

Review

Is the renewables transformation a piece of cake or a pie in the sky?

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ABSTRACT

Historically, long-waves have characterized transformations of the energy systems. There is not much reason to assume that our current energy system is here to stay. One possible future option is that renewables will provide all energy needed. While many scenarios exist showing that this is technically feasible, the related costs, speed of technology diffusion and social and political acceptance of such an energy transition are fiercely debated, both in the scientific field as well as in politics. Yet, there is growing consensus that renewables are becoming established as a key building block in the energy system, irrespective of the exact shares they represent. The focus should shift from a debate surrounding the feasibility of a 100% renewable system to how we can enable a speedy and immediate upscaling.

1. Introduction

Since the industrial revolution, the energy system has been subject to rapid technological change and altering dominating energy sources, characterized by long-waves of transformations [1]. For a relatively short time span now, the energy system has relied almost exclusively on fossils. Over the past decades, several of the “modern” renewable energy technologies² have quickly developed from serving niche applications to mature, cost-competitive technologies experiencing strong growth [4]. This has led to a crossroad with not much reason to assume

that our current energy system is here to stay. Brazil and France are two well-known examples where a transformation from fossils to renewables and nuclear, respectively, occurred within a few decades [5].

One possible future option is a (close to) 100% renewable energy system.³ While many scenarios exist showing that this is in principle technically feasible [6–11], the related costs, speed of technology diffusion and social and political acceptance of such an energy transition are fiercely debated, both in the scientific field [12–15] as well as in politics. Yet, there is growing consensus that renewables are becoming established as a key building block in the energy system, irrespective of

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² Traditional energy sources such as human and animal muscle power, biomass, solar energy, hydro- or wind power have been used by humanity for centuries. In contrast, modern renewable energy technologies refer to modern biomass and biofuels, solar PV, concentrated solar power, geothermal, tidal and wind energy. While hydropower, both large and small scale provides a substantial part of today's renewables, its potential for upscaling is limited compared to wind and solar and can come with negative environmental impacts. Notwithstanding, upgrades of existing hydropower plants can provide additional power at low cost. We do not exclude biomass as a renewable energy option as it is an important element of the energy transformation even if its sustainable potential is limited globally. We acknowledge though that an upper limit of approximately 270 EJ per year should not be exceeded in the near future to stay within sustainability limits, still a more than fivefold increase to today's 50 EJ per year. (see Ref. [2] GEA, Global Energy Assessment - Towards a Sustainable Future, Cambridge University Press and the International Institute for Applied Systems Analysis, Cambridge, UK and New York, NY, USA, Laxenburg, Austria, 2012. and [3] H. Haberl, T. Beringer, S.C. Bhattacharya, K.-H. Erb, M. Hoogwijk, The global technical potential of bio-energy in 2050 considering sustainability constraints, Current Opinion in Environmental Sustainability, 2 (2010) 394–403.).

³ There are many ways the future energy system could look like, also considering climate mitigation objectives such as staying within the Paris Agreement temperature guardrails (IPCC, 2018: Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. In Press.); renewable energy just being one of several possible low-carbon options (e.g. nuclear energy). In this article, we deliberately focus on renewable energy.

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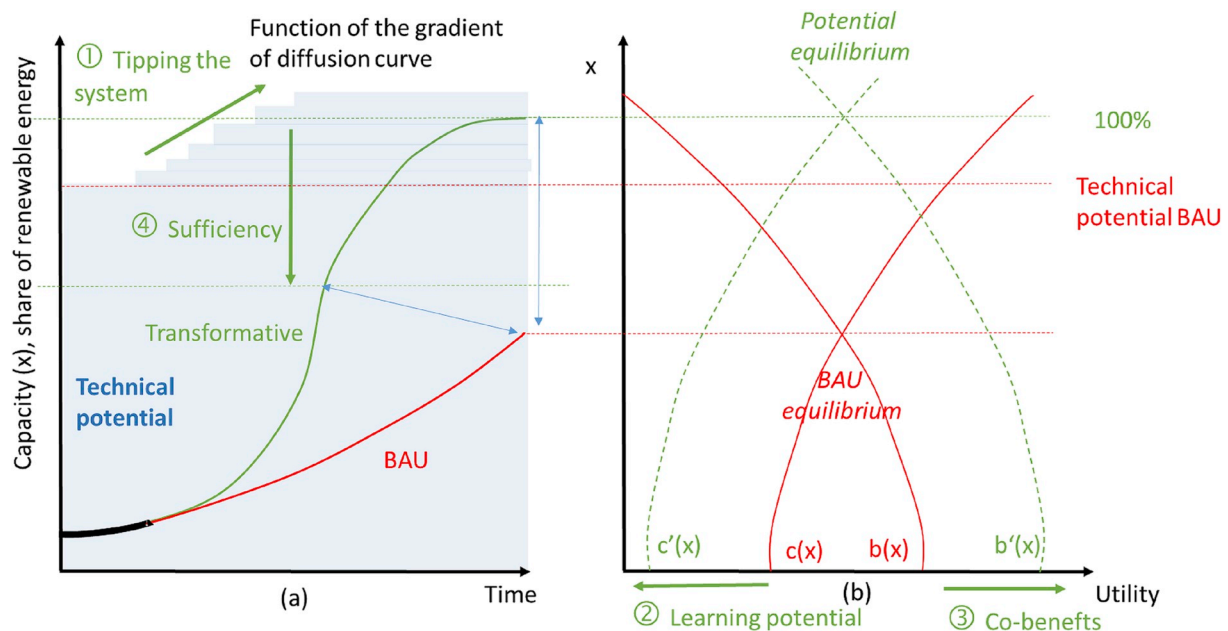


Fig. 1. Stylized scheme of four key drivers of a transformation of the energy system towards high shares of renewable energy: 1) tipping elements, 2) learning potentials, 3) co-benefits, and 4) energy sufficiency. The business as usual pathway of renewables related cost and benefit curves and equilibrium are shown in red. The transformative pathway and related (shifted) cost and benefit curves and resulting equilibrium based on drivers 1–3 are shown in green while energy sufficiency (driver 4) would lower overall energy demand, making achieving 100% even easier which would result in another equilibrium, and cost and benefit curves not shown here. Note on the y-axis: Renewable capacity (GW) is not meant to be equated to the share of renewable energy (GWh). Both are depicted as they are relevant for the drivers. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the exact shares they represent. The High-level Political Forum in its 2018 review of SDG 7 on energy ‘calls upon Governments and other stakeholders to accelerate the pace of transition towards renewable energy’ [16]. We do believe that the positive narrative of a future relying on renewables has not gained sufficient attention in recent debates [12–15] and is worth bringing forward explicitly to this end.

In this article, we argue that the scenario-based debate analyzing the role of renewables in future energy systems has put too much emphasis on the question whether a 100% renewable share is feasible over the question how renewables can be scaled up as fast as possible. Too much emphasis is put on the rather uncertain longer-term perspective over short to medium-term actions, deviating the debate. This in our view bears the danger of one-sided interpretations of scenario-based analyses of energy systems transformations, which could lead to “un-balanced” priorities, delaying much needed action. Policy makers ask for short-term and practical implications while many scenarios are targeted at long-term analyses. In the current discourse a set of arguments are often overseen. With this article we want to prompt an increased focus on short-term action both in scenario analysis and policy design, despite long-term uncertainty. Before elaborating on these arguments in more detail, we first take a closer look on what scenarios can teach us.

2. What scenarios can teach us!

Scenarios are a mean of identifying feasible future pathways, the impacts of different policy options and ranges of uncertainties of alternative futures. They can also support the formulation of objectives [17]. They are, however, not meant to be predictions of what will happen in the future, but rather consistent descriptions of what could happen. We thus like to think about scenarios as a consistent framework to compare alternative, plausible futures. When looking further ahead the future becomes more uncertain and predictions thus more difficult. Therefore, scenarios are used to construct contrasting visions that reflect the same boundary conditions but that differ enough from each other to capture a realistic range of possible future pathways as well as

resulting in different future challenges. They are also a useful tool to explore combinations of technologies that can be configured towards technically feasible systems and provide an indication on the speed of transformation.

We believe that the power of scenarios lies in proving the feasibility of an aspirational future, such as an energy system that relies on large shares of renewables, maybe even 100%. They guide us on what has to happen to get to such a desired state. Such sustainable scenarios have a range of common characteristics [18,19]: i) they decarbonize the energy system, ii) electrify applications of fossil fuel use in industry and buildings and as much as possible in the transport sector, and iii) reduce overall energy demand. Many of these scenarios also have a large portfolio of different energy technologies, incl. biomass, storage, demand side management, etc. as this increases the flexibility and resilience of an energy system [2]. Excluding any of these options ex-ante poses heavy constraints on the energy systems. Compared to scenarios with higher energy demand and less stringent climate objectives, the sustainable scenarios experience less rapid and lower growth rates in renewable energy technologies as they mostly have to meet lower overall energy demand [19]. Still, the deployment of renewables technologies in less stringent scenarios is in line with global potential estimates of renewables [20].

These scenarios show that technically the global energy system can transform toward 100% renewables within the 21st century. This question has been answered for some time now. Even with today’s technologies near 100% should be possible. The fact that there is still an ongoing debate on whether a renewables share of near 100% can be accomplished is mostly owing to questions about cost competitiveness and scaling potentials of renewables. Against this background we think that the current focus of the debate arguing on which share of renewables is feasible by when is partially misleading and should shift towards how renewables can be up-scaled substantially and quickly, starting the transformation immediately.

In the following, we want to point out four arguments that in our view have been partially overlooked or that at least have not received sufficient attention in the current discourse. If considered jointly they

would likely lead to different interpretations and implications of long-term energy scenarios. They are complementary and re-enforce each other. We want to illustrate this conceptually in Fig. 1:

Panel A, on the vertical axis displays the total renewable capacity, or the share of renewable capacity in total demand, respectively depending on the effects described in the following. The horizontal axis displays time. The black segment of the curve displays the historical trajectory of renewable energy (RES) expansion. It branches off in either a business as usual (BAU) trajectory (red) – which is a continuation of the historical transformation rate or a transformative trajectory with exponential rates of change (green). The renewable energy trajectories and therefore the maximum share of renewable generation serving demand is constrained by the technical potential (blue shaded area) which is determined by resource endowment, available conversion technologies, but also by the technical capability of the system to accommodate large shares of renewables. The whole technical potential however usually is never fully utilized as it would not be economical. Panel B shows conceptually two curves displaying the marginal cost c or the marginal benefit b in dependence of the deployment level x of renewables. By definition, costs increase marginally due to the gradual exploitation of the best resource sites and higher costs of integrating renewables. Contrary, the marginal benefit of renewables decreases for higher shares of renewables. The intersection of both curves constitutes the long-term equilibrium, which determines the – economically efficient – level of renewables deployment. When we look at the end-point of the red trajectory (BAU) (Panel A) achieving a renewable share of 100% of generation seems like a very tall order. Higher shares would be uneconomic and 100% would be beyond the technical and integration potential. We however think this discussion, which is strongly based on an extrapolation of the past into the future, is partially misleading as a near 100% renewables share in generation could be reached in another way, and potentially easier, than we think now.

3. Four arguments why a renewables transformation could be a piece of cake and not a pie in the sky

We now draw attention to a set of elements, which we feel could push such a transformation, as shown in the alternative future pathway (green) in Fig. 1.⁴ We will discuss them in detail below: 1) tipping points within the energy system; 2) vast learning potentials of renewable energy technologies with recent cost reductions to as low as €3/kWh and 3) multiple co-benefits related to the UN Sustainable Development Goals (SDGs) and the Paris Agreement and 4) a demand side focus emphasizing energy sufficiency and efficiency.

3.1. Tipping the system: disruption of the system can trigger innovation

Achieving the SDGs and the Paris Agreement requires a deep transformation of the energy system. Scenarios can guide the way how to get there and show what is technically feasible. They however cannot be translated one-to-one into an actionable agenda. The reason is that system transformation in ‘reality’ does not take place in the same gradual way as it can typically be observed in the models. This is so, since implicit assumptions underlying the scenarios in the “real world” typically cannot assumed to be given, but have to be created, which is the truer the greater the desired trajectory departs from a BAU trajectory. This pertains for instance implicit assumptions regarding perfect foresight, information or rationality, or centralized decision-making. We therefore argue it would be plausible to aim for a faster expansion of renewables than what is deemed “optimal” in scenarios. This creates accelerated renewables expansion. The energy system is known to be inert which is due to deeply rooted path dependencies of energy

infrastructures, but also cognitive ones (mental maps). A mere gradual push triggered through renewables policies is unlikely to enact the system transformation at the scale that is needed. What is rather needed is a “system shock” that pushes the system sufficiently out of its equilibrium creating incentives for new business models and technologies; or put differently: the new technologies to enable 100% renewables share cost efficiently will only be developed when the suitable incentives are in place to do so. To illustrate this more clearly, one can think of the rapid expansion of renewables in particular in the electricity sector in several pioneering markets globally, where some would argue that the expansion has taken place too fast as reflected by the decreasing market values of renewables – the dynamic view of this is however a different one. This “oversupply” of electricity creates incentives to think about new business models and actor coalitions, demand side participation, prosumerism and the like. It also triggers new applications, e.g. mobility, of sector integration. Altogether, this will cause the tipping points that can shift the system towards a new technology portfolio (Fig. 1a, driver 1).

On the other hand, in case of mere gradual change the current system is more likely to adapt and revert to the old equilibrium. As a consequence, potentials for cost efficient deployment and integration of renewables might not be fully deployed, which may effectively limit the overall renewables share. A “system shock” also has an important role to play to signal actors that the transformation will go beyond gradual changes. Actors have to internalize in their expectations that change will happen to generate new ideas and business models that are required. The positive message propagated by many actors is part of a self-enforcing process: initiatives get organized, set ambitious plans, which lead to shifts in perspectives, divestments, change in expectations and trust in future systems dynamic on the way to a tipping point. Ideally national plans get over fulfilled by bottom up goals (e.g. cities), investors, etc. Some elements of this can already be observed now. Irrespective of national or international policy commitments, there is a plethora of non-state actors who are already pushing for renewables within their scope of decision-making. Cities and investors are key actors in the support of renewables and decarbonization [21]. Several alliances of cities and communities, home to millions of people, are pushing for a renewable energy transformation (e.g. Carbon Neutral Cities Alliance,⁵ Climate Mayors,⁶ Global Covenant of Mayors for Climate & Energy,⁷ Go 100% RE,⁸ Go 100%⁹). Cities and local governments have strong purchasing power (public transport and fleet, public procurement) and agency in designing regulations, such as renewable energy targets. Many metropolitan areas exceed nation states in terms of income, population and energy demand. With increasing urbanization cities’ leverage within the energy transformation will further increase in the future.

Investors and businesses are also pushing renewables. An example is the Break through Energy Coalition¹⁰ that aims to accelerate innovation in the energy realm. It brings together investors with economic power larger than nation states. More than 100 non-energy sector businesses with 100% renewable goals in electricity have formed the initiative RE100.¹¹ Utilities are investing in renewable energy technology companies and are integrating renewables into their business plans. Recent divestment announcements include the World Bank Group’s stop on financing upstream oil and gas after 2019 [22] and Norway’s notion to divest the world’s biggest sovereign wealth fund’s oil and gas holdings [23].

⁵ Carbon Neutral Cities Alliance: <https://www.usdn.org/public/page/13/CNCA>.

⁶ Climate Mayors: <http://climatemayors.org/>.

⁷ Global Covenant of Mayors for Climate & Energy: <http://www.globalcovenantofmayors.org/>.

⁸ Global 100% RE: <http://www.go100re.net/>.

⁹ Go 100%: <http://www.go100percent.org>.

¹⁰ Break Through Energy Coalition: <http://www.b-t.energy/>.

¹¹ RE100: <http://there100.org/>.

⁴ For an exhaustive list of arguments in favor of a renewable energy transformation we refer the reader to the Global Energy Assessment (2012).

We conclude that scenarios do not (yet) reflect non-linear change dynamics in a satisfactory manner. A move to a low-carbon energy future requires a drastic change in energy investment and the resulting mix in energy technologies. If history is any guide, energy scenarios overestimate the extent to which the future will look like the recent past. We cannot and do not yet know all future technologies, change is not predictable. We have not set the incentives to create them, at the same time the current technology portfolio would be sufficient to carry the energy transformation through.

3.2. Learning potentials: a fundamental transformation towards high shares of renewables in the energy system is feasible because renewables can be up-scaled quickly and have become cost competitive

A diverse portfolio of different renewable energy technologies exists that can provide the best suitable option for each energy service need. The new renewable energy technologies predominantly produce electricity. The electrification of the energy system and the resulting decarbonization of the electricity system will be at the core of the energy transformation. Renewables play a critical role in electrification, contributing around 90% of this growth in 2015 [24]. Moreover conversion of electricity to mechanical work is very efficient while the efficiency of fuels going through the thermodynamic cycle is limited (average of 38% for OECD plants) [4].

The diversity, abundant availability and flexibility of renewable energy technologies is key for system resilience and security. In recent years renewables, foremost wind power and solar photovoltaics (PV), have excelled with faster growth rates and lower costs than [25–27]. Today, renewable energy technologies have reached grid parity challenging fossil fuel power generation [28]. The world's lowest auction result for utility PV has reached 2.69 €/kWh in Mexico [29], with global weighted leveled cost of energy (LCOE) estimated at 6.00 €/kWh for PV and 5.00 €/kWh for onshore wind in the coming year [30]. Fossil fuels are still often heavily subsidized, irrespective of their negative externalities such as air pollution and climate change.

The witnessed cost reductions, such as by more than two thirds in PV in the past six years [30], have not translated to appropriate diffusion rates in most long-term energy scenarios, which underestimate the renewable energy potential [25,26]. Yet, reality is moving fast. Capacity additions in renewable power reached more than 60% in 2016, with the highest ever annual capacity addition of over 160 GW. Investments in renewable energy have outpaced the ones in fossil fuels by a factor of two [4]. There is still room for further costs reductions, especially with up-scaled installation and production, affecting the potential equilibrium (Fig. 1b, driver 2).

New renewables are more granular than conventional energy technologies. Granular technologies are small scale, modular, replicable, divisible, and have low unit cost. They reach larger cumulative output numbers through up-scaling and have higher learning rates than lumpy technologies [31]. Novel analysis of historical data shows that granularity enables faster and less risky diffusion outcomes with more equitably distributed benefits [32]. Renewables have thus a larger potential for quick system transformation.

Both developed as well as developing countries have achieved large shares of new renewable energy in their electricity generation and strong recent growth rates. Denmark has increased the renewable energy share of its power generation from 16% in 2000 to 62% in 2016 [33]. Cabo Verde has become the country with the second largest share of wind power in its electricity mix, which it increased from only 5% in 2005 to over 28% in 2014. Individual regions and countries differ in their initial conditions, both with regard to resource endowments, geography as well as socio-economic and political circumstances but the new renewables portfolio is flexible and versatile enough to suit different demands. Especially when new infrastructure has to be built, it is a no-brainer to go for renewables to avoid long-term system lock-ins.

3.3. Co-benefits: multiple benefits of renewable energy systems support implementation of the SDGs and achievement of the Paris Climate Agreement

With SDG7 a proper goal within the UN 2030 Agenda on sustainable development on energy, the global community accentuates energy's crucial role for human advances as well as its environmental externalities that threaten Earth-system stability (45). SDG 7 calls, besides universal energy access, for a push for renewables and for improvements in energy intensity. Up to date the global energy system has had strong adverse impacts on humans, the economy as well as the Earth-system, from climate change [34], air pollution and health [2,24] to water stress [35] to name but a few. In a qualitative assessment of how SDG 7 interacts with the other SDGs [36], the positive interactions dominate the negative ones in absolute terms and magnitude. These co-benefits also influence the potential equilibrium (Fig. 1b, driver 3). The renewables target of SDG 7 is seen favorably in literature [36,37] as it has positive impacts on SDG 3 (health) and SDG 11 (cities) because of reduced indoor and ambient air pollution, SDG 6 (water) due to lower water demand, SDG 12 (sustainable production and consumption) due to natural resource protection and of course SDG 13 (climate).

With the adoption of the Paris Agreement, the global community agreed to jointly keep global warming (well) below a global mean temperature increase of 2 °C above pre-industrial times [38]. There is only limited time left to meet this objective. The energy sector has contributed intensely to anthropogenic climate change. With around 33 GtCO₂ [9] energy related GHG emissions amount to ~70% of total anthropogenic GHG emissions [39]. The global energy system must be decarbonized by mid-century, which translates to a complete phase out of fossil fuels [40]. The Nationally Determined Contributions (NDC) of the Paris Agreement and SDG7 are policy approaches to tackle the challenge of an energy transformation and they are broadly consistent. Neither of them is sufficient to meet the 2 °C or even 1.5 °C goal [41]. To meet both, reduction in energy intensity and more renewables are needed in the system.

In 2015, outdoor air pollution, predominantly driven by the current energy system, caused around 3 million premature deaths. IEA [24] highlights the importance of policies such as efficiency and renewable energy policies that avoid pollutant emissions when improving air quality. McCollum, Krey and Riahi [42] found synergies of decarbonization and energy efficiency with regards to pollution control and energy security of \$100–600 billion annually (0.1–0.7% of GDP) by 2030. IRENA [9] estimates benefits of between two to six-times the decarbonization costs. Health benefits of climate policies provide one of the most attractive entry points for policy makers to promote renewables, as the example of China [24] or the debate on diesel combustion engines and electric mobility in European countries [43] show.

The energy sector is responsible for around 15% of global water withdrawals¹² that are mainly needed to cool thermoelectric power plants [44]. Promoting renewables to mitigate climate change offers co-benefits for water as non-thermal renewables such as wind and solar PV have very low water requirements compared to other low-carbon electricity technologies [45]. Decreasing the water consumption per unit of electricity generated enhances the resilience of power supply, especially important for developing countries. Their electricity demand steeply increases while many are prone to water stress and strongly affected by climate change [46].

¹² Note the difference between the terms 'water withdrawals' (water withdrawn from its source to be used, which might be returned to varying degrees) and 'water consumption' (the portion of water that is not returned to the original water source after withdrawal. It is thus no longer available for reuse).

3.4. Sufficiency: demand side focus by emphasizing energy efficiency and 'negawatt' potentials

The role of the demand side is too often overlooked when discussing future energy transformations (such as in the recent debate on the US energy system, [12–15]). Reductions in demand provide a valuable and often most affordable energy “source” [2,28] and make achieving high shares of renewables easier. Investments in energy efficiency have long-term benefits – they are no-brainers when keeping in mind economic and population growth. Yet they only amounted to 14% of total energy system spending (USD 1.6 trillion) in 2015 [47]. Lowering energy demand increases flexibility on the supply side. The demand for base load decreases, which enlarges the technology portfolio. Every unit of energy that is not needed, be it through behavioral or technological changes need not be provided in the first place or can be used somewhere else. Given the conversion losses in the system, reductions on the end-use side translate to large upstream reductions on the supply side. These “negawatts” [48] are at least as important as additional megawatts from renewables. A recent scenario identifies energy needs and technological change from an end-use perspective, focusing on energy services [49]. This bottom-up approach leads to a global final energy demand of 245 EJ in 2050. Such a comparatively low demand can more easily be met with renewables. Looking at Fig. 1a (driver 4), lowering overall energy demand would make achieving a renewables transformation even easier.

Electrification of the energy system driven by renewables will lower overall energy demand significantly [2]. This can also lead to a great leap in efficiency in mobility. Propulsion with combustion engines requires roughly three times the energy compared to electric motors. Electric mobility would further drive overall renewable electricity production and support demand management. In addition to electrification of mobility, biofuels such as ethanol can play an important role in the transformation of the transport sector as the example of Brazil can show. Today, more than 90% of cars sold in Brazil are flex-fuel vehicles, running on pure ethanol or gasoline blends (18–27.5%) [50]. The year 2017 brought about unexpected policy announcements in transport. We can already see examples of legislation banning conventional combustion engines in cars by 2040 (e.g. France [51]). Norway has supported electric vehicles with a range of favorable policies which has led to the highest per capita penetration rate globally (21.5/1,000 people in July 2016) [52] and is aiming for 100% electric or plug-in hybrid car sales by 2025 [51].

Digitalization, demand management and smart systems will be an important element in an energy system with many volatile renewable energy sources. OECD/IEA [53] estimate that smart demand responses to provide system flexibility of 185 GW or savings in electricity infrastructure investments of USD 270 billion. Digital technology has transformative potential and is conducive for integrating variable renewables, electric vehicles and distributed electricity generation.

Minimum performance standards also spur improvements in energy intensity across applications and sectors. Increasing the coverage of energy use sectors by such standards would lead to harnessing fallow present but also future potential in reducing energy demand. Today, two-thirds of global energy use in buildings are still not subject to any minimum performance standards [53]. This is especially relevant when considering the long life times of buildings. Overall, aiming for improvements to match current best practices across industries and technologies would already contribute largely to decreasing overall energy demand. Despite energy efficiency standards in the end-use sector (e.g. electrical appliances) being more advanced than in other areas, more challenging changes relate to fundamental changes in behavior (e.g. shared economy, dematerialization, circular economy, sustainable consumption patterns) which will take longer to materialize but which has huge transformational potential. At the same time, the demand side is characterized through granular energy end-use technologies which, as mentioned, have higher learning rates and diffuse

faster [31].

Electrification will not be possible in all sectors and applications. Hydrogen can act as a complementary energy vector in the transport sector, especially for aviation and shipping but also for cars as Toyota and Honda show with their fuel cell vehicles. Hydrogen provides an energy storage option, complementing intermittent renewables. It can also complement electricity in the energy system with the possibility of grid-connection, both locally but also globally [54]. Magnetic levitation could be used for trains and elevators while the Hyperloop¹³ could revolutionize medium distance travel. Biofuels in aviation are another option [55]. Within the industry sector, efficiency can be spurred by switching to hydrogen. Hiebler and Paul [56] showed that steel production can be achieved in an environmentally friendly way while achieving cost reduction of around 20% if hydrogen is used for reduction.

4. Conclusion

We have raised four arguments that we believe will make high shares of renewables in the energy system easier to achieve than currently expected: 1) tipping elements in the system, 2) vast learning potentials of renewable technologies, 3) their many co-benefits and 4) energy sufficiency. We should capitalize on them. By highlighting these, we try to distill guiding elements for policymakers from a complex debate, which has been subject to ample research. Its scope, long-term outlook and uncertainties can be unsettling for current policy action. We believe that a positive narrative is a strong fundament for a renewables transformation.

A wide literature on energy scenarios exist covering a plethora of possible futures. Scenarios illustrate the long-term implications of policy decisions. They provide perspectives to guide current policy debate which we hope to enrich through this focused contribution. Even conservative scenarios (in terms of learning rates of renewable technologies or energy demand) can achieve close to 100% renewables. Scenarios with high growth rates in renewables based on currently observed trends, combined with low demand, as shown by Grubler, Wilson, Bento, Boza-Kiss, Krey, McCollum, D. Rao, Riahi, Rogelj, De Stercke, Cullen, Frank, Fricko, Guo, Gidden, Havlík, Huppmann, Kiesewetter, Rafaj, Schoepp and Valin [49], and also non-linear change in technology innovation could be added to the literature. A challenge lies in translating these long-term effects to current policy advice. Scientists should be clear about the effect their long-term scenarios – and their underlying assumptions - can have on short-term policymaking. We have tried to summarize key elements policy makers can act upon and that are common to sustainable scenarios. They translate to a set of no-brainers and no-regret options that policy makers should push and that all speak for renewable energy technologies, such as avoiding fossil fuel system lock-ins, harnessing dormant efficiency potentials and lowering demand, or maximize co-benefits and mitigate trade-offs in line with international agreements. The question whether 100% is feasible or not does not change the implications for immediate fast expansion of renewables.

What can policy makers do? In line with the High-level Political Forum's review on SDG7 this past July, we call upon policymakers to speed up the renewables transition: Do not lose time, start by starting. Policymakers can support ample technology research to develop a wide a portfolio of technology options, not in search of the silver bullet but to keep the system flexible. While disruption cannot be steered per se, policy makers can level the playing field by adjusting regulations to novel business models and evolving technologies and services. We need to create an enabling environment, with conditions that spur innovation and anticipation. All of this will push renewables and in the end, it

¹³Space X White Paper: http://www.spacex.com/sites/spacex/files/hyperloop_alpha-20130812.pdf.

is likely that this will translate to a close to 100% renewable future.

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