed, time was short. There was unfortunately little time to discuss specific policies, and this should be rectified in future sessions.

With respect to DLT use cases, it may have been clearer for respondents if we had people vote for whether they expected any of the use cases (which were presented at the beginning of the workshop) under each policy and each scenario.

Contributions

Methodological

This research integrated foresights methods with analytical frameworks from earth system governance, sustainable transitions theory, and innovation science in order to assess the governance and policy implications of distributed ledger technology within energy systems, with respect to sustainable development. In doing so, it contributed a novel methodological approach to anticipatory governance, and may be applied to other emerging technologies and sociotechnical systems.

Theoretical

This research contributes to the literature on transformative futures, by empirically demonstrating the importance of co-option of niche development by an incumbent regime on sustainability outcomes.

It also advances the theory on anticipatory climate governance, by suggesting that when policies are being considered for an emerging technology, interactive policy conceptualization, design, and evaluation are important factors.

This research also contributes to theoretical understanding of transformative futures by demonstrating the importance of information access and processing in systems change in the Anthropocene. Attitudes towards information-sharing, and institutions which structure it, should be part of the analytical scope of transformative futures research. For this reason, we stayed away from "socioeconomic" framing of transformative futures, opting instead for "info-socioeconomic" (yes, a more concise word is needed). Data is so much more than the new oil, and it needs a category of its own for deeper analysis.

Our next point is less a theoretical contribution, and more of a theoretical thread that we invite others to pull. In the area of innovation science, the potential role of military research and development in establishing technological path dependencies or shaping transition pathways within systems merits further investigation.

Policy

Several policy contributions are made in this research. Robust policies for a DLT-enhanced sustainable energy systems transformation are identified, in addition to envisioned governance modes.

The key policy takeaway should not be our advocating for a specific policy instrument, but rather how an interactive policy process can contribute to different outcomes.

Empirical

This research made empirical contributions both to policymakers, and to the workshop participants. Since the workshop participants are all active players in the energy sector, the sessions enabled them to expand their network and share knowledge, possibly influencing future developments.

Lastly, this work contributed to an understanding of the drivers and barriers in shifts in environmental governance, and relations between governance mode and transformative futures (i.e. sustainable outcomes).

Future Research

There are many paths forward extending from this research. If we hadn't connected certain aspects of the earth system governance with innovation science literature, we wouldn't have clearly seen the alignment between transformative future, transition pathways, and interactive governance. First and foremost, we propose future research in further developing and validating an integrated analytical framework which can be applied in foresights exercises to be used for anticipatory governance. The "failures framework" proposed by Weber and Rohracher, in which different types of system failures are framed with respect to transformative change, also presents an interesting analytical framework for future research (Weber & Rohracher, 2012).

When collecting policies, it would also be useful to investigate further into who the respondent feels should be responsible for which policy, and which stage of policymaking.

We also propose futures research in the domain of the specifically claimed use cases. A narrower and deeper investigation of the various claims made regarding each use case (e.g. Guarantee of Origin) could help further guide the search between groups investigating it.

The epistemology of people's perceptions of DLT is also an important area for future research. Over the past two years, various statements have disseminated into the energy and blockchain space which have an unexpected longevity. These terms can be traced back to a specific report or blog post, make the research team curious as to the knowledge which actors are drawing upon within this space. The two more frequent are "hype cycle[10]" and "solution looking for a problem[11]". How many people are determining whether it's true, and how many more others are simply echoing them (or each other)? As for those who are determining whether those statements are true, how are they going about doing so?

Regulatory sandboxes were identified as useful efforts in innovation; with the caveat that they didn't always accurately reflect broader societal conditions. Deeper study into the contextual conditions of regulatory sandboxes, in which new technologies and business models can be tested, is another area of suggested research.

The cognitive effect of the workshops, on how the participants interacted with other to arrive at ideas and visions, from where their assumptions came from, presents an attractive area of research. Similar to the caveats described surrounding regulatory sandboxes, the conditions of the workshop allowed for atypical behavior and reasoning to take place. The question here is – should we aim to make the workshops emulate a more realistic environment, or should we aim to learn how to alter the environment/choreography of these tools simulate various conditions. For example, it is was decided in this research to pair up participants with complementary knowledge bases, how might have scenarios differed had we siloed groups by background knowledge?

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[10] Gartner publishes an annual report titled "Hype Cycle for Blockchain Technologies", and has been observed by the researcher to be referenced continuously across meetups, conferences, and journal articles.

[11] Rob Drury, the CEO of accountancy software company Xero famously said this about blockchain in mid-2016, after a smattering of online articles being published with variations on that phrase in the title. The points he made about blockchain, however, are valid and came up again in this research.

Memorable Quotes

"Blockchain is not the end of history, it is just an iteration on the path of technological progress."

"Most claimed use cases for blockchain are not real use cases."

"Humans are coin-operated."

"People have lost their ability to reason."

"We need to restore analytical capacity to society"

"What I like about blockchain is how it triggers a change conversation about energy."

"In any case, for a sustainable energy transition, connecting users and producers is key. What will be the infrastructure which makes this all work? Possibly blockchain. Possibly."

"The energy sector is converging towards other industries. It typically trails the telecommunications industry by 10 years or so."

"Following 2030, all bets are off. Singularity is highly probable during that period."

"I doubt whether a fully democratic process will lead to an energy transition in time to avoid massive economic and social dislocations. And that is a frightening thought. I worry for my grandson's future"

"there is not a child that is born that is not very involved with plants and animals, so how can you say there is no end-user engagement from the start? People are born with care. There is nobody who is not born with care. … society persistently talks people away from it."

Conclusion

"we are accelerating into a new era of scientific discovery and engineering innovation, and the technologies being unleashed are proving (as usual) to be simultaneously strange, wonderful, and disturbing… One of the most visible examples of disruptive technology in recent years has been the emergence of the blockchain and associated crypto-currencies whose development trace back to just one scientific paper of uncertain provenance, published by an individual author most likely working under a pseudonym.

Indeed, this is both strange and disturbing, ***perhaps wonderful as well.".***

– Defense Advanced Research Projects Agency (DARPA) report, "A call to academia", 2018

The header quote in this section was retroactively chosen as the title of this report, because it touches on a key conclusion from our findings, that ***DLT applications within the energy transition do not necessitate a sustainable transition.*** Moreover, ***a transformation to a low-carbon energy system is not necessarily coupled to a positive social, economic, or information practices transformation.***

Many possible DLT/energy system futures were envisioned by the workshop participants, the majority of which described incremental DLT use cases. Some scenarios were strange, in which people were willing to share energy data, but low IoT enablement constrained DLT applications to incremental use cases. Others were disturbing, in which DLT was co-opted by existing energy oligopolies to make their existing administrative processes more efficient, without passing on that value to the end-users, leading to further consumer disenfranchisement. Another was comprised of a technologically advanced, dictatorial futurescape in which autonomous artificial intelligence systems have unfettered access to household, distribution, and transmission data. Optimisation was described as continuous and invisible to the consumer, with individual households able to use as much electricity as they want, when the system allows it. This dependency was disturbing to some and seen as inevitable by other respondents.

And as for Wonderful? The findings of this investigation echo the qualified optimism of the DARPA report. Perhaps. Five such scenarios were created.

The five scenarios in which a sustainable systems change occurred, accompanied by transformative DLT use cases, fell into two categories of transition pathways: reconfiguration and transformation. In some cases, the regime adopts DLT to optimise existing operations, and in the other pathway (transformation) the regime is forced to overhaul its structure in response to landscape pressures, with entry of DLT use providing a key impetus behind it.

This research makes several empirical contributions. First, it has collected blockchain use cases energy experts deem potentially relevant to energy systems. These include Guarantees- and Certificates-of-Origin for renewably sourced electricity, data management and facilitation of administrative processes (billing, settlement, clearing, data reconciliation, monitoring, and smart contracts), self-sovereign identity management, machine-to-machine communication and automatic transaction, enhancing demand response management by providing secure and trustless load data (which can be used to train machine and deep learning models), and peer-to-peer energy trading. Despite identifying these use cases, the current state of distributed ledger technology is that it remains both immature and co-optable by regimes. For this reason, it is not possible to definitively say whether it will have a positive or negative impact on achieving a sustainable energy system change.

Key drivers of said system change bridged levels and domains. Societally, an open attitude towards information-sharing is important, more so than trust in institutions and social cohesion. Blockchain scalability, security, and proliferation of IoT-enabled devices were selected as the most important technical drivers. Improvement of end-user incentives in energy, such as technology adoption subsidies, flexibility incentives, feed-in tariffs, and net-metering, are also needed in an engaged energy transition. Data autonomy and a long-term/optimisation orientation towards solution design were also highlighted. The degree of effects from climate change was identified as important, but the driver direction is already expected by most respondents to be set on a path towards inevitable economic and social dislocation.

From what can be discerned in the scenario descriptions, it is entirely plausible for energy infrastructure to transition to a low-carbon system, without social or economic transformation. While that is a worrying proposition, this research suggests that shifting energy governance arrangements to become more interactive may stave off that possibility. Innovation policy mixes also need to be structured in order to support this in the long-term.

The policies which were proposed in the visioning interviews, then subsequently stress-tested in the workshops, covered a range of soft, economic transfer, and regulatory instruments. Regarding niche-developing and regime-destabilizing innovation system functions, all three types of policy instruments were deemed robust for niche-development, whereas regulatory and economic transfer instruments alone were highlighted for regime-destabilization. The common sentiment among respondents was that most of the discussed policies are already planned over the coming decades, so the content of the policies is not the question, but rather their design, implementation, and evaluation.

In democratic scenarios, information-sharing between supply and demand side, and between competitors was selected as an important driver in innovation. However, the perceived legitimacy of how such data are collected is considered by most respondents to be the bottleneck. If data is unethically collected, that may lead to pushback by end-users. In the long run, having a sustainable relationship between those who generate data and those who trying to innovate with it is critical. This may require a transformation of the ways in which actors gain value from these processes.

Navigating the governance of a critical infrastructure during a time of urgency is a fraught task. This period of energy systems digitalization is a collision between two of the most disparately regulated sectors: ICT and energy. The former, ICT, is just now awakening to the hangover from the "*Move fast* *and break things"* party, while the latter is bound by regulation to deliver its product reliably, despite being increasing pressure by decentralisation of supply and renewables growth.

Energy systems are increasing in complexity, it is much more difficult to profit off something which one does not entirely control. However, it is not impossible. Understanding complexity requires massive amounts of data, in order to both understand actor-level and systems-level phenomena. These data must be collected somehow, and the current approaches are either siloed or illegal and facing enormous backlash. Energy actors who refuse to share information out of fear that it will compromise their competitive advantage are not playing to win, they are playing to not lose a narrowly-framed game. The landscape is changing and playing by the same rules is not expected get most of them far for long. Each year of waiting only increases the pain of the inevitable transition, and places planetary boundaries further at risk. If data is treated and defended as a scarce resource, technological innovation and sustainable development will not fully flourish.

Interactive governance is fed by rich local knowledge, and societal attitudes towards information-sharing are considered one of the most important drivers of change in a DLT-enabled transformative energy systems future. Therefore, we conclude this work by reiterating that the means by which said knowledge is gathered and used to inform action must be deemed legitimate by stakeholders, if we are to coax out a transformative energy future.

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APPENDICES

Appendix A: Workshop Comments and Feedback

Key Points of Improvement in the Workshop

- More clarity of explanation for the breakout sessions
- More discussion of specific use cases
- A more thorough introduction to scenarios and the design process
- Clearer definition of the goals of each exercise
- Spend more time on the scenarios
- Fewer drivers, more explanation on how to design driver boundaries
- Establish a common definition for common concepts *(ex. Decentralised data ownership. Is the data owned by a private company in a decentralised manner, or is it owned by a distributed body of entities?)*
- Less time spent on voting, more time spent on discussion

Appendix B: List of respondents

Visioning Interviews
Electrical engineer, Public research university
Energy department, Technical University
Energy research institute
Privately-held utility
Government-associated university research center
Venture capital firm
Former director of government agency, independent consultant
Independent consultant
Energy industry-oriented venture capital firm
C-level executive, Energy Supplier & Services provider
Analyst, Media publication
C-level executive, blockchain/energy startup
Co-founder, Microgrid services provider
Partner, Law Firm
C-level executive, blockchain startup
Independent consultant, IT & Utilities
Energy expert, independent consultant
Founder, Energy supplier
Workshop Participants
Master's student (blockchain-focused research), Dutch university
Master's student (blockchain-focused research), Dutch university
Project manager, Dutch DSO
Project manager, Energy supplier
Independent consultant
Environmental Portfolio Manager, Bank
Energy systems engineer, French utility
Project consultant, Bank

Regulatory affairs, Energy supplier
Independent consultant
Dutch consultancy
Dutch market actor platform
Follow-up Interview Participants
Master's student (blockchain-focused research), Dutch university
Master's student (blockchain-focused research), Dutch university
Project manager, Dutch DSO
Project manager, Energy supplier
Independent consultant
Regulatory affairs, Energy supplier
Independent consultant
Dutch consultancy
Dutch market actor platform
External Consultations
Dutch DSO
Dutch DSO
Energy science department, Dutch public research university
Innovation consultancy start-up
Dutch research institute
Dutch energy market facilitator
Dutch DSO
Independent consultant, IT & Utilities
Rijksoverheid