Seven key principles for assessing emerging low-carbon technological opportunities for climate change mitigation action

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Introductory comments

It is virtually certain that there is going to be a scramble for technological innovation in the coming years, to ensure that society can operate without today’s vast reliance on fossil fuels and their associated CO2 emissions, nor the emissions of methane (CH4), nitrous oxide (N2O) from agriculture and waste, and other greenhouse gases from human activities. Indeed, it has been estimated that almost half of technologies making up a net-zero energy system in 2050 are as-yet commercially unavailable [1].

In this technology goldrush, there will inevitably be both successes and failures. Some new technologies will help tackle both climate change and other energy-related or societal challenges (such as energy security and reliance on volatile fossil fuel prices) [2], whereas others—despite their contribution to reducing greenhouse gas emissions—will risk augmenting existing concerns or even give rise to new societal issues (such as local environmental pollution, or bottlenecks and disruptions to communities affected by extraction of energy transition-critical materials and over-reliance on brittle international mineral supply-chains with the associated geo-political tensions that could result) [3, 4].

Furthermore, technology development will not occur in isolation of broader infrastructures (such as roads and city designs, electric vehicle charging networks, district heating and cooling networks, or hydrogen pipelines), but rather technologies will be central “artefacts” within a system of physical, regulatory, and political innovation systems [5]. The success or failure of such systems will depend on multiple actors (including researchers, businesses, investors, governments, and consumers) and factors (regulation, policy, capital availability, information, social legitimacy for new technologies, etc.) as well as the efficacy of their interactions [6].

Evaluating emerging technologies

We summarise seven key principles that must be considered when evaluating the success levels of new, emerging technologies (summarised in Fig 1). This evaluation framework derives from our own experience in considering the potential benefits and risks of a range of technological solutions to climate change, as evidenced across multiple analyses of low-carbon transition pathways.

First, we assert that new technologies must demonstrate a significant degree of additionality to emissions reductions, compared to already-existing technologies and solutions. For example, technologies for the synthetic (as opposed to natural) removal of greenhouse gases, such as direct air capture, do not yet exist at meaningful commercial scales even if the additionality of
these technologies is already demonstrable [7]. By contrast, it is unlikely that new low-carbon electricity technologies can succeed in the golden era of renewables, unless they can confer significant advantages over them, in terms of lower costs, greater flexibility, and/or lower land, mineral, or other resource footprints. Similarly, the role of technologies supporting low-carbon technologies should be carefully considered—for example, electricity storage, smart grids, demand management aggregation, and other “balancing” technologies are likely to enable significant penetrations of variable renewables, or even baseload nuclear, in many countries [8].

Second, emerging technologies may stumble in some regions as a result of political, regulatory, or societal factors and/or feasibilities [9]. India’s electricity sector is a prime example, with high coal dependence, whose stranglehold will not easily be loosened with falling costs of renewables alone, especially considering the industry’s critical role in supporting many regions of India through employment and welfare support [10]. Careful consideration should thus be given to assessing early whether the barriers to a technology’s role in decarbonising a given sector in a given region are surmountable in a timescale meaningful to achieve a desired return from that technology.

Third, a key consideration is the timescale for development and deployment, and the associated risk, of any low-TRL technology [11]. Possible (at-scale) availability too far into the future could equate to too risky a prospect; as such, any new technology should be thoroughly stress-tested with a view to understanding its innovation timescale. When considering such timescales, Li-ion batteries are a useful benchmark, given their rapid journey from invention to commercial-scale deployment [12]. Careful consideration should be given to the characteristics of new technologies vis-à-vis such success stories—for instance, how were Li-ion batteries’ material cost, energy density, manufacturability, durability, and safety advances able to sequentially unseat all competitive battery technologies in a range of markets so quickly?

Fourth, new low-carbon technologies and products should ideally outperform their fossil fuel-incumbent counterparts, on desirability or price—ideally both. At this stage, there is insufficient social responsibility to buy less-polluting technologies at-scale if they are as or more expensive than incumbents [13]. This will clearly not be possible in many cases without sufficient innovation and learning-by-doing in production and deployment, so there must be credible assessment of the cost reduction potentials of proposed technologies and products, as well as of their reliability and durability.
Fifth, no matter how good a low-carbon technology may appear, its long-run prospects in any given market could suffer if it is easily replicated and outcompeted when commercially available. As with any new product, protection of competitive advantage over the long run could stem from a “secret sauce” of patents or production know-how, or (more audaciously) the establishment of brand loyalty. We are seeing how this plays out with Tesla, e.g., having continued to achieve notable sales success, even though it has lost its first-mover position and its sales share of electric vehicles has eroded, with all major car companies crowding into the electric vehicle market at speed and scale [14].

Sixth, a technological artefact will not succeed without supporting infrastructures [6], as in the case of electric vehicle charging networks, delivery networks for replacement products/parts, and interconnection and flexibility infrastructure. In many cases, an enabling regulatory landscape is even more important: the technological artefact could critically use—at least in its early period of potentially higher cost—supporting regulation, so a key consideration is the degree to which this is likely to be in place or become available.

Seventh, a rapid transition to a low-carbon society is likely to be an extremely delicate process, fraught with the danger for unintended consequences, evaporation of support, or even backlash; unsurprisingly, the incumbent technological regime may abuse previously enabling windows of opportunities [15]. One critical area in which low-carbon technologies must perform well is in their societal and environmental impact. This means any new investment must be cognizant of the wider consequences of its large-scale deployment, in terms of employment potential, impacts on water, land, and ecosystems, and equity.

Concluding remarks

The above framework is an intuitively obvious one, yet still serves as a climate technology-specific "checklist" to ensure that any newly proposed technologies or products can succeed. There will be continuous changes to the regulations, infrastructures, and political contexts, in which new technologies will be developed, which is why each consideration is not intended as a one-shot "yes/no" process but must rather be continuously reviewed and reconsidered in light of potentially rapid developments.

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References

4. Eyre N, Darby SJ, Grünewald P, McKenna E, Ford R. Reaching a 1.5°C target: socio-technical challenges for a rapid transition to low-carbon electricity systems. Philosophical Transactions of the Royal


