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ORIGINAL ARTICLE

Surprise as the new normal – implications for energy security

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Abstract
We are living in a world of increasing interconnectedness through digitalisation and globalisation, exacerbating environmental conditions, severe economic challenges, uneven distribution of wealth, and geopolitical crises. The world is a complex system and the rapid change among its sub-systems builds up pressure for any efforts to anticipate change and shape the processes of transformation. Surprise is an intrinsic aspect of change, in particular when it takes place at an accelerating pace with high degrees of volatility, uncertainty, complexity, ambiguity (VUCA) - or within the condition of post-normality as described by Ziauddin Sardar. Emerging technologies such as AI and renewable energy systems add to the complexity of societies, and thus to the world of VUCA and post-normality. In foresight horizon scanning has much focused on the probable or even predictable -surprise-free developments. More emphasis should be paid on systematic anticipation of wild cards and black swans, and on the analysis of weak signals. Foresight should also focus on discontinuities - broader phenomena and developments instead of single events. Energy is a complex issue. Without energy there is no life, neither biological nor economic. Taking into account the huge ecological and social costs of the present energy system, the need for a new emission-free, cost-effective, and democratised energy system is obvious. An energy transformation to reach 100% renewable energy is envisioned in four transformational neo-carbon energy scenarios. Energy is increasingly a societal and even cultural issue - above all a security issue. As regards energy security, various sudden events and surprises could play a major role. New energy systems themselves, with other new technologies, nudge the world into unknown, discontinuous directions. Therefore, we probe the resilience, anti-fragility and discontinuity of these transformational, societal energy scenarios. The results of a futures clinique where the scenarios were tested are presented. Implications of surprises for energy security, as the world increasingly seeks to move towards a renewable energy based society, are explored.

Keywords Renewable energy · Transformative scenarios · Energy security · Resilience · Complexity · Wild cards · Black swans · Uncertainty · Discontinuity · Turbulence

Introduction

The world is in constant change, and still, it seems that we think in a linear mode. Today's world is increasingly interconnected through digitalisation and globalisation, exacerbating environmental conditions, severe economic challenges, uneven distribution of wealth, and geopolitical crises. Emerging technologies are expected to transform tomorrow's world in unforeseen ways [78[1]]. Change, including that deriving from the emergence of technologies, should be understood beyond risk assessment, but also in terms of the unpredictable [1, 2]. Nation-states claim independence and sovereignty for themselves, but their autonomy is restricted by the tsunami of trans-border flows of trade goods and finance, of information, people, weapons, technology, energy, emissions, and pollution. The world is

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[1] WEF (World Economic Forum) - The Global Risks Report 2017: http://reports.weforum.org/global-risks-2017/

a complex system and the rapid change among its subsystems builds up enormous pressure for any efforts to anticipate change and shape the processes of transformation.

Energy plays a central role in enabling change and increasing its pace and complexity. The more energy humans are able to harness, the more complex societies are enabled [3]. The whole human history and its development can be seen as the mastery of new sources of energy [4]. This paper argues that as humanity is anticipating a transition into renewable energy systems – and towards the potential of energy abundance they promise [5, 6] – broad and deep discontinuity developments should be paid more attention to.

Energy itself is a sector facing massive change pressures [7, 8]. Energy is not only an economic or technical issue, but increasingly a societal and even cultural issue – above all a security issue. Risks are conceived to be an intricate part of the energy sector because of economic interests, geopolitics and environmental issues such as nuclear waste. Changes in energy prices alone are enough to shock entire nations. The 2011 Fukushima disaster was not considered possible, because the risk probability of a tsunami and an earthquake combined was judged negligible [9]. Energy security, as security of supply [10, 11], has been applied to conceptualise the complexity of energy in foreign and energy policy [12]. Problematically, conventional energy security analysis, including when looking at unexpected events, has primarily focused on a set-up of fossil fuel and nuclear energy technologies [13].

Many energy security analyses omit potential future changes in the energy mix, the implications that a growing uptake of renewable energy could have [14, 15], and the influence of broader societal transformations. The first attempts to address energy security in a renewable energy world are emerging [16–18], but few efforts to date capture the true complexity to reach or sustain such a future society. A growing body of literature examines energy transitions to understand energy landscape changes [19–21]. This includes studies on a 100% renewable energy system as a neo-carbon energy system [14, 15]. "Best-guess" future conditions might not be enough, and therefore multiple plausible futures should be considered [22]. Non-linearities, various sudden events and surprises – wild cards and black swans – could play a major role. New energy systems themselves, with other new technologies, nudge the world into unknown, discontinuous directions.

A renewable energy based future may be a desirable one, but in envisioning transformations, renewable energy pathways and futures have to be tested for resilience for both internal and external events [23]. This can enhance the ability of a future system to cope with change. This provides us with the theoretical framework of radical change: exploration of transformational possible futures, built on discontinuities towards the preferred future of renewables. The research question is how to dwell deeper into uncertainties, discontinuities and surprises as preparation for the forthcoming change. The prevalent hypothesis is that by paying more attention to discontinuities and surprises a better understanding of change could be formed. For the purpose, as a part of a foresight research project, a hybrid method experiment was conducted to describe discontinuities and possible black swans on uncertainty "soil". It consisted of the use of transformative scenarios, ideation of discontinuities and black swans, cross-impact analysis of the imagined black swans on the scenarios, and a Futures Clinique [72], a special type of a futures workshop [24].

Renewable energy driving the VUCA world

This chapter opens up the features of the complexity and change as manifested in the VUCA world concept. The concept of VUCA is relevant when discussing and constructing scenarios for the renewable energy transformation within the context of societal change – renewable energy may further the VUCA world, as the following will claim.

VUCA world

In recent times, companies, governments and international organizations have paid increasing attention to risks and vulnerabilities [80, 81,[2]]. For good reasons, disruption has become one of the key terms in discussions about innovation, economic and societal change. We seem to live in a world of permanent and profound change, driven by technology, by the requirements of sustainability and human development, and by rather unpredictable societal and political processes [25, 26]. Concepts like "megatrends" or "grand challenges" are coined to describe the underlying phenomena with their tensions and contradictions.[3] Often far reaching characterizations and interpretations are given. From a systems theoretical perspective, dynamic complexity ("dynaxity") causes rapid, erratic processes with sudden tipping points where a system transgresses its former behavioural boundaries and starts to display completely new traits. Indicators from fields as different as finance, mobility, and lifestyles support the hypothesis that we live in an Age of Acceleration, which means higher frequencies of innovation, faster economic processes, increasing societal fluidity, and faster paced political decisions. Some researchers even speculate that we might approach within the next three decades a "technological singularity" where technological change becomes so rapid and profound that it represents a rupture in the fabric of human history [27]. Even if

[2] WEF (World Economic Forum) - The Global Risks Report 2017: http://reports.weforum.org/global-risks-2017/

[3] The Millennium project uses the framework of 15 Global Challenges that is updated annually. The aim is to assess global and local prospects for humanity. Some of the global challenges are megatrends in themselves (such as sustainable development and convergence of IT) while many of them are key issues (such as energy, clean water, health) the development of which is critical for humankind. See: http://millennium-project.org/millennium/challenges.html

we do not follow Kurzweil, the main message is quite obvious: the future will not be like the present – and not even resemble the future we have been used to.

On this background, it makes sense to break down the present challenges for decision makers in four main dimensions, for which the acronym VUCA has found wide spread use: V for 'volatility', U for 'uncertainty', C for 'complexity', and A for 'ambiguity'.[4]

V for 'volatility' describes the increased dynamics in many fields characterized by "changing directions of change", by a high frequency of ups and downs, by more rapid disruptions of trends. The paradigm is given by the stock markets that have become more volatile after the financial crisis of 2007 – with impacts on all economical spheres. In recent years, a rather high volatility can also be observed in political processes, at least in democratic states. Furthermore, PR departments and marketing experts complain about a more erratic behaviour of consumers, quickly shifting demands and preferences. It seems obvious to regard increased connectivity and (social) media at least as one of the main catalysts of volatility. From systems theory we know that the volatility of system parameters increases when it approaches a tipping point [28]. Interestingly, energy markets are also affected by an important volatility, caused in parts by new technologies, but also by lifestyle changes. This creates opportunities for new market entrants – and it makes radical energy scenarios, such as neocarbon scenarios based on renewable energy [7] more plausible. Is there already a tipping point approaching?

U for 'uncertainty' indicates a fundamental condition that decision makers have met in all ages. The lack of predictability, however, has become more prominent during the last decades, since the impacts of innovations, the outcome of political developments, and shifts in lifestyles have increased. Objective indeterminacy due to internal and external factors that are beyond control is complemented by subjective unpredictability due to a lack of knowledge about the dynamics of large, interconnected economic and societal systems. Chance combines with choice [29]. A multitude of actors with different, often clashing interests attempt to influence the unfolding of events and to get their specific answers about the big challenges of our age. In sum, developments become unpredictable and full of surprises.

Even most advanced prediction tools (e. g. use of big data and deep learning) have revealed fundamental limitations for social phenomena (see e.g. [30, 31]). In technology foresight, more humble approaches are now state of the art: technology forecasting (in the sense of predicting breakthroughs with definite timelines) has been supplanted by scenarios[5] and recently by hermeneutic approaches, the deconstruction of future images ("vision assessment") [32]. For most challenges with long time horizons, optimism about "superforecasting" [33] seems not in place. However, one lesson can be drawn from forecasting exercises: one needs to distinguish first the realm of predictable developments, second the realm of black swans (unpredictable outliers), and third the vast space in between of rather well or rather poorly predictable events. In the sphere of intermediate predictability, such as stock market movements or elections, the difficulty of prediction depends tremendously on the details of the task (e.g. per cent margins, time horizons).

It would, however, totally miss the point to regard uncertainty primarily as a problem for decision makers. Uncertainty safeguards the openness of the future, and provides the space for human decisions.

C for 'complexity' implies that there is a multitude of qualitatively different factors or elements that interact in many different ways. Complex systems display complex dynamics, often with self-organization and the emergence of novel structures. There are no clear-cut cause-and-effect chains, but intrinsic webs of interaction through which disturbances or disruptions propagate in elusive ways.

When it comes to grand challenges, e. g. the transition to sustainable energy systems, there is always an interplay of many actors with their specific organizational or network structures (from centralized to peer-to-peer). In the last decades, with global networking, with social media, digitalization of the economy, linkages have become much closer, exchange much more rapid. From the decision point of view this produces "wicked problems" [34] without clear, simple, and lasting solutions, from a change-oriented point of view this produces opportunities to break up existing structures and to quickly shift to novel ones.

A for 'ambiguity' describes the difficulties to understand and interpret novel, emergent or simply unusual phenomena, to make sense of them, to draw conclusions. Reality becomes opaque and hazy, one might confuse causes and effects, misread weak signals and even strong ones.

According to epistemology, there is a tension between prediction and explanation. Understanding a system, interpreting its behaviour needs simple, straight-forward models, in difference to prediction that is usually based on complex models (mapping a multitude of influencing factors). "It is both possible to make sense of something ex post that cannot be predicted ex ante and to make successful predictions that are not interpretable" [30].

[4] Originally, the acronym VUCA was introduced by the U.S. Army War College in the 1990s to describe the situation after the end of the bipolar world. Since then it has been used in the framework of foresight and strategic leadership.

[5] For several decades Japan has made large Delphi studies on technology at NISTEP (National Institute for Science and Technology Policy), whereas recently the effort has been changed into scenario construction.

In many cases, ambiguity implies that there are competing haphazard interpretations based not only on diverging perspectives and differing interests (the usual reasons for dissent) but – on a deeper level – on the lack of applicable concepts and terms. Really new, "emergent" phenomena, sometimes heralded by weak signals, escape existing mental models.

Futures research have a long tradition in embracing VUCA developments and in supplementing trend-based thinking by analyses of possible disruptions and corresponding extreme events [35, 36]. Concepts like "black swan" [37] and "wild card" [38, 39] capture in an almost metaphorical way key aspects of sudden changes in the mental landscape of the future. Black swans, wild cards and X-events are used almost synonymously to refer to sudden, surprising, unanticipated events with broad and radical consequences [40, 41], but to elaborate the three concepts, certain distinctions can be drawn.

The concept of *black swan* refers to a highly improbable event that is difficult to anticipate, but if realised, will have dramatic, global impacts. Black swans may be positive or negative by their impacts. According to Taleb [37], black swans cannot be foreseen, but clusters of weak signals may point out to a possible black swan. The impact of black swans is also difficult to assess. One is to calculate the power of a black swan by a set of criteria: rate of change, reach, vulnerability, outcome, timing, opposition and power factor [42]. Aven [1] claims "near-black swans" to be surprises as a subset of black swan conditions, where an event does not result in extreme consequences because the barriers work and extreme outcomes are avoided.

Wild cards are events or developments with a very low probability before they occur and with a very high impact on the system under consideration, e. g. in the business, political, or social sphere. From a methodological point of view, one can distinguish realised ("historical") and potentially possible, imagined wild cards [43]. Like black swans, they can have either positive or negative impact. Because of the low ex ante probability combined with a broad and often radical impact, they emerge as a strategic surprise and very often provoke inadequate, delayed, badly aimed, sometimes only symbolic responses. While black swans are "unknown unknowns", things we cannot name or beyond our minds, wild cards are events or developments we can with sufficient effort imagine and at least abstractly identify – so that large collections of wild cards can be established.[6] Such collection can help to promote "thinking out of the box" in foresight exercises and to extend both the space of envisioned futures and of options for action. Both wild cards and black swans are different from risks because their probability is difficult to assess, as singular events without any precedent. In assessing their impacts, they may be low probability/high impact, but it has to be guessed. Preparedness for surprises is necessary to avoid situations without any prophylactic – or even preventive! – measures or alternative planning [44]).

Extreme events, or X-events, are considered in the short term mostly negative and problematic, whereas in the long-term they open up as opportunities - clearing out existing structures that are no longer serving a useful purpose. In this sense, extreme events are drivers of human progress [35, 36]. The motivation to understand X-events emerges from criticism of concentrating on trends. Trends are based on continuities, and thereby, the trap of linear thinking. It may be more relevant to explore trends in terms of how long they last, how they are going to end, and what can be expected to replace them [45]. Colonomos [25] points out that for anyone looking into the future the distinction between continuity and rupture is the first indication of importance.

Anticipating the impacts of black swans and X-events is difficult because there is no historical precedent [36]. The aspect of surprise may be viewed as a relational one: black swans, X-events or wild cards should be assessed as relative to one's worldview, knowledge and beliefs [2, 46]. Black swans, X-events or wild cards cannot thus be foreseen, but they can be imagined and described within the context of the observer. One also has to bear in mind that large technological, infrastructural, or economic transitions – like the transition to a neo-carbon economy – imply not only changes in the built landscape but equally deep tectonic shifts in the mental landscape. The most important black swans for renewable energy may possibly emerge from the fields of society and politics [44].

Renewable energy system and the VUCA world

To mitigate climate change, it is evident that the structure of energy production must change. Today's energy systems are still 80% reliant on fossil fuels [47, 48]. Therefore, humanity is at a historical crossroads, expecting an emerging transition from non-renewable to renewable energy systems.

It is often assumed that the transition to renewable energy requires reducing energy consumption, and that the energy abundance provided by oil has come to an end [49]. However, this may well not be the case. Today, global total primary energy demand is approximately 110,000 TWh.[7] By 2050, we may expect global total primary energy demand to be at least 130,000 TWh with significant increases in energy efficiency [50]. The energy system can be 100% by then [7, 51], and it can provide energy at lower prices than today [52], in some cases – such as in household solar PV systems – even with zero marginal costs [53]. Further, as opposed to the non-renewable energy system, the renewable energy system can be

[6] For a paradigmatic example see Ravetz et al. (2011).

[7] IEA 2016: https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html

built as, at least partly, decentralised so that energy consumers will become prosumers [54].

Thus, in the relatively near future we may have a sustainable energy system that increases energy supply and energy efficiency, decreases the price of energy, and allows citizens and organisations to become energy producers. These changes, then, enable wide use of new technologies – such as artificial intelligences (AIs), smart cities, internet of things (IoT), robotisation, and ubiquitous virtual realities – and empower new actors, big and small. To meet sustainable criteria, also material production should be designed as sustainable – for instance as circular economy.

Socio-political destabilization and, in the worst case, social collapse are often seen as among the consequences of decrease in energy demand [55] or of severely descending energy supply [56]. However, the opposite may also destabilize societies: an increase in energy supply. More and cheaper energy may promote the VUCA world – increasing volatility, uncertainty, complexity and ambiguity. If we are reaching sustainable energy abundance, the traits will only strengthen. More and cheaper energy with other new technologies means faster and deeper changes [3, 57] and realignment of power [53].

Complexity can be seen as key here [58], as it is complexity that feeds to volatility, uncertainty and ambiguity. Societal complexity can be defined as differentiation in social structure (more parts and more types of parts to a system) and variation in organisation and ranges of behaviour [3, 59]. If increased energy supply allows for "more parts" (human and technological actors) and variation in organisation and behaviour, it should then also increase complexity, and with it, volatility, uncertainty and ambiguity.

It may therefore be that in the VUCA times, furthered by the renewable energy system, social and cultural stability decreases – which is both good and bad. In any case, we have to see the energy transition to renewables as a much more complex and multifaceted phenomenon than it is often understood. If progress is stable, predictable and controlled development, the VUCA times may render the world a more *discontinuous.*

Discontinuities and surprises in a world of complexity

Discontinuity is a feature of complex systems [60]. A system is complex, if it is interconnected with numerous other systems and if its cause and effect relations are not linear. The world economy is a complex system (virtually everything that happens in the world affects the global economy), whereas a combustion engine is not. If the world becomes increasingly complex, for instance because of the interconnectedness of nations, so should discontinuities increase, too, and the world becomes more volatile. The energy system is also an apt example of a complex system.

Instead of trends, Futures Research pays increasing attention to black swans and wild cards (see above) and weak signals. Weak signals are signs – such as events, new technologies and novel practices – pointing to possibly emerging issues and phenomena which can either strengthen or wither away as time passes [61, 62]. They are the first symptoms of important discontinuities, warning signs, or new possibilities [63]. This is understandable, as future is about change, and most novel and exciting things emerge from weak signals and black swans. Weak signals are important indicators for upcoming potential change, impending wild cards or black swans. If they are properly identified, they can be used to discover latent processes, potential discontinuities (see below) and to give hints as to the approach of wild cards or black swans [28, 31, 64]. From this point of view, they are of utmost practical advantage as early warning signals [65].

Further, technological developments, increases in (renewable) energy supply and decreases in energy price could steer our world into unknown futures. If we subscribe to the idea that the world is becoming increasingly VUCA-like, imagining weak signals and possible black swans is becoming more and more crucial.

Weak signals and black swans are, however, rather "unpractical" as a method for anticipation. As singular issues, phenomena and events, weak signals and black swans – which are besides by definition very difficult to anticipate – are not very reliable in trying to anticipate how the future will differ from the present. Trends, in turn, are more reliable, not only because they deal with things that are familiar to us, but also because they are constructed by different phenomena. For instance, the trend of increasing life-expectancies is not a singular issue but consist of numerous different factors.

Therefore, in addition to weak signals and black swans, Futures Research should pay more attention to *discontinuities*. Saritas and Smith define discontinuities as "*rapid and significant shifts in trajectories without the aspect of being mostly unanticipated or deeply surprising*" which "*[extend] beyond single events*" and "*fundamentally [alter] the previous pathways or expected direction of policies, events and planning regimes*" [66].

The key elements in the definition are that discontinuities are not singular issues and events (but consist of different interacting trends, weak signals and black swans), and that they fundamentally alter the linear, known pathways. There is, however, no reason to define discontinuities as exclusively rapid shifts – they can as well be gradual, long-term and deep change processes. Saritas and Smith mention Facebook as one example of a discontinuity, but in fact the rise of Facebook was not a rapid shift [66]. Established in 2004, it took Facebook three years to reach fifty million users and eight years for a billion users.[8] Furthermore, Facebook was preceded by many other social networking sites and applications such as MySpace and the Finnish Irc-Galleria in the early 2000, Internet Relay Chat (IRC) in the 1980's and Bulletin Board Systems (BBS) in the 1970's. Perhaps, then, Computer Mediated Communication (CMC) is the deep, long-term discontinuity here, of which Facebook is only one, albeit the most known, manifestation.

The internet and the First World War are two other illuminating examples of discontinuity. Both are often seen as black swan events, although in reality they are the result of longer discontinuity processes – neither is *an event* which black swans by definition should be. The internet was invented in the 1960s, but began to spread and influence society in the early 1990s with the invention of the World Wide Web. The development of the internet was a gradual process rather than a single event, a discontinuity in relation to the centralised mass media technologies such as the television. There were also many other discontinuity processes during 1970s and 1980s that laid the groundwork for the spread of the internet, such as globalisation and transition from industrial to information economy. The First World War, in turn, had many underlying processes such as militarism, nationalism, and strategic alliances between nations. Eventually, the war was triggered by the assassination of Archduke Francis Ferdinand in 1914, an event that may be claimed to be a black swan. However, numerous other events might have had the same effect (Fig. 1).

From this perspective, black swans and weak signals as single events and phenomena are less relevant than the wider and deeper discontinuity processes underneath them. Black swans and weak signals should be seen as tools to discover hidden discontinuity processes, which in turn help in interpreting the meaning and significance of black swans and weak signals. They should always be related to broader phenomena they are part and signs of. Black swans can thus be seen as the culmination, and weak signals as the "signifiers" [62], of discontinuity processes. According to van Notten et al. "*Abrupt discontinuity tends to manifest itself through events but these are usually connected to underlying processes. In such cases, events are often the proverbial last straw that broke the camel's back.*" Along these lines, the fall of the Berlin Wall (a black swan) was preceded by discontinuities in the Soviet system, as for instance by Michael Gorbachev's rise to power and the politics of glasnost and perestroika (ibid.) [67].

Issues that constitute a discontinuity often emerge from different fields. The iPhone, for instance, is an innovative combination of existing technologies. Machine learning is starting to converge with other technologies in a variety of unexpected ways. Together with patient data and an algorithm, machine learning can predict breast-cancer risk 30 times as fast as a human can [68]. Solar photovoltaics were in use already in the 1990s, but have begun to spread only in recent years [52], especially as China has risen as a mass-manufacturer. Real transformations will come about when low-cost and abundant solar electricity is combined with, for instance, self-driving cars and smart-city technologies.

The issues and trends behind discontinuous development processes are often regarded as unrelated and irrelevant. Because of complex interconnections and apparent insignificance, discontinuities may not be easily recognised and are ignored [69, 70]. For instance, ecological deterioration can have a significant impact on the global economy, and tipping points may only be revealed ex-post, but this is seldom taken into consideration in economic projections. In this light, the rapid emergence of solar photovoltaics (PV) in the 2010s may also be better understood as a discontinuity built over time rather than a black swan event.

Anticipating discontinuities and black swans - implications for energy security

Casti emphasises the role of unexpected events, i.e. surprises for humankind by claiming "*…off we go now into the land in which almost nothing is actually known but where much of our future lives will be determined*" [14: 33]. If surprise is the new normal, its implications for energy security – our critical life supporter – should be anticipated by using various kinds of foresight tools. This chapter presents the results of a methodological experiment to anticipate and analyse discontinuities and black swans and their implications for renewable energy.

A set of transformations to renewable energy is envisioned by four transformative neo-carbon scenarios 2050. These semi-backcasting scenarios represent *energy futures* based on renewable energy as radically different from the present, and contextualise such change with emerging *societal futures*. Instead of addressing the transition to renewable energy as an ecological or techno-economic issue, the scenarios probe alternative possibilities on how the society at large could change under the new energy regime. The scenarios are transformative and discontinuous, as *none* of them is a business-as-usual scenario and all assume deep societal changes. In all of the scenarios ecological values prevail (either deep ecological or practical). From a socio-cultural perspective, the core assumption of all of the scenarios is that peer-to-peer practices will strengthen – the scenarios map out different possibilities for a "peer-to-peer society" to organize (as centralised or decentralised). Peer-to-peer refers to self-organising individuals and groups.

[8] Ben Foster: How Many Users of Facebook? http://www.benphoster.com/facebook-user-growth-chart-2004-2010/

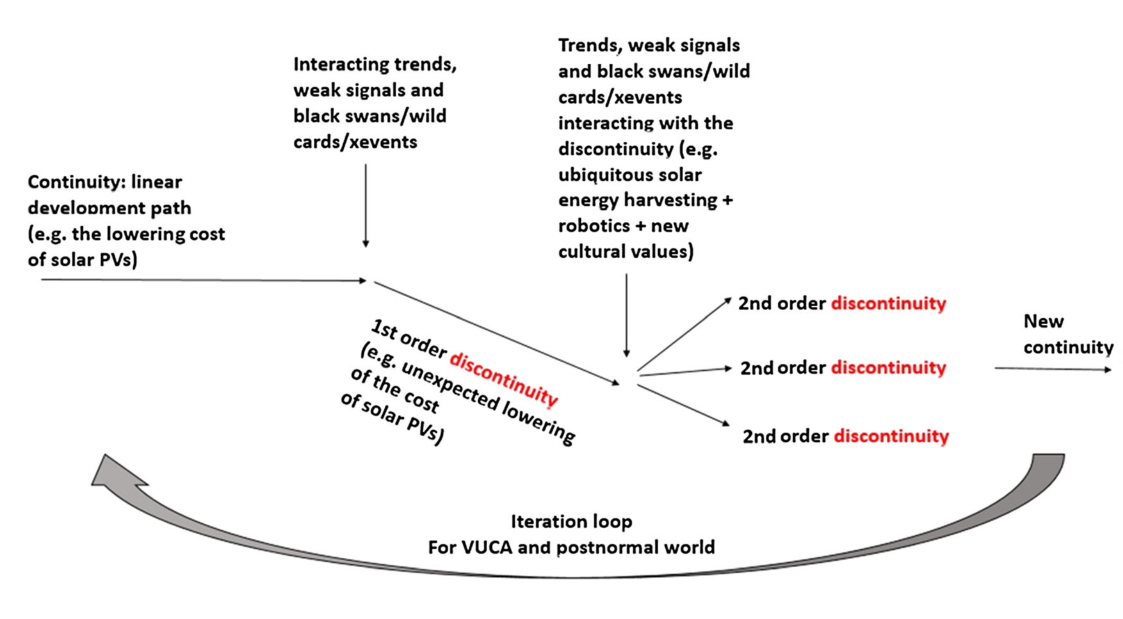

Fig. 1 A conceptual map of drivers of change with a view to continuity/discontinuity

Renewable energy technologies have a potential to promote peer-to-peer, as it allows citizens to become energy producers and thus increase their independence [53]. The core technological driver towards peer-to-peer are, however, information and communication technologies, which have dramatically decreased the costs of information and self-organising [71].

In the *Radical Startups 2050* scenario, startups with 'radical' approaches become the platform for self-organising citizens and drive the uptake of innovative energy solutions. In the *Value-Driven Techemoths 2050* scenario, citizens self-organise within profit-seeking technology giants, where they help them solve energy problems commercially. In the *Green DIY Engineers 2050* scenario, energy solutions are low-tech and citizens self-organise as local tribes, as the world faces an environmental catastrophe. *New Consciousness 2050* scenario envisions a world where ICT and profound ecological thinking have brought about a thoroughly networked society without traditional organisations and institutions, and a new systemic way of conceptualizing the world [79].

Scenarios can be used as exploratory tools for exploring discontinuities of long-term energy transitions. In a Futures Clinique conducted in May 2017 in Helsinki, Finland, 39 participants in seven groups investigated central themes related to the scenarios to test the resilience of a renewable energy based society. Futures Clinique is a participatory and exploratory futures workshop used to tackle uncertainties, identify disruptions and generate innovations [72]. The aim was to identify different interlinked trends and weak signals to probe how they could shape the energy transformations – to a future renewable energy based world. The participants consisted of energy, innovation, economy and environmental policy experts, working alongside futures researchers and students. After documenting and reporting the results, the key insights are expected to inform further discussions about energy security at a research- and policy-level nationally and internationally.

The Futures Clinique proceeded in phases (Table 1). In the beginning, the scene was set with introductions to megatrends and trends that may enable 'radical change'. This set the context for exploring future discontinuities and focusing on emerging issues and weak signals of change. There were two broader tasks: first to map out possible discontinuities to think about deep and cross-sectoral changes. After that, to ideate possible black swans and reflect on their impacts on renewable energy world. The discontinuities were anticipated through five pre-selected themes: 1) Politics: nation-states, governments, geopolitics, new ideologies; 2) Corporations and economy; 3) Civil society & peer-to-peer practices; 4) Robotisation & artificial intelligence; and 5) New lifestyles, chosen because of their significance in society and potential for surprises. Subsequent small groups elaborated on these themes.

The Clinique consisted of two sessions. The objective of the first session was to identify discontinuities related to the allocated theme of the group. The participants started by exploring how their theme is changing – discussing emerging issues, novel characteristics and dimensions. The ideas were noted down on post-its and those resembling each other were clustered. At the end, the participants classified the ideas that resemble each other into clusters, and gave titles for the found 'discontinuity clusters'. In the second session, the implications of the discontinuities were systematically analysed. The discontinuities deemed as most discontinuous were chosen to elaborate what black swans could emerge from them. At the

Table 1 Futures Clinique methodology to explore the implications of discontinuities and black swans for renewable energy and its energy security

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Setting the stage and objective	Exploring and clustering emerging issues thematically	Describing discontinuities	Probing black swans	Analysing implications for renewable energy

end of the session, the group considered what implications, either advancing or hindering, these black swans could have on the renewable energy world by 2050.

After a qualitative content analysis on the groups' results, six categories of discontinuities could be differentiated: 1) new risks, 2) converging technologies, 3) value changes, 4) environmental economy, 5) changes in big companies, and 6) geopolitical changes (Table 2). In the following we accordingly summarise the results in more detail, with the aid of these six categories. In interpreting the themes as results, it has to be borne in mind that, as Gordon warns, the choice of future events to test resilience may not be free of unintended bias [73].

New risks As the world changes, new risks emerge, and oftentimes we do not know how to deal with them. Amidst turmoil, we are seeking for sources of trust − from 'the new' and 'the old'. In the years to come, a major cultural issue concerns how the tensions of nationalism versus globalism and liberalism versus conservatism will play out. If nationalism and conservatism begin to strengthen, this could be a major discontinuity globally, and as such pose new risks. In turn, anticipated transformations imply that we have to think in advance of their winners and losers. If we are moving to a predominantly immaterial, creative and automated economy, what kinds of social issues will we have to deal with? New kinds of inequalities can also be a source of discontent, and cause severe risks.

Converging technologies In terms of technology, convergence may be one of the main factors that disrupts linear developments. In this respect especially the convergence of humans and machines, "the Internet of Everything" (IoE), and autonomous transportation are key. As artificial intelligences (AIs) become more developed, we may begin to think of them as our peers. Biochemical "robots" in our bodies would converge humans and machines in a very concrete way − and even change our consciousness if they had cognitive functions. The Internet of "Everything" refers to a situation where everything − our energy systems, businesses, leisure etc. − are thoroughly networked. Crowdsourcing and crowdfunding would become the prevailing norm, not the exception. If transportation became autonomous, it would not change only how we move but for instance how we socialize and design our cities. Transportation would become much more efficient, which would free city space for other uses and make crossing distances easier than today.

Value changes Changes in values are fundamental, as value systems guide our behaviour. In terms of production systems, if more goods and services were exchanged peer-to-peer outside established market mechanisms, as already is happening, this could shape how we today perceive the "free market". This, in turn, would have wide systemic effects. Whether we will live in market economies in the future or not, the rupture of hierarchies could be expected to change the world. Among many other things, it would make cultures more pluralistic,

Table 2 Six areas for emerging discontinuities described in a Futures Clinique, with summarising narratives

New risks	Converging technologies	Value changes	Environmental economy	Transforming large companies	Geopolitical changes
As the world changes, new risks emerge, and oftentimes we do not know how to deal with them. Old identities are contested, new kinds of inequalities are emerging. Amidst turmoil, we seek for sources of trust – from 'the new' and 'the old'.	Human-machine interface with "biochemical robots" in our bodies prevails. There is a world of "Internet of Everything" (IoE) with AI, electric vehicles, 3D printing, and autonomous transportation in a circular economy.	The rupture of hierarchies may change the world, make cultures more pluralistic, and more prone to change. Value changes are also connected to identities and how we perceive our place in the world, and where we seek meaning.	Running an economy sustainably as an immensely complex task is also an enormous opportunity. Emerging economies – including in Africa – could prosper in unprecedented ways, with new energy technologies, harvesting energy everywhere.	When the vast resources of companies are put to good use, this may drive positive change. But the concentration of corporate power is always risky. Can private sector benevolence be guaranteed, and if not – what then to be transformed?	If 'the West' decreases in significance in world politics, and China and emerging economies gain power, what would be the guiding values of a post-Western world? And, what types of broader, cultural changes would this imply?

and more prone to change. Values are also connected to identities and how we perceive our place in the world. In times of rapid change and increasing social complexity, developing, searching and realising oneself would become even more important than today. Values could affect how we choose to allocate the use of resources and what we expect to disrupt current trends.

Environmental economy By 2050 the rise of an environmental economy may have changed societies much more than we can conceive today. Multiple new energy technologies and sources could lead to a situation where energy can be harvested everywhere. As an outcome, China, India and other developing economies, especially in Africa, might prosper in unprecedented ways. On the other hand, keeping the system running sustainably − including how circular economy can be used to deal with waste − is an immensely complex task. Information, big data analysis and artificial intelligences are thus imagined to be an integral part of an environmental economy.

Transforming large companies The Facebooks and Googles of tomorrow may develop as all-encompassing entities that are involved in virtually everything. This would change the nature of such companies as some kind of semi-public actors (which they to some extent are already). This could be a positive thing, if their vast resources are put to good uses, but on the other hand concentration of corporate power is always risky. In any case, it is deeply uncertain how these mega-corporations can change currently established paths. Already, the emergence of platform economy, resulting from technological change and peer-to-peer principles, has raised questions about the justification of profits, and raised proposals about changes in taxation. And, can small, nimble companies that use global networks challenge these giants?

Geopolitical changes It may well be that the power of 'the West' decreases in world politics − and thus its place and significance in steering the global development. However, in place of the current international norms, we fail not imagine what the alternative is. Except for authoritarianism, what would be the guiding values of a post-Western world? Perhaps some kind of religious, national/regional conservatism? Or a mixture of these two? And, if sustainability continues to gain importance, will this change geopolitics? Regarding the future, the core question in geopolitics is not which countries are expected to gain power at the cost of others, but what the cultural consequences of these power shifts will be.

As a follow-up of the futures clinique work the previous day, a small ad hoc group consisting of the research project staff and external experts convened to conduct a further, hybrid methodological experiment: a *Post-Futures Clinique cross impact analysis with black swans*. Out of the results generated in the futures clinique, black swans (or combinations of different black swans), which could emerge as surprising events from these discontinuities were chosen and refined for a cross impact analysis. Cross impact analysis was then used to examine them [74]. The anticipation of possible black swans was combined with a description of their possible impacts across the four transformative neo-carbon scenarios 2050, described briefly earlier in the chapter, into a cross impact matrix. Adapting from Petersen's criteria [42] presented earlier (chapter 2.1), a more simplified version of *semi-quantitative (QUAN)* and *qualitative (QUAL)* implications was considered to score the black swans. Table 3 summarizes the results.

As presented in Table 3 in a synthesised and simplified form, five black swans altogether were selected for analysis and named: *Total industrial revolution*; *Collapse of the United States of America*; *Mass deaths due to climate change*; *Revenge of the fossil fuel industry*; and *Digital Anarchy*. It may also be concluded that the imagined black swans vary in terms of their impact, either positive or negative, impact (large or small), timing effects (first, then), and level of surprise. The chosen black swans are results from the Futures Clinique work. To meet the strict definition of a black swan they should, however, include *an event* that is now missing in the description. The event can though be imagined for each one of them, for example, the mass deaths due to the climate change could be depicted in specifying the event that will cause the deaths.

The black swans seem to have drastic impacts, several of them, while none seem to entirely collapse a scenario, at least indefinitely. They also have different *indirect* or *direct* impacts for energy security: 1) A holistic 'clean' industrial revolution likely would improve energy security. 2) The collapse of an influential state and a major energy player would surely induce instability, and consequently also influence energy markets. 3) If climate change effects increase instability and health costs, governments become increasingly strained. 4) An attack by the fossil fuel industry would not be unprecedented, but perhaps the participants anticipated it to find a new way or form. And, finally, 5) the effects of digitalization and self-organising are interpreted to lead in negative outcomes in terms of chaos. Then again, a positive interpretation of the same factors might emphasize localised energy solutions, which actually would have a positive impact for energy security.

Black swans are a useful tool to test scenarios, as they reveal possible need to re-visit the gaps within scenario stories. Instead of aiming to 'save' scenarios from black swans, it is more important to critically observe the future presented in it. A black swan event can be timed at any point of each scenario pathway, or at their end point, when it tests

Table 3 Post-Futures Clinique cross impact analysis with black swans

Black swans	Four transformative scenarios 2050			
	Radical Startups 2050	Value-Driven Techemoths 2050	Green DIY Engineers 2050	New Consciousness 2050
Total industrial revolution	QUAN: ↑↑↑ QUAL: Startups 3D print RE solutions.	QUAN: ↑ QUAL: Further polarization.	QUAN: ↑ QUAL: Self-made 3D printers.	QUAN: ↑↑ QUAL: Open source 3D, open ownership
Collapse of the U.S.A.	QUAN: ↑ QUAL: Radical startups in other countries.	QUAN: ↑↓ QUAL: US techemoths fall, Asian rise.	QUAN: ↑ (US) ↑ (others). QUAL: Re-juvenation of the USA.	QUAN: ↓↓ QUAL: World fears other 'failed states'.
Mass deaths due to climate change	QUAN: ↑ QUAL: Startups' innovations help or prevent.	QUAN: ↑↑ QUAL: Techemoths are called to help.	QUAN: ↑↓ QUAL: Survival of the fittest.	QUAN: First ↓↓, then ↑↑ QUAL: First shock, then collective action.
Revenge of the fossil fuel industry	QUAN: ↓ QUAL: Commercial and cyber warfare against RE startups.	QUAN: ↓↓ QUAL: Large oil companies' warfare against RE techemoths.	QUAN: ↓↓ QUAL: DIY Engineers criminalized, sanctioned.	QUAN: First ↓↓↓, later ↑↑↑. QUAL: Missionaries of the old world. Revenge mostly fails.
Digital Anarchy	QUAN: ↑ QUAL: Hacked robots and Internet of Things used in attacks.	QUAN: ↓↓ QUAL: Outside hackers as a counterforce.	QUAN: ↑ QUAL: Back to handmade world.	QUAN: ↓↓, later ↑ QUAL: Diabolization of fossil thinking.

the resilience of a scenario as a future image. Do Black Swans advance, postpone or destroy a scenario? Is this change at the core of the scenario or not? An examination of black swans alone may be prone to leave out the richness of the scenarios, as only the main actors of the scenarios are addressed. An examination of discontinuities and black swans jointly can allow an enquiry of factors that can potentially build surprises.

Anticipating discontinuities and black swans of renewable energy can be useful for enhancing the resilience of such possible futures. Resilience explains the resistance of a system to shocks and disasters, recovery ability, recovery times, and costs of recovery [75]. In a Futures Clinique, covering the broad range of discontinuities in detail is an ambitious task; but provides useful grounds for analysing their implications for energy security beyond conventional risk assessment. While feedback was not collected from the participants to evaluate the quality or impact of this process, the workshop participants are key stakeholders for this research question, expected to be able to carry the findings in their own future work. In the post-black swans session, the use of four transformative scenarios for each black swan allowed a differentiation to be made across a range of possible black swans and their contexts, to open up another level of different possible futures. Exploring discontinuities allowed for a depiction of a fairly rich 'futures map' [76]. Resilience could be understood a countering dimension for discontinuities and black swans, and rich futures maps may be important for resilience. It may help understanding how energy services can be provided in a future society even in the case of disruptions [77].

Conclusions

The future cannot properly be anticipated in a linear way only. Discontinuities, disruptions, and surprises are the robust building blocks of the future world.

In a VUCA world, anticipating energy futures is important. Not only has energy been narrowly defined, the way it has been analysed has left little room for imagining alternative development pathways. The dilemma of non-linear thinking has ignored multiple developments that, when put together jointly, may over time pose radical shifts in the energy landscape. The emergence of solar energy may be understood as a surprise, but it would be more accurate to conceptualize it as a discontinuity, building over time as an outcome of various developments, eventually intertwining with each other.

In anticipation, it is crucial to pay attention to not only trends but also to weak signals, and black swans as unexpected events. The aim was to overcome an omission of the complexity of the real and future world of forecasting exercises. Furthermore, besides identifying weak signals and anticipating possible black swans, special attention should be paid in probing discontinuities. Discontinuities are not sudden events or individual phenomena. They are long-term change processes which consist of different interlinking trends, weak signals, and black swans. For instance, new events and new policies can make scenarios shift [74], but discontinuities may question their assumptions altogether. It is precisely these broad and deep processes of change that, in the end, change the world.

In thinking of the rapid pace of technological development, one may make the claim that in the present, discontinuities are increasing (e.g. [36]). If this indeed is the case, it has partly to do with energy as well as new energy technologies. When new energy systems provide more energy than their predecessors, additional energy can enable the use of new technologies, to create even more complex societies. As we are preparing to take into use a renewable energy system that is increasingly distributed and can harness the abundance of solar and wind energy, changes could become faster, and even more transformative, than today.

Anticipating discontinuities is helpful for semi-backcasting exercises on possible or desirable futures. This hybrid methodological experiment worked to refine understanding about an anticipated transformation. With the aid of the transformative scenarios and related themes, the Futures Clinique participants were able to explore the interdependencies of renewable energy and a future society. It allowed the participants to develop their understanding about alternative futures and open its implications for energy security. The black swans generated in the workshop and later analysed, exemplify unexpected events that could influence the scenarios and their energy security. The generated insights will be used to refine the final scenarios before their completion. Our scenarios have a sociocultural element in them, which underscores the point about their societal significance. As the exercise was part of a broader foresight project, the findings are expected to also inform and feed further research and policy work about energy transformations.

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