



Perspectives

Energy scenarios—Exploring disruption and innovation

Gert Jan Kramer

Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands



ARTICLE INFO

Keywords:

Energy transition
Scenarios
Futuring
Disruptive innovation

ABSTRACT

In this perspective I argue that the term ‘disruptive innovation’ is at best too narrow and at worst meaningless to describe the important transformation of energy in the light of the pressing problem of climate change and the ambition to reach the targets of the Paris accord. Breaking the term apart, however, into disruption and innovation opens up a rich space for scenario exploration. If we take stock of what is possible or even likely to happen over the next decades, I conclude that we would do well to be more open-minded with respect to the nature and impact of disruption, and broaden the discourse of innovation beyond technical and business innovation.

Ever since Pythia, the high priestess of Apollo who served as the oracle of Delphi, we humans have had the irrepressible habit of cloaking pronouncements about the future in ambiguity. The future is of course unknowable, and therefore ambiguity may simply be seen as a prerequisite for prognosticators – ancient or modern – to stay in business. A modern-day Pythia might say “go forth from Paris and thou shalt witness disruptive innovation.”

In this Perspective I will argue that ‘disruptive innovation’ is classic Pythic language. If we foretell an era of disruptive innovation, then, after the fact, in – say – 2050, we will recognize that the first half of the 21st C saw indeed ‘disruptive innovation’. In fact, we can faithfully conclude this about any half-century after 1800. So we’re good. On the flip-side, looking forward, the phrase is rather not so much vacuous, but all-encompassing. As I see it, disruption and innovation are different concepts, they point in different directions and we may see them in *any combination*; combinations that may have very different characteristics. Disruption and innovation span scenario space.

What are scenarios? And how do they differ from pronouncements on the future? To illustrate this, let’s go back to Pythia and consider her most famous asseveration: “If Croesus goes to war he will destroy a great empire.” She spoke these words to Croesus, King of Lydia, in answer to his query whether or not to go to war with Persia. Croesus took her words as a blessing of his expedition, went to war, was ingloriously defeated and saw his *own* empire destroyed. Clearly Croesus was jumping to conclusions, without considering properly the scenario space that was spanned by Pythia:

- “Coward”, a.k.a. Business as Usual; not going to war; no great empires destroyed;
- “Hero”, the first go-to-war scenario; Lydia is victorious over Persia;

its King’s name will be venerated through the ages;

- “Victim”, crossing the Halys river; Lydia defeated by the Persians.

It has been said that oracles were the management consultants of the ancient, but customer intimacy was less developed than it is today. Pythia should have sat down with Croesus and taken him through the scenarios and explored with him for each of the scenarios, the question: “What would you do if the future played out in this way?”

The purpose of this short introduction was to make clear that scenario making is not about predicting the future, but about defining the space of future development and using it as a basis for answering what-if questions, so as to engage into a meaningful conversation about the best course of action in the face of an uncertain future.

I proposed that disruption and innovation are good axes to span the scenario space for the discussion of the energy transition and the pressing issue of climate change. I’d like to stick closely to the dictionary definitions of the two words. The Oxford dictionary defines innovation as ‘the change of something established by the introduction of new methods, ideas or products’. Though the introduction of ‘something new’ is not universally welcomed (there are people who hate change), we live in an age where innovation is – at the level of society at large – seen as something good and desirable. The more of it, the better. In view of the global challenges ahead of us this will not change. The old proverb necessity is the mother of invention, suggests that, if anything, we will see more of it in the future, rather than less.

For disruption it’s different. Going back again to the dictionary definition, disruption is ‘serious alteration or destruction of structure’, from the Latin *disrumpere*, to break apart. Disruption is therefore something that we – collectively, as a society – want to avoid, never mind that we sometimes profess differently. (The reader will now

E-mail address: g.j.kramer@uu.nl.

<http://dx.doi.org/10.1016/j.erss.2017.10.047>

Received 7 October 2017; Received in revised form 17 October 2017; Accepted 23 October 2017

Available online 08 November 2017

2214-6296/ © 2017 Elsevier Ltd. All rights reserved.

appreciate and understand the oracular beauty of the word combination ‘disruptive innovation’ – as aspect that was surely not lost on Clayton Christenson, whose name is so often associated with the term [1].

But, like it or not, the world will see disruption. According to latest assessment, we have 28 years of emissions left – at the going rate – before we’ve exhausted the 2° budget and just 9 years before we’re through the 1.5° budget [2]. To exceed the 1.5° budget engenders environmental disruption; staying below will inflict major economic disruption. (If it were otherwise, what are we waiting for?) Exceeding the 2° budget will cause more environmental disruption, but might be just be achievable without too much economic disruption. I am deliberately vague in not even qualitatively describing either the economic or the environmental disruption, because a) we don’t know it, and b) it’s apples and pears anyway. The point is: one way or the other, there will be disruption. Decoupled from the soothing notion provided by ‘disruptive innovation’, disruption sounds neither inviting nor attractive. Could it be that the notion of ‘disruptive innovation’ allows us to face up to disruption, but (for the moment) allow us to believe the disruption might be benign? Teslas for everyone!

But before we look at the two-word combination any further, let us pause for a moment and consider the breadth of the term innovation. The ‘something new’ can range from new technologies, new ‘stuff’, to new paradigms, new norms and new behaviors, and everything in between. Everything from the wheel to the Tesla, and from monotheistic religion to the scientific revolution can lay claim to being innovations. And humans and society have evolved in an endless cycle of innovations: from invention via dissemination to unintended consequences and problems, and then on to the next round of innovation.

When, however, we speak of disruptive innovation in the energy system, the implicit understanding of virtually anyone I’ve ever spoken to – both during my time in industry and in academia – is that we’re speaking here about technical and business innovation. But what about innovation in our institutions? In global governance? Or lifestyle change? I believe that, in the light of the challenges ahead of us, the narrow focus on the technical and the business-technical in the mainstream discourse of innovation is unjustified.

Before I take you away from this beaten track, let me share with you what I see as the limits that disruptive technical and business innovation can accomplish.

In a 2009 paper, together with a colleague from Shell’s scenarios team, I wrote an opinion piece in *Nature* for which we proposed the title *Growing Pains: The challenge to make low-carbon energy Big by 2050*. As it goes with contributions in the front half of *Nature*, we were not

fully in charge of the title of the piece, and the editors published it under the title *No quick switch to low-carbon* [3]. This made sense in the context of the other pieces in the same issue, but it took away the ambiguity and uncertainty that was implied by the original title. The paper was recently quoted as a bad example of vested-interest thinking in a Rocky Mountain Institute report on the basis of the title rather than the content [4]. In our paper we proposed that new energy technologies are subject to two laws-in-between-quotes, ‘laws’, namely that energy technology will not be scaled up by more than one order of magnitude per decade (‘law’ #1), and that after reaching ‘materiality’, which we defined as 1% of the total energy supply, growth would level off and become linear, growing to the technologies’ maximum share in the energy mix over a time period of 20–30 years (‘law’ #2). This nicely explains the growth of anything from nuclear energy since the 1950s to the growth of PV and wind, right up until today.

It means that if disruptive innovation is to help us realize the Paris ambitions, it cannot come from technologies yet-to-be-invented – at least not on the supply side. The notion that “someone in a garage somewhere” will invent something that will somehow save us, as US presidential candidate Jeb Bush offered by way of energy policy, is illusory [5]. It takes 30 years or so to get from the proverbial garage to the threshold of materiality and then another 20–30 years to reach full potential. And the clock only starts ticking the moment there actually is something in the garage!

Disruptive technologies are the technologies that the world started working on back in the 1970s in the wake of the first oil crisis. Solar, wind, biofuels, geothermal, etc. Fig. 1 shows how the R&D investments from the 1970s, continued through 80s and 90s spawned the renewables industry that developed spectacularly since the year 2000. PV, wind and biofuels all surpassed the threshold of materiality in the last decade, a generation or more after these options left the garage. (I will not go in further depth here, but the proverbial garage in conservative’s mind is actually a government laboratory, as Mariana Mazzucato showed [8] In summary, when it comes to renewable energy, it’s no longer about ‘breakthrough technologies’; the disruption comes from ‘technologies breaking through’.

In many ways, the world at the closing of the second decade of this 21st century has realised the technical basis for a ‘green revolution’ that Thomas Friedman explored in his 2008 book *Hot, Flat and Crowded* [9]: REEFIGDCPEERPC < TTCOBCOG, or: a renewable energy ecosystem for innovating, generating and deploying clean power, energy efficiency, resource productivity, and conservation < the true cost of burning coal, oil and gas (chapter 10: *The Energy Internet: When IT meets ET*). As of the time of writing, the records for unsubsidised clean energy projects are 2.42¢/kWh for Solar PV, 3.0¢/kWh for onshore wind and 4.9¢/kWh for offshore wind, comfortably meeting Friedman’s acronymic criterion [10].

Because of this, PV and wind in particular have today become forces of Schumpeterian disruption, as Friedman and others foresaw.¹ Utility companies in many countries struggle to reinvent themselves in order to avoid being ‘creatively destructed’. I am confident that in its wake a whole raft of ancillary technologies will be developed to cope with the intermittency of wind and solar energy. These include a great many technologies and adaptations ranging from batteries to pumped hydro and from demand management and smart grids to stronger, continent-spanning interconnectors. Precisely the variety of options on the table create the right preconditions for engineers and entrepreneurs to create the ‘ecosystem for innovating, generating and deploying clean power’ that Friedman spoke of.

Sadly, not all energy is electricity. If the power sector looks set to be

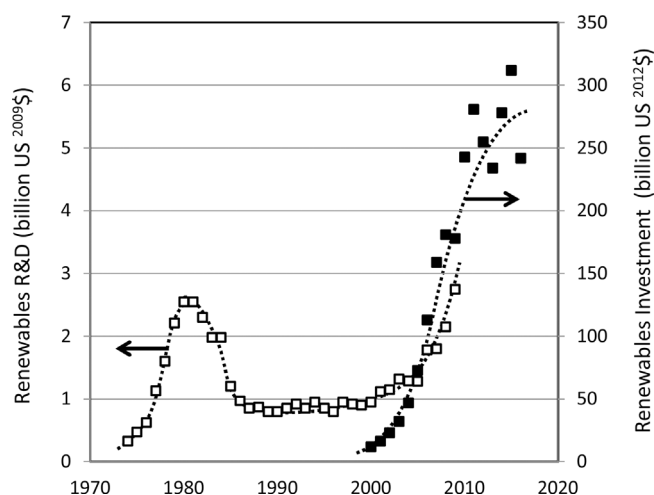


Fig. 1. Global spending on renewables since the 1970s. Starting with a spurt in government funded R&D in the wake of the first oil crisis, renewables developed into a major industry only after the year 2000. Sources: Government R&D in IEA member countries, from IEA [6], Renewables investment from FS-UNEP/BNEF [7].

¹ I am referring here to the theory of creative destruction, proposed by Schumpeter in 1942, as a “process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one” [21].

overhauled on the wings of Schumpeterian innovation, the outlook is decidedly less rosy on the fuels side. It is good to be reminded of the basic statistics. Today, just 10% of the world's total primary energy supply (TPES) is not carbon-based: 5% nuclear, 2.5% hydro, and just under 1% each for PV Solar, Wind and geothermal. The remaining 90% of TPES is carbon-based: 80% is fossil and 10% is biomass, half of it 'traditional' [11].

A recent analysis by Shell showed that pushing the boundaries of the technically possible and the societally plausible, the world might push towards a 50:50 split between primary electric and primary hydrocarbon energy by mid-century [12]. And that only if we really push hard. Carbon-based fuels and feedstocks as they are used in heavy goods and air transport, and in industry, cannot be replaced by power, and the low-carbon alternatives that are at hand have so far refused to show even the faintest signs of initiating disruption. These low-carbon options are biofuels, hydrogen and carbon capture and storage of fossil emissions (CCS). In our 2009 opinion piece, as in the Shell New Lens Scenarios on which the piece was based [13], we were hopeful that second generation biofuels and CCS would take off in about a decade (which would be just about now), and we gave arguments why CCS's deployment curve might be faster than that of renewables. Specifically that technically CCS would build on the capabilities and industrial base of the oil & gas industry. Alas, it was not to be.

For reasons both technical, economic and social, fuels present a much harder challenge than electricity. It is beyond the scope of this paper to explain the technical possibilities and impossibilities in depth. A good starting point for readers not already familiar with the technical challenges of decarbonization across all sectors of the energy economy, would be the yearly Energy Technology Perspectives of the IEA [14].

A high-level argument why the dynamics of innovation for fuels must almost inevitably be different than for power is the following. Power is produced from fossil fuels by thermal conversion in power plants, with 50% efficiency at best. PV and Wind produce electric power directly as their primary product. The converse is true for fuels: fossil fuels, most notably oil and gas for transport and heat respectively, are directly, or with highly efficient conversions usable for end-use. Moreover, the resources are abundant and highly concentrated. Renewable fuels would ideally come from biomass, but there is too little of it (*vide infra*), and the conversion of renewable electricity (of which there is potentially an unlimited and cheap supply) to hydrogen and possibly on to hydrocarbon 'solar fuels' using (air) captured CO₂ comes with significant conversion losses.

From a societal perspective, the options are compromised by the sustainability of land use for biomass production, the potential conflict with 'higher' uses of biomass according to the food-feed-fibre-fuel hierarchy, and by acceptability and lack of emotional appeal in the case of CCS.

This implies in my mind that once the growth of the electric renewables and all its ancillary technologies reaches its limits, the bull run of Schumpeterian innovation that we're presently witnessing will come to a natural end. And it will do so, well before the Paris targets are in sight. This means that collectively we have to come to terms with different types of disruptive innovation, other than the Schumpeterian type which we accept and embrace, precisely because at a deeper level it is *not* disruptive. Schumpeterian disruption is business as usual, perhaps best illustrated by the fact that the weekly business column in *The Economist* bears his name.

Let us now return to disruption in the light of the threat of climate change. I would like to propose three levels of disruption:

'Light' disruption, which the world might see *if we're lucky*, that is, if the climate sensitivity with respect to greenhouse gases in the atmosphere is at the low end of the scientists' assessment. If we're lucky enough to have 2000 Gtons of CO₂ budget left, rather than a 1000, then – who knows – Schumpeterian disruptive innovation might work its magic just in time. (A recent paper suggesting a larger budget is Millar [15].)

Economic disruption, is what for me would be the next level of disruption and it would exemplify what Malthus called 'preventive checks' on growth (in our context of the economy, of emissions, of environmental burden). Given where we are, if the climate sensitivity falls around the average and we want to prevent significant (potentially catastrophic) environmental disruption, we must work so hard on CO₂ mitigation that it will significantly disrupt the economic process.

Environmental disruption, is the end of the scale and they would be Malthus' 'positive checks' [16]. If we fail to act pre-emptively, Mother Nature will rein us in involuntarily. In spite of all the good work of IPCC, the science community and a range of good popular science books, it seems that the threat so far fails to inspire action to stave it off. Even if the means to do it exist (see the technical discussion above), we lack a mental image of how to innovatively tackle the challenge. When the preferred – and de facto only mode of innovation that we consider plausible, and therefore possible, the Schumpeterian type – falls short, then... What can we do?

To round out this essay on disruption and innovation I want to map out the space spanned by disruption and innovation. Here above I defined the main points along the disruption axis. Let us now turn to the innovation axis. Above we have amply discussed the scope for **technical innovation** and **business innovation**. But they are but the first points on a quasi-continuum of different ways and means to change something established by introducing new methods, ideas or products – to quote the dictionary definition again. Important additional modes of innovation include **institutional innovation**, which is important in the light of climate change as a commons problem, which will require our institutions (nationally and internationally) to find new ways to constrain and direct our individual actions which – in aggregate – threaten to overtax the atmospheric commons. It also includes **societal innovation**, which is the systemic change resulting from the interplay of institutional change – ultimately embodied by the state – with civil society, leading to changes to the structures of society and the ways in which it works [17]. At the very end of the spectrum we should perhaps add **behavioral change**, that is new ideas about the 'normal' or the 'right' behaviors replace established ones.

This spans a space shown in Fig. 2, where I have identified types of scenarios by names that I associate with the respective combinations of disruption and innovation. **Schumpeter** needs no further discussion. I see its relevance as limited to the lower left-hand corner of scenario space, where the 'energy revolution' in the power sector is enough for now, and we may be confident of alternative fuel technologies slowly maturing to their REEFIGDCPEERPC < TTCOBCOG moment.

With the climate sensitivity that we have and the Paris targets that stem from it, there must in my view inevitably be a shift to more institutional innovation: strong frameworks to bind governments, companies, people and peoples to strict targets. We don't have them today. Those we do have, for instance the World Trade Organization, are often seen as blockers rather than as enablers. I've called this space **Northian**, after Douglas North, the 1993 Nobel laureate in economics for the foundational work he did on institutional economics. He has shown how institutions of successful societies change in response to the evolving pressures, problems and needs of societies since antiquity (see e.g. [18]).

In order to drive the change needed, especially the pace of it, a Malthusian awakening might be needed. What I mean is not Malthusian in the dystopian sense, but **Malthusian** in the spirit of a set of moral principles – or some other sort of principles, or perhaps just lifestyle – which provides a framework for us to enact the preventive checks necessary to stave off overshoot. Malthus' prime motivation was, of course population, and he called for preventive checks on population growth so that "[t]here should be no more people in a country than could enjoy daily a glass of wine and piece of beef for dinner." In the two centuries since then we have obviously not heeded his advice and find ourselves now in a position where that daily piece of beef all by itself could push the world over the brink.

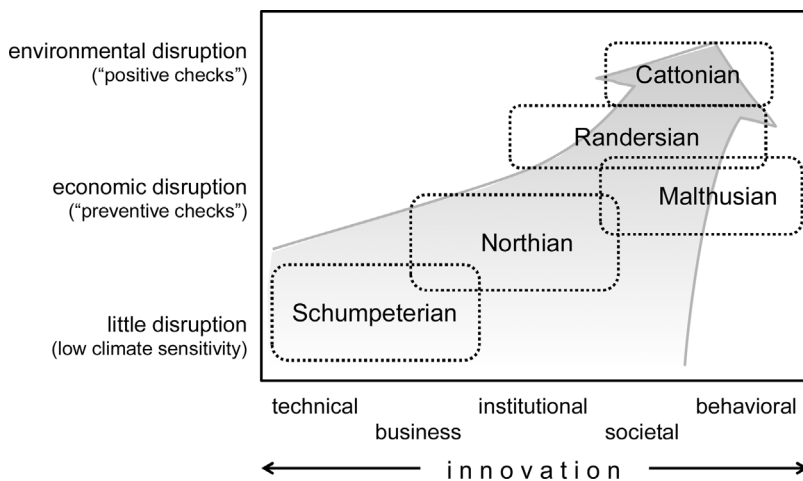


Fig. 2. The proposed scenario space for disruption and innovation which is presented and discussed in this perspective. The scenario types refer to respectively the economists Schumpeter, Douglas North and Malthus, the environmentalist Jorgen Randers and the sociologist William Catton. The wide arrow is primarily meant to indicate that as action on climate change is delayed, the world will have to rely ever more on non-Schumpeterian type innovation, and ‘disruptive innovation’ might take on a rather different meaning than is today associated with it.

If in the coming decades we once again fail to exercise a measure of preventive checks on our behaviors, we may well end up with what Malthus called positive checks – enter the four horsemen of the apocalypse, bringing war, famine pestilence and death. This I’ve labeled **Cattonian** scenarios, after William Catton’s 1980 book *Overshoot* [19]. In a way I do him injustice, since, like Malthus, he calls on us, ecological sinners, to repent and prevent overshoot as evidenced by the subtitle of his book, ‘the ecological basis of revolutionary change’. But he explored the realm of environmental overshoot, of living above our environmental means, in a prescient way. To note: there is plenty of apocalyptic books on offer by environmental writers, but this space is out of bounds for scenarios by companies, think tanks and NGOs. This seems to be due to the often-stated position that doom and gloom are off-putting to people and it is better to stick to uplifting stories.

The final blob in scenario space I’ve named **Randersian**, after Jørgen Randers, one of the co-authors of *Limits to Growth*, and lifelong practitioner of futures studies, based on the analysis in his recent book, *2052, A global forecast for the next 40 years* [20]. This is a thoughtful exposition of what Randers says is his best shot at predicting the future. What I find a particularly useful notion is his idea that the world will see a 50:50 split in its efforts on adaptation and mitigation (which justifies the vertical positioning in Fig. 2 of the Randersian scenarios box between economic and environmental disruption). This builds on the real-world notion that sustained, radical action on climate change mitigation in all likelihood will need the prodding of climate induced disasters. Already today, we see that the reinsurance industry is at the forefront of the business lobby for climate change action.

When we take stock of the scenario space spanned by disruption and innovation, we find that disruptive innovation in the Christensen mold, is a driving force in the corner of scenario space that I have called Schumpeterian scenarios. If disruptive innovation looms large in our minds as our best hope for combating climate change, this is only so because of the biases which are firmly nested in our brains. That, in Vannevar Bush’s famous words, science is ‘the endless frontier’ and that science translates into technology which is translated in practical solutions that will once more moves the boundaries of environmental constraint further out. It has always been thus. And right now, there’s a guy in a garage, somewhere...

I have tried to argue that the scenario space is much larger. Any realistic set of scenarios that describe the world’s dealings with the energy and climate conundrum must recognize this. In Fig. 2 I have drawn a broad arrow diagonally across to indicate that the longer the world waits to radically reduce its yearly emissions, the more it will be forced to move away from its intellectually comfortable reliance on Schumpeterian-type disruptive innovation, and we’ll be forced to quickly master quite different types of innovation.

References

- [1] C.M. Christensen, *This Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, Boston, Massachusetts, USA, 1997.
- [2] Carbon Brief, 2016. Retrieved from Carbon Countdown: <https://www.carbonbrief.org/analysis-only-five-years-left-before-one-point-five-c-budget-is-blown>.
- [3] G.J. Kramer, M. Haigh, No quick switch to low-carbon energy, *Nature* 462 (2009) 568–569.
- [4] M. Abramczyk, *Positive Disruption: Limiting Global Temperature Rise to Well Below 2 °C*, Rocky Mountain Institute, 2017.
- [5] O. Milman, Jeb Bush Pins Hopes on ‘someone in a Garage’ to Tackle Climate Change, *The Guardian*, 2016.
- [6] IEA, *Global Gaps in Clean Energy RD&D: Update and Recommendations for International Collaboration*, (2010).
- [7] FS-UNEP/BNEF, *Global Trends in Renewable Energy Investment 2017*, (2017).
- [8] A. Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*, Anthem Press, 2013.
- [9] T.L. Friedman, *Hot, Flat and Crowded: Why the World Needs a Green Revolution – and How We can Renew Our Global Future*, Farrar, Straus and Giroux, 2008.
- [10] M. Liebreich, *Breaking clean: state of the clean energy industry*, BNEF EMEA Summit 2017, September 19, London, 2017.
- [11] IEA, *Key World Energy Statistics*, (2017).
- [12] Shell, *A Better Life with a Healthy Planet*, Shell, London, 2016.
- [13] Shell, *New Lens Scenarios*, Shell, London, 2013.
- [14] IEA (2012–2017). *Energy Technology Perspectives*. Retrieved from: <http://www.iea.org/etp/>.
- [15] R.J. Millar, et al., Emission budgets and pathways consistent with limiting warming to 1.5 °C, *Nat. Geosci.* 10 (2017) 741–747.
- [16] T.R. Malthus, *An Essay on the Principle of Population*, (1798).
- [17] V.V. Lehtola, P. Strahl, Societal innovation at the interface of the state and civil society, *Innov. Eur. J. Soc. Sci. Res.* 27 (2) (2014) 152–174.
- [18] D.C. North, *Understanding the Process of Economic Change*, Princeton University Press, 2005.
- [19] W.R. Catton, *Overshoot: the Ecological Basis of Revolutionary Change*, University of Illinois Press, 1980.
- [20] J. Randers, *2052: A Global Forecast for the Next Forty Years*, Chelsea Green, 2012.
- [21] J.A. Schumpeter, *Capitalism, Socialism and Democracy*, Harper & Brothers, 1942.