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Editorial

A more versatile policy framework is essential for dealing with the massive scaling up of clean energy to meet climate goals

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Meeting the climate targets requires not only scaling up of clean energy but also addressing the impacts from such a massive technology build-up, some of which can be adverse. Disruptive clean energy technologies such as solar and wind power have made huge progress over the last decades, and they have helped the power sector to become the dynamo of decarbonization making electrification one of the key strategies to decarbonize other sectors as well such as transportation and industries.

This trend is expected to prevail in the future. According to the latest scenarios by the International Energy Agency [1], renewable energy sources (mostly modern renewables) will make up at least four-fifths of the total power capacity additions by 2030, and their global share of all electricity would increase from 30% at present to 45%–60%. The impacts from such a volume increase on energy systems and surrounding societies could be large, some even unprecedented, because of the quite different characteristics of the new technologies from the traditional ones.

For example, the variable nature of the new renewable electricity forms requires additional measures to increase flexibility to match the supply and demand of electricity, which is inherently handled by traditional fuel-based systems. Similarly, though solar and wind are the cheapest forms of electricity in many places, the growing supply variability increases the volatility and unpredictability of power prices, which may hamper investments. Another evident difference to traditional power plants is the land requirement, which is many-fold compared to the traditional power plants as the whole fuel chain is included in the wind and solar installations. This may cause conflicts with local neighborhoods and competition with other land uses, such as agriculture.

Scaling up means more investments. The global market of clean energy technologies amounted $700 billion in 2023 and is expected to rise to more than $2 trillion by 2035, which approaches the value of the global crude oil market [2]. The new clean energy economy is starting to replace the fossil industries which is also the prerequisite for declining emissions. The new energy manufacturing relies much on materials, some of which are labeled as critical for society. This has resulted in global competition in controlling supply chains of the new energy technologies. The geopolitical implications from this "new energy economy" are huge, and a reason for increasing tensions between the superpowers, which could in the worst case lead to trade wars between the large economic blocs. China has become the global leader in clean energy technology manufacturing, followed by the United States, Europe, and increasingly India [2], whereas emerging and developing economies seem not to be able to profit from the new energy economy.

The new energy economy creates many new jobs important to the local communities and their economy. For example, in solar photovoltaics alone, there are close to 8 million working places. But stronger emission reduction measures also mean shutting down fossil power plants. For example, closing coal mines may wipe out the livelihood of whole communities causing major social problems, unless new jobs are created locally simultaneously. For example, the coal regions of Eastern Germany have suffered major losses from the closure of coal power plants and mines causing political unrest.

Above examples of the different impacts from the energy transition demonstrate that the increasing scale of clean energy has turned into a socio-technical transition affecting the whole society and all of us in multiple ways, and not just the energy systems as in the early stage of the transition. This will be a major challenge, as clean energy use must be accelerated from the present in the coming years to meet the climate targets. How to handle such transitions optimally from the societal side is in itself a major task, not to speak about the unknown challenges that will be in front of us when proceeding along the low-carbon path eventually to the zero-emission goal. The framework of the transition ahead requires strong scientific input and new research to advice the policymakers and decision-makers about what should be done, what can be done, and what may be possible in the future, but also about the different limitations that may prevail.

Oxford Open Energy (*OO Energy*) is committed to be part of the dialog to improve our understanding of the underlying science, problems, and solutions in the energy transition. Our Special Collection of Papers from the year 2022 offers a useful set of papers for a start. It has been broadened by several contributions during

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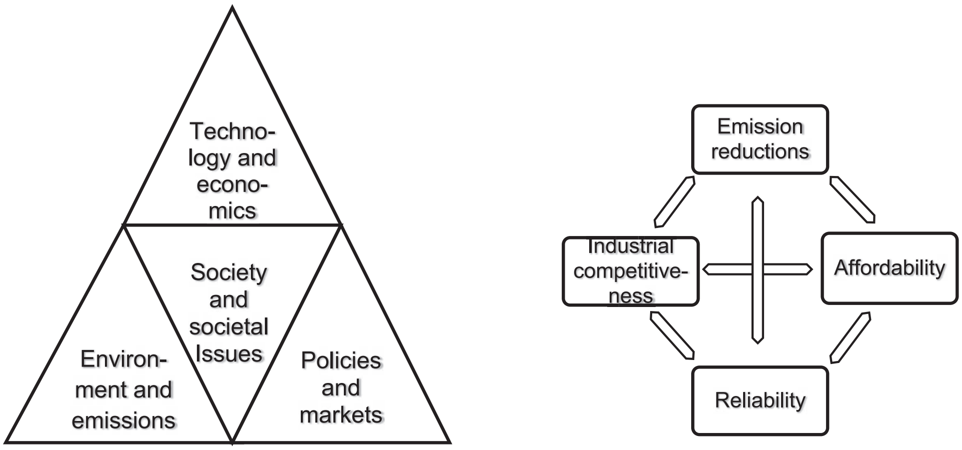

Figure 1. Examples of possible frameworks for accelerating the energy transition. (left) General framework for a socially just transition (adopted from [11]), (right) modified framework focused on key economic factors along with emission reduction (adopted from [12]).

2023 and 2024 such as Andersen *et al.* [3] on directions for research on net-zero transitions, Lægreid *et al.* [4] on the coal phase-out, Jolly *et al.* [5] on renewable energy and industrial development in pioneering and lagging regions, Olbrich *et al.* [6] on system building of the transition using Germany as an example, and Khatoon *et al.* [7] on sustainable passenger transport transition in Dhaka, Bangladesh.

The challenges ahead with the scale-up of clean energy solutions, including the harmful effects mentioned earlier, should not only be considered negative but also as challenges that may set off new innovations to provide better solutions. For example, as industrial-scale solar will need huge land areas, new types of solar photovoltaic modules and systems are emerging for less valuable land use, or, to enable multiple uses of land, e.g. covering water surface areas with PV enabling also fisheries (off-shore PV [8]), or enabling both cultivating food crops and producing electricity (agri-PV) from the same unit of land.

The yearly United Nations climate meetings are important milestones in climate change mitigation to update the goals and measures needed for reducing emissions, which also will affect the energy transition. The previous 28th Conference of the Parties, or COP28 in Dubai, agreed about abandoning fossil fuels and reaching global net-zero emissions in the energy sector by 2050. This agreement had important energy implications such as requiring tripling the capacity of renewable energy by 2030, doubling the rate of energy efficiency improvement by 2030, and accelerating the deployment of other critical low-emissions technologies [9].

Though most countries worldwide agree on the necessity of cutting emissions, the political will to find a consensus on the measures has been less successful. Numerous scenarios and studies have shown technically optimal solutions and pathways to net-zero carbon emissions, but the emissions still reached record-high level in 2023, though starting to level out. The present trend of emissions is heading toward well above 1.5°C increase in the global temperature perceived as the upper limit to avoid massive irreversible damage to our planet's life-supporting ecosystems and biodiversity.

The upcoming climate meeting COP29 in Baku, Azerbaijan in November 2024 will therefore need to address the urgent question of how to put the global emissions on a new trajectory to meet the Paris Climate Agreement goals. Discussing the ample literature of updated technical pathways and technology solutions may be the least challenging task in Baku, whereas issues such as who pays for the future transition and how much and when are hard tasks. Questions on social fairness, shared futures, that is, how to formulate a socially just transition not leaving anyone behind, but being inclusive, need to be high on the agenda to turn the emissions to a rapid downward trend. Of particular importance in this context is to support the transition in the merging and developing economies which requires not only external funding but also strengthening local innovations, technology base, and local engagement for implementation [10].

The questions and criteria included in the political framework for shaping a climate mitigation blueprint, or any national energy-climate policy, will affect the solutions that follow. Understandingly, political affinities, ideologies or models put a strong pressure on shaping the policies, though the scientific facts or the empirical data would remain the same. For example, the views presented on climate change and its mitigation during the recent US Presidential Campaign in 2024 well demonstrated the extreme sides in policies on climate albeit the same facts base.

The empirical observations from the energy transition strongly indicate that an integrated framework addressing not only the environmental and techno-economic factors but also economic, political, and in particular social factors will be necessary (Fig. 1 left) for a successful transition, and it would the framework for a socially just energy transition [11]. Importantly the above-mentioned factors are interconnected, and therefore their full consideration would lead to more optimal solutions. Such a holistic whole-view approach would also better account for UN's Sustainable Development Goals (SDGs), in which the progress has been much too slow. Sustainability, SDGs, and climate change mitigation go hand in hand. The kind of integrated policy framework should be endorsed in the COP29 negotiations.

An integrated framework emphasizes that a successful transition to net-zero emissions requires focusing not only on the emissions but also on multiple goals, in particular those that affect and enhance human economic well-being [12]. A poorly implemented transition could weaken the affordability and reliability of energy, and industrial competitiveness, and the opposite is true for a successful transition. Advancing these three factors together with emission reduction could accelerate the transition itself. Therefore, addressing emissions reductions together with the challenges of affordability, reliability, and industrial competitiveness forms an important framework (Fig. 1 right) under the more general transition framework (Fig. 1 left).

Finally, it should be noted that cheaper and better technologies and innovations are still at the heart of the transition. Advances in science are important to deliver more powerful solutions, e.g. to energy system flexibility or sustainable synthetic fuels such as hydrogen. These new developments are strongly connected to energy systems and systemic issues as well, some of which could be denoted as "hot topics," too. *OO Energy* has touched on several of these. For example, Ajanovic [13] noted the importance of the whole well-to-wheel efficiency when planning sustainable mobility and discussed the future role of hydrogen in transport. Lavieri and Martins de Oliveira [14] found that the user groups may affect the electric charging infrastructures. A recent theme of high importance is the increasing power demand from digitalization and AI, e.g. in the EU, the data centers' power demand could raise by 20% per annum [15]. Manner [16] noticed the energy unsustainability of software systems and identified major opportunities for energy savings. Platt *et al.* [17] pointed out that energy demand unawareness may lead to high energy demand in digital services using Bitcoin as an example and emphasized the importance of education and information to mitigate these. Mytton *et al.* [18] put the whole digitalization trend into a broader context by investigating the management of data center energy demand and grid capacity. Also, the definition of innovations must be broadened from mere technological to social innovations to develop effective solutions [19].

Science plays an important role in anticipating and investigating different alternatives for an equitable and inclusive transition and informing society and decision-makers about the best solutions. *OO Energy* offers a platform across the disciplines to present and discuss their latest findings. To better support multifaceted approaches, we have recently introduced a new article type, the so-called *Vignette*, which is a multiauthored perspective or review article on compelling, topical issues in energy.

We call on the scientific community to join us in this important journey of forming a people-centered just energy transition and strengthening the evidence base of the best practices ranging from technologies to policies.

Author contributions

Peter Lund (Conceptualization [lead], Formal analysis [lead], Investigation [lead], Methodology [lead], Writing—original draft [lead], Writing—review & editing [lead])

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