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An Overview of Issues and Options for Technology Innovation and Climate Change Policy

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ABSTRACT: Climate change is a prominent global environmental challenge that is predicted to have a significant impact in the future. Addressing this issue requires substantial reductions in greenhouse gas emissions, which, in turn, necessitated major technological changes in the energy and related sectors. Those changes are crucial to achieving emissions reductions at an acceptable social cost. Fortunately, there is some consensus at the international level regarding the need for action and solutions to combat climate change.

Both at the domestic and international levels, implementing policies that promote the necessary technological innovations for climate change mitigation presents institutional challenges. Developing and successfully implementing such policies requires navigating various perspectives on understanding the economics of technological innovation. To move forward and make progress in mitigating climate change, it is essential to explore viable pathways.

Technological advancements offer promising solutions for combating climate change. Leveraging technology can enable countries and companies to meet their emission reduction targets effectively. Emphasizing sustainable behaviors and household actions can play a crucial role in rapidly reducing carbon emissions. Moreover, the energy transition in Europe highlights the systematic approach needed to address the challenges of decarbonization.

The Intergovernmental Panel on Climate Change (IPCC) has emphasized the urgency of limiting global warming to 1.5 degrees Celsius, underscoring the need for transformative actions and innovation. A comprehensive understating of barriers, emotions, and motivational levers can inform effective pathways for lifestyle transformations and household decarbonization.

While technological innovation is pivotal, it should be complemented by policy interventions that target household consumption and behavioral decisions to achieve low-carbon futures. Behavioral change, combined with technological advancements, can provide a sustainable pathway toward reducing carbon footprints and mitigating climate change

The paper attempts to explain the various points of view on understanding the economics of technological innovations and a way forward on what appears to be possible for climate change mitigation.

KEYWORDS: climate change, emission, energy, innovation, technology

1. INTRODUCTION

Increases in global air and ocean temperature, rising global sea levels, reductions in ice cover, changes in atmospheric and ocean circulation, and alterations in regional weather patterns have all been observed throughout the twentieth century. These changes are primarily caused by the addition of greenhouse gases to the atmosphere, resulting from human activities such as fossil fuel use, deforestation, agriculture, and land-use changes. These human activities contribute to the accumulation of "heat-trapping" greenhouse gases in the atmosphere, leading to climate change. Predictions for the future include major global ecological changes.

The energy-related carbon dioxide (CO_2) emissions are expected to more than double by mid-century due to expanding economies and populations. However, in order to stabilize greenhouse gas concentrations, significant reductions will necessary, which requires a radical transformation of the energy systems (Edmonds, 2001; Zhang et al., 2021). Addressing challenges such as reducing industry emissions and transforming energy systems in an environmentally friendly manner calls for wide-ranging and significant innovations. Climate change affects various systems, and it is important to address the different sources of greenhouse gases, including the agricultural sector, transportation sector, deforestation, land use, and industrial process such as fossil fuel combustion. Each of these causes of climate change requires corresponding technological solutions.

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Cardon dioxide emissions from energy systems are driven by energy demand in major components such as buildings, industry, and transportation. While it is unrealistic to expect zero-carbon technology to meet the decarbonization requirements across all sectors, it is necessary to develop or improve technologies that utilize alternative energy sources with lower or no greenhouse gas emissions to mitigate CO_2 emissions. Decarbonization of energy inputs should involve a balanced approach that includes the widespread adoption of efficient technologies across sectors.

A review in science challenges the claims that the Intergovernmental Panel on Climate Change (IPCC) that existing technologies are sufficient to follow trajectory for next hundred years. The review highlights the misconceptions regarding technological readiness and calls for "revolutionary changes" in mitigation technology including fusion, space-based solar electricity, and artificial photosynthesis (Hoffert et al., 2002). Fundamental research is crucial for developing innovative mitigation strategies to stabilize atmospheric CO_2 at levels below twice the preindustrial concentration. The most recent IPCC report on emissions scenarios presents a wide range of plausible development paths, with global primary power demand projected to range from 20 to 50 TW by 2050. In order to keep greenhouse gas concentrations below twice the preindustrial levels, total CO_2 emissions need to peak within next few years. Pacala and Socolow (2004) introduced a new way of thinking about the magnitude of the challenge and the available options, providing a useful framework for addressing the technological challenges and structuring innovation strategies to achieve the necessary changes in the atmosphere.

2. LITERATURE REVIEW

In light of the fact that the world appears to be paying no deliberate attention to global carbon emissions, projections indicate that emissions will double from the current level of 7 billion tons of carbon per year to 14 billion tons per year by middle of the century (Pacala and Socolow, 2004). However, Pacala and Socolow propose a solution in the form of seven "wedges" of alternative technologies, each capable of displacing approximately 1 billion tons of carbon emissions annually by 2050. They argue that by implementing and scaling up these existing alternative technologies, we can effectively address the carbon and climate change challenges within the first half this century (Pacala & Socolow, 2004).

Their proposed options for reducing carbon emissions include improving automobile efficiency, reducing vehicle usage, enhancing power plant efficiency, implementing carbon capture and storage, promoting wind and nuclear power, encouraging renewable energy sources, reducing deforestation, implementing new plantation practices, and adopting improved soil management in agriculture. They emphasize that all these options are commercially viable, and by expanding their implementation, we can effectively tackle the carbon and climate problems.

Despite the raising prominence of climate change as a critical issue, researchers have highlighted that climate change policies are often influenced by multiple agendas within different interest groups (Olsen, 2007; Nugent, 2011; Kronsell et al., 2016). This has led to a lack of focus on the primary goal of decarbonizing the economy. Climate policy debates in Western economies frequently revolve around two contrasting views: the “technology push” and the “demand pull”.

The ‘technology push’ perspective prioritizes the development of low greenhouse gas technologies as the main objectives, rather than focusing on emissions reductions directly. This approach considers technological advancements in the energy sector crucial for addressing long-term environmental issues such as climate change. It argues that the fastest and most effective solution lies in technological innovation to reduce GHG emissions. Additionally, imposing emissions limitations after technological innovations have reduced the costs of limiting emissions is seen as more favorable. Researchers advocate for further studies and development to create technological options that can achieve both climate stabilization and economic development (Wigley et al., 1996; Hoffert and Caldeira et al., 2002).

On the other hand, the "demand pull" viewpoint assets that technological change primarily originate from the business sector, driven by economic incentives. This perspective prioritizes the regulatory measures, including technology-based limitations and GHG emission caps, as effective policies for mitigation (Grubb et al., 2002). However, there is a concern that profit-seeking businesses may only innovate technologies that reduce emissions at a lower cost to gain a competitive advantage, potentially hindering technological innovation for greater environmental impact (Weyant et al., 1999). The divergent perspectives on technological change led to policy recommendations that differ substantially in various dimensions.

In terms of responsibility, it is believed that we have the right to development and bear the responsibility to protect the right for others. According to the principle of “common but differentiated responsibility and respective capabilities” established by UNFCCC, it is our responsibility to fund the global emergency program aimed at reducing emissions. This entails bearing the costs associated with reducing emissions from our won consumption while also ensuring that those below the sustainable threshold can transition towards low-emission pathways (Baer et al., 2007).

3. INNOVATION CHAIN

Innovation is a crucial factor in addressing the issue of climate change. Climate change mitigation innovations include energy efficiency, low-carbon and non-carbon technologies, carbon reduction technologies, and carbon capture and storage technologies (Newell, 2009). However, the development and widespread adoption of low-carbon technologies across various sectors and countries are progressing too slowly to ensure climate stability (Matos et al., 2022). Government direction and support are necessary to drive the required innovation for low-carbon options, as industries are unlikely to risk significant capital investments without strong policies in place. Recent years have seen improvements in the feasibility of innovative technologies such as renewable energy (e.g., solar photovoltaics and microinverters), smart grids, and distributed energy storage, thanks to increased deployment and resulting cost reductions (Viardot, 2013). Nevertheless, investments in low-carbon innovation remain insufficient, and significant increases are unlikely without stronger policymaker support (Reid & Toffel, 2009).

Controversial technologies, like "geoengineering" aim to intentionally alter the climate on a large scale to slow or educe global warming. These proposals include injecting particles on the atmosphere, capturing and storing cardon underground, and deploying giant mirrors in space to deflect the sun's rays (Sovacool & Science, 2021)

Well-designed policies that include coordination between consistent carbon pricing, performance-based regulations, and public funding have shown promise (Veugelers, 2012). Many countries have implemented incentives for research and innovation, such as renewable portfolio standards (popular in North America) and feed-in tariffs (popular in Europe; Zhou et al., 2019). For instance, the European Union has provided billions of euros in co-funding to companies developing cheaper and more efficient solid-state batteries. Governments have played a significant role in stimulating demand for renewable energy in countries like China and Germany, resulting in a substantial increase in solar panel production (Arantegui et al., 2018). However, further support is necessary to accelerate the adoption of cleaner technological innovations, including procurement policies, carbon taxation, environmental and safety regulations, and tax rebates for consumers to offset the market power of incumbent technologies offering less environmentally friendly alternatives (Polzin & Friedemann, 2017).

Understanding the innovation process and the potential role of policy is critical. Grubb (2004) outlines six distinct stages of energy innovation in a market economy: basic research and development; technology-specific research development and demonstration; market demonstration, commercialization, market accumulation; and diffusion. Technological advancement and cost reduction are involved throughout these stages, but primary barriers and driving forces may differ.

Innovation process can vary significantly across different sectors, with some sectors taking longer or facing greater challenges. Sectors that require significant energy processing often involve large capital investments and long timescales, which increases risk and discourages private finance. While the Information Technology and pharmaceuticals sectors have made great deals strides in innovation, the power generation sector has seen minimal change, with the same fundamental technology dominating for nearly a century and private sector research, development, and deployment (RD & D) investments dwindling to less than 0.4% of turnover following the privatization of energy industries (Margolis & Kammen, 1999). This context sets the stage for considering low-carbon innovation policy. Government plays a crucial role throughout the innovation chain, although the nature of their involvement changes overtime and varies across sectors. Government fund basic and applied technology research and development, as well as some demonstrations, to establish a foundation for further advancements. They also need to define and enforce a regulatory structure that incentivizes the market value of low-carbon technologies through measures like carbon taxes, making climate change mitigation more feasible. Incentives to support the diffusion of low-carbon technologies can indicate that innovation will eventually be more rewarding.

4. INTERNATIONAL STRATEGIES ON CLIMATE CHANGE

There is significant potential for beneficial international collaboration in publicly funded research and development (R&D) for low-GHG emission and adaptation technologies. Such collaboration can lead to scale economies, cooperative specialization, and mutual learning. While the costs of emission are borne by the countries implementing them, the advantages of reducing emissions benefit the entire global community. However, governments tend to seek international support for their own industries or technology innovations, especially when there is a potential for commercial success. This creates a reluctance to invest in technologies and industries of other countries. Intellectual property issues can also become sensitive when participants seek funding from a common source but keep their own sources hidden. These factors can lead to the development of unviable technologies within an international technology program. International law is often ineffective in providing public goods and each sovereign country is primarily concerned with benefiting from others' emission-reduction efforts (Carraro & Siniscaico, 1994).

To ensure effective international cooperation, strategies should have defined goals, such as an R&D strategy and mechanism, clear guidelines on the extent of participation by different countries, and accountability mechanisms. In cases of international emergencies, such as epidemics, countries come together to assess the situation and determine the required resources. Each country pledges whatever resources it can provide. A similar approach is needed to address the steady increase in GHG emissions that we are currently witnessing. The Paris Agreement of December 2015 is an important step forward in the International climate policy (Tol, 2017). International cooperation should focus on the development and acceleration of industrial participation in low-carbon technologies and various stages of innovation chain. International technology agreements as solutions for climate change must be better defined.

5. STRATEGIES AVAILABLE TO REDUCE THE CARBON EMISSION

Wedges can be achieved through various means, concluding energy efficiency improvements, the decarbonization of electricity and fuel supply, and the implementation of biological storage in forests and agricultural systems. These options are already being used at an industrial scale and have the potential to be scaled up to effectively reduce carbon emission. However, achieving a wedge requires a carbon price trajectory, the specifics of which depend on several assumptions such as future fuel prices, public acceptance, and cost reductions through learning. To provide a straightforward case for the technological readiness of options already available in the marketplace, the following are some full-scale options that can complement the integrated assessment of carbon mitigation.

Increased fuel efficiency: Assuming there will be approximately two billion cars in three decades from now, which is roughly four times the current number, and that these cars will travel an average of 10,000 miles per year, one potential solution to reduce carbon emissions would if these cars achieved an average fuel efficiency of 60 miles per gallon (mpg) compared to the current average of 30 mpg , while keeping the fuel type and distance traveled constant (Pacala & Socolow, 2004).

Efficient Buildings: To reduce the emissions from buildings, one effective approach is to promote and integrate energy-efficient space heating and lighting systems in all types of buildings.

Increased energy plant efficiency: A potential wedge could be formed if , by 2054, twice as much as coal-based electricity were produced at a minimum efficiency of 60% instead of the current 40% efficiency.

Replace coal with natural gas: Natural gas power plants emit approximately half as much carbon dioxide per unit of electricity compared to coal plants. Therefore, a significant reduction in carbon emissions can be achieved by shifting a large portion of the current power generation from coal to gas (Pacala & Socolow, 2004).

Wind energy: To account for the intermittent output of windmills, we can equate 3 GW nominal peak capacity (3 GWp) with 1 GW baseload capacity. Therefore, to achieve a wedge of wind electricity that would displace coal electricity by 2054, it would require the deployment of 2000 GWp (Pacala & Socolow, 2004).

Renewable hydrogen: In 2054, renewable electricity can be used to electrolyze water and produce carbon-free hydrogen for vehicle fuel. If 4 million 1-MWp windmills are used to produce hydrogen, it could achieve a wedge of displaced gasoline or diesel fuel when utilized in high-efficiency fuel-cell cars. This intriguing advantage of wind-electricity over wind-hydrogen, with a factor-of-two carbon-saving advantage, becomes even more significant if the coal plant is less efficient or the fuel-cell vehicle is less efficient (Pacala & Socolow, 2004).

Biomass fuel for fossil fuel: Biofuels, such as ethanol, offer an alternative to fossil-carbon fuels and contribute to cardon reduction efforts. In 2054, biofuel wedge could be achieved by producing around 34 million barrels per day of ethanol, which would displace gasoline, given the ethanol itself is free of fossil-carbons. To accomplish this, the ethanol production rate would need to be approximately 50 times greater than the current global production rate, with Brazilian sugarcane and US corn being the primary source (Pacala & Socolow, 2004).

Forest and agricultural soil management: Reducing deforestation and implementing forest management practices can significantly contribute to carbon emission reduction. Additionally, practices such as conservation tillage, cover crops, and erosion control can help reserve carbon losses in soil.

Various options can be pursued to achieve carbon emission reduction, including energy efficiency, decarbonizing electricity, and fuel supply through strategies as such as fuel shifting, carbon capture and storage, nuclear energy, and renewable energy, and biological energy sources. A study by Gross and Bauen (2005), highlights the potential pathways to achieving very low carbon electricity systems within a decade, particularly when associated developed industries. The study indicates that it is possible to achieve very low carbon electricity at a low cost.

Table 1 provides the summary of the survey and study conducted by Gross and Bauen (2005) as a part of the UK Energy White Paper and the precursor analysis of the UK Performance Intelligence Unit.

Table 1. The current and projected medium-term costs of various electricity-generation technologies.

Technology	Current cost (Us cents/kWh)	Medium term projections	Comments
Present fossil fuel plant			
Gas CCGT Coal	3-4 3.5-4.5	Depends on fuel prices	Gas price and volatility increasing. Modest capital cost decreases 5 and efficiency gains may be offset by rising fuel prices
Very low carbon electricity technologies			
Carbon Capture and Storage (CCS)			Costs are based on engineering assessments; there is currently no market experience to allow for learning rate derivation. Although techniques are well known, they have not been tested for this application.
Nat. Gas with CCS	NA	4 – 6	
IGCC Coal with CCS	NA	5 – 8	
Nuclear Power	5 – 7	4 – 8	The industry provides extremely low-cost estimates. MIT and PIU have significantly higher numbers. Low historical learning rate.
Biomass			The cost of conversion varies greatly depending on the technology used, the scale, and the cost of the feedstock.
Co-firing with coal	2.5 – 5	2.5 – 5	
Electricity	5 – 15	5 – 9	
CHP-mode	6 – 15	5 – 12	
Wind Electricity onshore			Evidence of the learning curve and strong market growth (30% pa) combined with good engineering data allows for a robust assessment for onshore. Offshore is less certain due to limited experience, but engineering assessment, learning rate extension/proxy indicates strong potential.
offshore	5 - 8 9 - 12	2 – 4 3 – 8	
Tidal Stream/Wave	13 – 20	<15	Due to immaturity of technologies, the future costs are difficult to estimate, and the estimates are from parametric models of hypothetical costs. Uncertainties are huge for these technologies. Installed capacity roughly doubled during 2004, through new demonstration projects.
Grid connected PV			Strong market growth and a learning curve suggest cost reduction. Recent cost-cutting trends appear to have slowed, which could be due to temporary factors (price increases due to high demand) or to longer-term issues. Added value in applications close to end use.
1000 kWh/m2 /year (temperate)	50 – 80	15 – 25	
2500 kWh/m2 / year (tropics)	20 – 40	5 – 15	

The table presents a range of options for achieving low carbon emission, including carbon capture with storage, nuclear power, biomass, tidal Stream, wind electricity, and grid connected PV. These options have medium-term potential costs(5-6c/kWh). Gas turbines and onshore wind energy are comparatively less expensive per kWh, while PV may benefit from its small modular nature when it comes to end-user applications.

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In the transportation sector, the goal of atmospheric stabilization requires transport fuels with near-zero CO_2 emissions. Biofuels, electricity, and hydrogen are the main options, with the latter two being effective only if produced from very low net CO_2 energy sources (Gross & Bauen, 2005). Electric and plug-in hybrid vehicles can contribute to CO_2 reduction when powered by CCGT or low-carbon sources. However, the production of hydrogen for fuel cell vehicles from noncarbon electricity can be costly. A long-term, transition to low-carbon transportation could involve vehicles powered by biofuels, and low-carbon hydrogen, but the economics and pathways for these options appear to be more complex and potentially more expensive than those for electricity(Gross & Bauen, 2005).

Emerging technologies such as blockchains, additive manufacturing, the Internet of Things (IoT, autonomy, information and communication technologies (ICTs), and artificial intelligence (AI) can address managerial challenges related to climate change. Building and maintaining a low-carbon supply chain requires understanding the issues that arise in the upper tiers of the supply chain, which can be facilitated by digital technologies (Kesidou et al., 2019). These technologies also have the potential to significantly influence consumer behavior in relation to environment.

6. CONCLUSION

Climate change is a pressing global issue that has worsened due to increased greenhouse gas emissions from fossil fuel reliance. Innovative solutions are crucial for combating climate change in the energy sector. This review examines various technologies and their potential for mitigating climate change. It emphasizes the need for substantial innovation, private sector engagement, and effective policy frameworks to transition to low-carbon industries. The identified options include wind turbines, photovoltaic arrays, gas turbines, carbon capture chemistry for hydrogen production, biofuels, and energy-saving devices. However, the effective transfer of publicly funded ideas to private-sector industries remains a challenge. Carbon pricing alone is insufficient for comprehensive carbon mitigation, requiring strong policies in less innovative sectors like power generation and buildings. International technology collaboration is complex but vital. By addressing these challenges and promoting global collaboration, significant progress can be made in mitigating climate change.

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