Katowice Committee of Experts on the Impacts of the implementation of response measures
Sixth meeting

31 May 2022

Bonn, Germany, 2-3 June 2022

Background note on compilation of concrete examples

I. Background

1. The Conference of the Parties (COP) at its twenty-fifth session, the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) at its fifteenth session, and the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) at its second session agreed on workplan of the forum on impacts of the implementation of response measure (the forum) and its Katowice Committee on the Impacts of the Implementation of Response Measures (KCI).[1]

2. As per activity 5 of the workplan for forum and its KCI, the KCI is to prepare technical paper on assessing the impacts of potential new businesses and industries resulting from the implementation of response measures.

3. At KCI 4, the KCI agreed on an outline and elements for the technical paper. Further, the KCI also agreed to launch a call for input from Parties and observers in line with the agreed elements and stocktake the progress of the work at KCI 6 before finalizing the technical paper at KCI 7.

4. The secretariat worked intersessionally and prepared a draft technical paper, under the guidance of task lead of working group and with the support of a consultant.

II. Scope of note

5. This background note provides in its annex draft technical paper prepared by the KCI task lead of working group.

III. Expected action by the Katowice Committee on Impacts

6. The KCI will be invited to provide comments and guidance on the draft technical paper for its finalisation.

[1] Decision 4/CP.25, Decision 4/ CMP.15, Decision 4/CMA.2

Annex

Draft Technical Paper on Assessing the Impacts of Potential New Businesses and Industries Resulting from the Implementation of Response Measures

Assessing the Impacts of Potential New Businesses and Industries Resulting from the Implementation of Response Measures

Work-in-progress draft
technical Paper (28.5.2022 version)

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1. Introduction

The Conference of Parties to the United Nations Framework Convention on Climate Change (COP), the Conference of Parties serving as the meeting of Parties to the Kyoto Protocol (CMP) and the Conference of Parties serving as the meeting of Parties to the Paris Agreement (CMA) each adopted their decisions on the functions, modalities and work programme for the forum established to address the impacts of implementation of climate change mitigation policies and measures, (often referred to as response measures), at their sessions in Katowice, Poland in December 2018[2]. The CMA, by its decision 7/CMA.1, subsequently established the Katowice Committee on Impacts of Implementation of Response Measures (KCI) to assist the forum[3] in the implementation of its work programme. The forum which was established by the Conference of Parties (COP), deals with all issues related to the impacts of the implementation of response measures under the Convention, the Kyoto Protocol and the Paris Agreement. All the three supreme bodies, in Katowice, agreed that the Forum will have the following functions, to:

- Provide a platform allowing Parties to share, in an interactive manner, information, experiences, case studies, best practices and views, and to facilitate assessment and analysis of the impact of the implementation of response measures, including the use and development of modelling tools and methodologies, with a view to recommending specific actions;
- Provide recommendations to the subsidiary bodies on the actions referred to in paragraph (a) above for their consideration, with a view to recommending those actions, as appropriate, to the Conference of the Parties, the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol and the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;
- Provide concrete examples, case studies and practices, in order to enhance the capacity of Parties, in particular developing country Parties, to deal with the impact of the implementation of response measures;
- Address the effects of the implementation of response measures under the Convention, the Kyoto Protocol and the Paris Agreement by enhancing cooperation among Parties, stakeholders, external organizations, experts and institutions, by enhancing capacity and the understanding of Parties of the impacts of mitigation actions and by enabling the exchange of information, experience and best practices among Parties to raise their resilience to these impacts;
- Respond and take into consideration the relevant outcomes of different processes under the Paris Agreement;
- Promote action to minimize the adverse impacts and maximize the positive impacts of the implementation of response measures.

The decisions also adopted the following four areas for the work programme necessary to address and manage the impacts of the implementation of response measures:

- Economic diversification and transformation;
- Just transition of the workforce and the creation of decent work and quality jobs;
- Assessing and analysing the impacts of the implementation of response measures;
- Facilitating the development of tools and methodologies to assess the impacts of the implementation of response measures.

After this, in 2019, the Parties also adopted a detailed workplan, (with deliverables and timelines), for the implementation of the work programme covering the above four work programme areas[4]. Consequently, the KCI was mandated to prepare, among others, a technical paper aimed at "building awareness and understanding of Parties and other stakeholders to assess the economic impacts of potential new industries and businesses resulting from the implementation of response measures with a view to maximizing the positive and minimizing the negative impacts of the implementation of response measures".

There is overwhelming and compelling scientific evidence on the need for urgent and deep decarbonization(IPCC, 2022). This evidence underpins the global efforts to implement climate change mitigation policies and

[2] Decisions 7/CP.24, 3/CMP.14, and 7/CMA.1 respectively.

[3] The forum on the impacts of the implementation of response measures for brevity is hereafter referred to as the Forum

[4] https://unfccc.int/sites/default/files/resource/cp2019_13a01_adv.pdf#page=22

measures that lead to net zero greenhouse gas emissions(UNFCCC, 2015). Governments and national stakeholders are therefore preparing and implementing short-medium[5] and long-term low emissions development strategies[6] in response to this imperative. These efforts have given rise to many innovative, new/emerging industries, businesses and technologies that are aiding the implementation of these mitigation policies and measures.

The effective implementation of these urgent climate mitigation policies and measures demands that equal urgent attention be paid to addressing and managing the intended and/or unintended, positive and/or negative impacts associated with, and arising from the implementation arising of these deep decarbonizations measures.

This technical paper is thus structured in response to the mandate to the KCI by amplifying the objectives of the paper, the definition of new/emerging industries and businesses, the process, scope, and criteria for selecting some new industries and businesses, the methodological approach applied, as well as the methods and tools used for the assessments of their associated impacts.

2. Objectives

The purpose of this technical paper is to respond to the mandate of the KCI by developing criteria for defining and selecting new/emerging industries and businesses resulting from the implementation of climate change mitigation policies and measures with a view to maximizing the positive and minimizing the negative impacts of the implementation of the response measures.

The narrow view of the mandate to consider only the economic impacts of these new/emerging industries and businesses have been expanded to include both social and environmental impacts to ensure a more comprehensive and coherent treatment of the subject and to be consistent with the sustainable development concept. This amplification of the mandate has thus resulted in the following objectives of the paper to:

- Define what constitutes new/emerging industries and businesses in the context of deep decarbonization effort and climate change mitigation in general,
- Enhance the awareness and understanding of stakeholders on new/emerging industries and businesses resulting from climate change mitigation policies and measures,
- Understand the social, economic, and environmental impacts of these new/emerging industries and businesses, and
- Explore ways to maximize the positive and minimize the negative impacts of these new/emerging industries and businesses by using appropriate methods and tools for assessing and categorizing these impacts.

3. Methodological Approaches

This section will include the context, definition of new/emerging industries and businesses, scope (considering the complete value chain for up- and downstream/allied industries and businesses) and criteria for selecting/shortlisting particular industries and businesses. It will include extensive literature review constrained by year of publication, and it will build on relevant works undertaken by other constituted bodies under the Convention, Kyoto Protocol, and the Paris Agreement, including the work undertaken by KCI, as well as submissions from Parties and other stakeholders in response to the call for inputs by KCI. It will provide a well-documented methodological approach taken to shortlist the potential new/emerging industries and businesses that would be subjected to further analysis.

3.1 Research Methods

The technical paper was prepared using information gathered and synthesized through mix methods (a) desktop reviews; (b) systematic literature search, (c) qualitative shortlisting (d) qualitative impact assessment and (e) feedback. With the mix methods, the technical paper reflects the current understanding and diverse views on potential new/emerging industries/business; selection criteria and rationale for shortlisting of potential new/emerging industries/business as well as and framework for assessing economic/social/environmental impacts of same. A brief overview of the mix method is below:

[5] Through the maintenance of nationally determined contribution in accordance with Article 4, paragraph 2 of the Paris Agreement

[6] Consistent with requirements in Article 4, paragraph 19 of the Paris Agreement

- **Desktop reviews** - the desktop review involved reviewing and gleaning pieces views from country submissions to UNFCCC on new/emerging industries and businesses, works by constituted on technology development and transfer, and grey publications to understand and synthesize the findings inform the criteria and justification for the shortlisting.
- **Systematic literature search** – x number of publications were consulted to obtain information for the technical paper. The choice of publication for the technical paper depends on its relevance to the subject, recent publications, geographic focus and scope of assessment.

  The literature search involved a comprehensive review of publications in peer review journals to obtain a broad list of new/emerging industries/businesses. The search was according to the following details:

  - *Journals* - include Science Direct, Web of Science, International Journal of Emerging Technology in learning, Scopus, DOAJ, Google Scholar, Institute for Technology and Engineering Inspec, Portico and Taylor and Francis).
  - *Constraint by Years of Publication* – Twenty-two years (2000 to 2022).
  - Literature search strings/key words are as follows:
    - New industries and businesses arising from implementation of climate mitigation policies and measures
    - Climate change and new industries and businesses
    - New and emerging industries and businesses
    - New and emerging climate change relevant industries and businesses
    - Climate change, new risks and opportunities for businesses
    - New and emerging climate change mitigation relevant businesses and industries
    - Climate change and new industries and businesses in 2022
    - Emerging industries
    - New industries and businesses
    - New businesses and industries for climate change
    - Top 20 new climate mitigation businesses
    - Top 20 emerging climate mitigation industries
    - New industries and businesses spring up due climate change
    - Emerging technology
    - Socio-economic and environmental impacts of hydrogen
    - Socio-economic and environmental impacts of CCUS
    - Socio-economic and environmental impacts of AI
    - Top trends in technology 2022
    - Top trends in Business (Business trends 2022)
    - New Technology Trends for 2022
    - Top Strategic Technology Trends for 2022
    - Full economic cost and benefit analysis of hydrogen

The desktop review and the systematic literature searches produced fifty-two new/emerging industries and businesses from implementation of climate mitigation policies and measures for the subsequent shortlisting. Table 1 presents the overview of the broad list of new industries/businesses that met the literature search strings/key words.

  - **Shortlisting of literature-based of new industries/businesses** – A set of qualitative criteria was used to create a shortlist of new/emerging industries/businesses selected from the literature search in excel spreadsheet. The shortlisting produced Hydrogen (H_2), Carbon Capture, Use and Storage (CCUS) and Artificial Intelligence (AI) as new industries/businesses to focus the impact assessment in the next stage.

- **Qualitative impact assessment shortlisted new industries/businesses** – based on the assessment of literature on economic, social and environmental impacts of shortlisted new/emerging industries/businesses, the technical paper presents synthesis of the major economic, social, and environmental impacts and tools used for the assessment.
- **Reviews and Feedback** – views from UNFCCC secretariat and KIC members have been reflected in the technical paper. The draft technical paper was shared with the KIC members during the SB56 for their feedback and incorporation.

3.2 Definition and scope of new/emerging industries and businesses

3.2.1 Definitions

To assist readers to better understand what constitutes new and/or emerging industries and businesses in terms of climate change mitigation this paper provides the following definitions viz; new/emerging industries and businesses, in the context of climate change mitigation, are those that have the potential to significantly contribute to global deep decarbonization effort by changing the current state of greenhouse gas emissions trajectory towards a net zero emissions.

3.2.2 Scope

New and emerging industries and businesses may include but not limited to hard and soft technologies that lend themselves to applications that limit greenhouse gas emissions. Soft technologies in new industries and businesses covers skills and knowledge, whilst hard technologies are tangible component such as equipment, tools, computers, and software. To address the complexity of the climate emergency, which is the motive of this paper, a combination of both hard and soft technologies may be needed in new businesses and industries to address the climate change mitigation challenge.

According to Alairys et al, 2018, the combined value delivered by multiple emerging technologies is multiplicative across sectors. That is the impact to business innovation and the transformative effect of a combination of emerging technologies is far more profound than what a single technology can provide alone. This is what Alairys et al, 2018 described as the combinatorial effect of emerging technologies. The scope of new/emerging industries and businesses thus cover both hard and soft technologies. Table 1 lists some of the new and emerging technologies, industries and businesses discussed in existing literature.

Table 1: List of new/emerging industries and businesses by literature search

No	New/Emerging Industries and Businesses	Sources
1	Hydrogen	Author's suggestions
2	Carbon capture, utilization, and storage (CCUS)	
3	Artificial Intelligence (AI)	
4	Internet of Things (IoT)	McKinsey Trends in Tech[7]
5	Artificial Intelligence	
6	Information and Communications Technology (ICT)	
7	Next Generation Computing	
8	Distributed Infrastructure	
9	Trust Architecture	
10	Future Connectivity	
11	Future Programme	
12	Bio Revolution	
13	Next-level Process Automation and Virtualization	

7https://www.mckinsey.com/~/media/mckinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/The%20top%20trends%20in%20tech%20final/Top-trends-in-tech-executive-summary-6-24-21
https://www.weforum.org/agenda/2021/10/technology-trends-top-10-mckinsey/

14	Nanomaterials	
15	Future Clean Technologies	
16	Computing Power	Forbes[8]
17	Smarter Devices	
18	Quantum Computing	
19	Datafication	
20	Artificial Intelligence and Machine Learning	
21	Extended Reality	
22	Digital Trust	
21	3D Printing	
22	Genomics	
23	Artificial Intelligence and Machine Learning	Tech Trends in Practice[9]
24	Internet of Things and the Rise of Smart Devices	
25	From Wearables to Augmented Humans	
26	Big Data and Augmented Analytics	
27	Intelligent Spaces and Smart Places	
28	Blockchains and Distributed Ledgers	
29	Cloud and Edge Computing	
30	Digitally Extended Realities	
31	Digital Twins	
32	Natural Language Processing	
33	Voice Interfaces and Chatbots	
34	Computer Vision and Facial	
35	Robots and Cobots	
36	Autonomous Vehicles	
37	5G and Faster, Smarter Networks	
38	Genomics and Gene Editing	
39	Machine Co-Creativity and Augmented Design	
40	Digital Platforms	
41	Drones and Unmanned Aerial Vehicles	
42	Cybersecurity and Cyber Resilience	
43	Quantum Computing	
44	Robotic Process Automation	
45	Mass Personalization and Micro-Moments	
46	3D and 4D Printing and Additive Manufacturing	
47	Nanotechnology and Materials Science	
48	The AI revolution	Business Trends in Practice[10]
49	Robots and business processes automation	
50	Remote working, working from home and new flexibility	
51	Social & environmental Responsibility	
52	Increased Diversity	

Source: Compiled by author

Emerging technologies include but are not limited to virtual reality implementations (Merchant et al., 2014), augmented reality implementations (Dunleavy, & Dede, 2014), mobile learning devices (Crompton, Diane, &

[8] https://www.forbes.com/sites/bernardmarr/2022/02/21/the-top-10-tech-trends-in-2022-everyone-must-be-ready-for-now/?sh=35604570827d

[9] Source: Marr, Bernard. Tech Trends in Practice (p. v). Wiley. https://bernardmarr.com/

10 Source: https://bernardmarr.com/

Gregory, 2017), physical computing tools (Katterfeldt et al., 2018), internet of things hardware with sensors (Cukurova et al., 2018), and technologies that allow collaborative learning at a great scale (Cress, Moskaliuk, & Jeong, 2016).

3.2.3 Criteria and methodological approach for shortlisting

To better comprehend and appreciate the impacts associated with new/emerging industries and businesses, a couple of important questions need to be answered, which are generally consistent with the principles behind the theory of change, and multiple level perspective methodology. By applying the theory of change it is possible to explain how an emerging industry or business can lead to specific development change, drawing on a causal analysis which is based on available evidence and methods to generate it that are the most appropriate for the state of the emerging industry or business. The questions that arise are:

- What are the expected impacts of the new/emerging industry or business?
- Are there any intermediate outcomes of the new/emerging industry or business?
- What does it take to facilitate the implementation of the new/emerging industry or business?
- What additional resources or input are needed for the change to happen?
- Will stakeholders be prepared to accept the change?

Guided by these questions the set of criteria in section 3.2.3.1 for the shortlisting of the relevant industries and businesses was developed.

3.2.3.1 Criteria

The overarching condition for selecting a given new/emerging industry or business is its proven ability to contribute to achieving sustainable development objectives. Specifically, the potential of the new/emerging industry or business in contributing to the achievement of national environmental, social, and economic development imperatives that are aligned with global decarbonization efforts forms the basis for the development of the criteria used for the shortlisting of these new/emerging industries and businesses. Based on this overarching condition and guided by the theory of change principles, the paper proposes the following set of criteria:

- Decarbonization potential – greenhouse gas emissions reduction potential and contribution to the achievement of net zero and low emissions development pathways
- Potential for allied new businesses and/industries springing out from the parent technology, this could be either downstream or up stream
- Broad application across numerous sectors (applicability)
- Ease of geographical applications that meet diverse regional/national natural resource endowments
- Potential for replication
- Technological maturity
- Availability of methodologies for assessment of impacts
- Positive societal impacts
- Relative cost of technology
- Easy management of associated risks
- Combinatorial effect – ease of combining or coupling multiple new/emerging industries and businesses to achieve multiplicative impacts.
- Availability of literature

3.2.3.2 Methodology

Using the criteria developed above, both quantitative and qualitative approaches are used to aid the shortlisting of the new/emerging industries and businesses by providing a ranking for each criterion and using the fraction of total score[11] (in per cent) as a shortlisting decision-making point. Table 2 lists the new/emerging industries considered and the scores assigned to each criterion.

[11] Fraction of total score is equal to the total score for an industry or business divided by 120. Where each criterion is ranked from 0 to 10, and which results in 120 for the twelve criteria considered.

Table 2: Lists the new/emerging industries considered and the scores assigned to each criterion

Criteria for shortlisting of new/emerging industries and businesses	New/emerging industries and businesses		
	Hydrogen	CCUS	AI
Decarbonization potential	High	High	Medium
Allied industries/ businesses	High	Medium	High
Sector applicability	High	High	High
Geographical application	High	Medium	High/Medium
Replication potential	High	High	High
Technology maturity	Medium/High	Medium/High	High/Medium
Methods for impacts assessment	High	Medium	Low
Societal impacts	High	High	High
Technology cost	Medium/High	Medium/High	Medium/High
Risk management	Medium	High	Medium
Total score	**High**	**Medium/High**	**Medium**

4. Social, Economic and Environmental Impacts

[**Focus**: systematic and in-depth review and analysis of the social, economic, and environmental impacts as well as elaboration on assessment methods and tools].

4.1 Essentials of Impact Assessments

This section provides a systematic and in-depth review and analysis of the three impact categories, namely social, economic and environmental for the shortlisted new/emerging industries and businesses including by providing a description of the methods and/or tools used for assessments of each impact category. The assessment of the impacts of the emerging industries and businesses is important for effectively building the awareness and understanding of all stakeholders with the aim of highlighting the benefits or otherwise to society. This could be done ex-ante and/or ex-post, including through the design and implementation of appropriate and impactful policies and measures aimed at maximizing the positive and minimizing the negative impacts of these industries and businesses.

Assessing the effectiveness of new/emerging industry and business is challenging due to the many uncertainties associated with them. However, the generation of scientifically robust evidence for the shortlisted new/emerging industries and businesses could be an important information for all stakeholders to inform change, and as well as to develop standardized methods for the assessment and reporting of these impacts, with the view to avoiding the "shield of change" (xx), and promote their adoption, replication and scale up. Gathering this evidence could involve primary environmental and socio-economic research which is beyond the scope of this paper. This paper, therefore, resorts to gathering, to the extent possible, impacts reported in existing technical reports and scientific journals. These impacts are considered in detail under the shortlisted new/emerging industry and business.

4.2 Impacts of shortlisted new/emerging industry and business

4.2.1 Carbon Capture Use and Storage (CCUS)

4.2.1.1 Technology information and application

In the most recent decades, Carbon Capture Use and Storage (CCUS) has featured in high-profile Government and Corporate strategies as among the ubiquitous climate-smart technologies. CCUS is a greenhouse gas mitigation technology that is critical to the transition to a net zero emissions economy. Without the deployment of CCUS at scale, the cost for meeting the long-term climate target would be prohibitively high (xxx). It is even particularly imperative that without CCUS it may be impossible to achieve net zero in hard-to-abate heavy industries (xxx).

Kearns et al, 2021 describes CCUS as consisting of technology for capturing carbon dioxide (CO_2) produced by industrial plants (e.g. steel mills, chemicals plants and cement plants) coal and natural gas-fired power plants, and oil refineries. It also has a component for compressing the captured CO_2 for transportation to storage site and use for in allied industrial application or and injected into at least 800 meters below the surface for a long-time rather being emitted. The site for the long-time storage is carefully selected to ensure safe geological sequestration where it is trapped and permanently stored in porous rock.

CCUS has versatile applications that can be used to decarbonise energy intensive industries such as power, steel, cement, and fertiliser production. In the power sector, it can be a source of low-lost fuel for electricity generation and greenhouse emission reductions. The role of CCUS in attaining least cost net zero emissions include deep decarbonization in "hard-to-abate industry" such as cement, iron and steel, chemical sectors; enabling the production low-carbon hydrogen; provide low-carbon dispatchable power and delivering negative emissions. CCUS can also reduce CO_2 emissions already in the air by delivering negative emissions through Direct Air Capture (DAC) and Bioenergy with CCS (BECCS).

4.2.1.2 Methods of impact assessment

Several studies have used different methods to assess the decarbonisation and socio-economic potential for CCUS. The methods range from physical model to integrated quantitative models. The summary information CCUS impacts methods are provided below:

- **Integrated Assessment Models (IAMs)/Scenario models)** - explore interactions between climate and socio-economic systems and present pathway options to meeting climate goals.
- **Numerical simulation** - Carbon Capture Simulation Initiative (CCSI) used in the assessment of CCUS impact on water and sub-surface transport over multiple phases (STOMP-CO_2).
- **Life cycle assessment (LCA**) – LCA has been used in several studies to assess the environmental impact of CCUS system (Rao et al. 2002, Viebahn et al. 2007, and Pehnt et al. 2009).
- **Economic impact assessment** using Computable General Equilibrium (CGE) modelling - EYGEM model (Ernst & Young, Australia, 2021).
- **Qualitative assessment** of the potential social and environmental benefits (Ernst & Young, Australia, 2021).
- **Dynamic recursive Global** Trade Analysis Project (GTAP) model and the Input-output method used to assess socio-economic effects of CCUS (Chen et al.2022)

4.2.1.3 Economic impacts of CCUS

The deployment of CCUS technology in multiple sectors could also generate economic benefits. Below is the overview of the economic impacts of CCUS technology:

- **Boost clean economic growth** – The deployment of CCUS can stimulate substantial clean value-added growth or increase outputs of high productivity in industries involved CCUS application in the construction and operations phases (Townsend, et al 2020, Ernst & Young, Australia, 2021) through industry chain transmission and job creation (Chen et al.2022).
- **Substantial flow-on effects** – CCUS investment can also provide cascading economic benefits through agglomeration and clustering of allied industries. When CCUS investment carefully infused into industry, it can boost productivity and efficiency from increased transactions and interactions between firms, increased competition, innovation and knowledge creation. It could stimulate

innovation as companies compete for market share which can cascade into growth. New industries would emerge from the high end of the CCUS deployment on carbon negative opportunities such as biomass (BECCUS) and direct air capture (DAC).

- **Source of high-value spill overs that can stimulate innovation-led growth –** CCUS technology is a higher value new/emerging business, but lower volume technologies when it comes to spill overs. The largest source of innovation for CCUS deployment is AI, Biotech and ICT.
- **Extension of lifetime of existing infrastructure** - The lifetime of existing infrastructure can be extended, and the cost of decommissioning differed if they are retrofitted for the adoption of CCUS. For instance, it can provide opportunities to re-using existing oil and gas infrastructure by repurposing it for CO_2 transport and storage. The re-use of infrastructure can provide cost savings and defer decommissioning costs. It could still provide material cost savings that benefit both operators and taxpayers. But there are range of commercial, technical, operational and regulatory risks that could discourage the re-use of particular aspects of infrastructure. The rationale for re-using infrastructure ultimately rests on whether the cost savings of re-purposing assets outweigh the potential risks and costs of remedial work associated with using older infrastructure.
- **Economic barriers exist for the adoption of CCUS –** the deployment of CCUS has the potential to increase in the electricity cost in CCUS-fitted thermoelectric power systems (David J, et, 2000). Therefore, there is there for large, long-term and sustainable funding sources for achieving and scaling up significant reduction in CO2 emissions (Gibbins et al, 2008).

4.2.1.4 Social impacts of CCUS

The adoption of CCUS technology could spur critical societal benefits at the construction and operational phases. Summary of the social impacts of the CCUS deployment at scale are provided below:

- **Creation and sustenance of jobs –** There are opportunities to create low-to-high skilled jobs at the construction, operation and maintenance of CCUS facilities. Construction jobs are normally temporary and can often last for the construction phase. CCUS construction can more create jobs for low and high skilled workers at the peak of construction. Conversely, the operation of CCUS facilities will require relatively small number of skilled workers (managers, operators, maintenance personal and lab technician who normally work on shift). CCUS operation jobs are often long-lived covering the plant life.
- **Support to indirect jobs in the supply chain –** the employment multiplier effects of CCUS deployment in industries can be large but the indirect jobs are more geographically dispersed and are less likely to be additional.
- **Increase skills and knowledge** – The integrated CCUS deployment could enhance skills and unlock innovation capacity among the industry players as a strategy for preventing economic and social disruption.
- **Ensure just and sustainable transition -** The transition to a net-zero carbon economy will boost prosperity, but there will be winners and losers. If the transition is planned poorly, it could result not only in stranded assets, but also stranded workers and communities in those regions most at risk of job losses. One of the challenges of achieving a just transition is the disconnect between the geographic spread of job losses and gains, and the timing of these changes. Deployment of CCUS could provide employment opportunities at the time and place where they are most likely to be needed to support the just transition to a net-zero economy. CCUS could enable existing industries to continue to make a sustained contribution to local economies while transitioning to a net-zero economy.
- **Societal acceptance –** Societal acceptance of CCUS is based on the risk-benefit perception and information provision (Yang et al, 2016)**.** Public perception of risk associated with CCUS due to concerns the sequestration technology and potential leakage of CO_2 (Selma L, 2014).

4.2.1.5 Environmental Impacts

Positive impacts

- CCUS can help avoid CO_2 emissions at point sources which hitherto would have been emitted to atmosphere.
- CCUS can decrease at scale the stock of CO_2 emissions already in the atmosphere through carbon dioxide removal (CDR) technologies. This could contribute to enabling low-emissions future (Ernst & Young, Australia, 2021).
- CCUS will improve the improve air quality as it reduces air pollutants when used for hydrogen production that fuel transport or when fitted with a thermal plant that does not have pollution control system.

Negative impacts

- Eldardiry et al, 2018 grouped the risk associated with CCUS deployment into global and local effects.
- CCUS deployment in power plant could impose water stresses due to additional water requirements for chemical and physical processes to capture and separate CO_2 in CCUS-fitted fossil-fuel thermal plant (Eldardiry et. al, 2018)
- Parasitic load imposed by CCUS in power plants can reduce their efficiency and thus require more water for cooling the plant due to high water requirement.
- Groundwater contamination due to CO_2 leakage during geologic sequestration could affect in water quality.
- Leakage of CO_2 with CCUS system via boreholes overlaying rocks or natural fractures and faults may be local effect (Mertz B et al, 2005)
- Large scale hazard includes global climate effect due to low-level CO2 leaked back into the atmosphere (Eldardiry et al, 2018) (accidental or deliberate releases.

4.2.2 Hydrogen Fuels

4.2.2.1 Technology information and application

Hydrogen fuel is a zero-carbon fuel depending on how it is sourced (Wikipedia, 2022). As an energy carrier like electricity, hydrogen can be produced from renewables or hydrocarbons such as natural gas or coal. Brandon et al, 2017 categorises the hydrogen production pathway as follows: (a) Power-to-gas (P2G): Electricity is used to generate hydrogen via electrolysis. The hydrogen is then either injected into the gas distribution grid or transformed to synthetic CH4 in a subsequent methanation, (b) Power-to-power (P2P): Electricity is used to generate hydrogen via electrolysis. The hydrogen is then stored in a pressurized tank or an underground cavern or re-electrified when needed using a fuel cell or a hydrogen gas turbine. The hydrogen produced can also be used as a fuel for Fuel Cell Electric Vehicle FCEVs in the transport sector, which is referred to as power-to-fuel and (c) Gas-to-gas (G2G): Steam Methane Reform (SMR) is an established process for producing hydrogen from natural gas, and approximately 95% of hydrogen produced worldwide is produced through SMR technology. To lower the carbon footprint, CCUS technology is needed to capture the CO2 released as the by-product

The optimum hydrogen pathway depends on the trade-off between several factors, including system costs, efficiency, decarbonization impact and the practical feasibility (e.g. public acceptance) of changing the existing energy system in a given area to incorporate these new technologies. Hydrogen is a clean energy carrier and a primary energy source and be used as a fuel in transportation, electricity production and as feed stock in industry (You et, al 2020, Weichenhein et al, 2021). As a clean energy carrier, hydrogen offers a range of benefits for simultaneously decarbonizing the transport, residential, commercial and industrial sectors.

Hydrogen is popular because of its high energy content, environmental compatibility and ease of storage and distribution (Mirza et al, 2008). Increase in hydrogen technologies, infrastructure and application at unprecedented pace. Hydrogen is one of the keys to the energy transition[12] and sector-coupled energy system. It has the potential to cut emissions from heavy industry and transport. For instance, in the transport sector, hydrogen is expected to replace liquid and gaseous fuels in replace the end of the century (Mirza et al, 2008). Its deployment must be

[12] https://hydrogencouncil.com/en/hydrogen-decarbonization-pathways/

economically viable, socially acceptable, to maximize the decarbonisation impact and minimize its resource requirements.

4.2.2.2 Method of impact assessment of the deployment of hydrogen fuels

Life Cycle Assessment (LCA) and Integrated Process model (IPM) are the main method of assessment of impacts of the deployment of hydrogen (Ullman, A, Kittner, N., 2022, You et, al 2020).

4.2.2.2.1 Economic impacts of Hydrogen of Hydrogen fuels

- Integration with low-carbon alternative in energy, transport and industry: Hydrogen can be linked with other low-carbon alternatives to enable a more cost-effective transition to de-carbonized and cleaner energy systems (Brandon et al, 2017). It can boost the opportunity to use renewables in transport and heavy industry. The integrated hydrogen and energy system can secure supply (storage and transport energy), affordability (hydrogen is abundant and increase competitiveness) and sustainable (low life cycle carbon emissions). Electricity and hydrogen in mobility can boost companies in a variety of industries, such as logistics suppliers, transportation companies, garages, agricultural contractors, ship builders, automobile leasing companies, sail boats and city distribution.
- **Promotion of industries and revitalise regional economies through patents relating to hydrogen technology:** The development of hydrogen technology is an increase in research and development. Certain countries such as Japan are far advance in this area, and this will need to more patents which has a positive correlation with revenues.
- **Reschedule the decommissioning of existing gas infrastructure**: Existing gas infrastructure can be used to transport the renewable energy in the form of hydrogen. The investment requirement needed to support the adoption of hydrogen may be reduced as existing gas infrastructure can be modified for use. Hydrogen can be transported through already existing gas pipelines and industries that make us of these already existing pipelines can supplied through same.
- **Enable large-scale, efficient renewable electricity integration due to the intermittent character of solar and wind, the electricity system**: The advent of hydrogen takes away the inefficiencies associated with intermitted challenges of solar and wind as it can be combined to support electricity production from solar and wind.
- **Decarbonisation for industrial energy use**: Industries can use a mix of green electricity and green hydrogen to produce high temperature steam which is necessary for many industrial processes and growth of the economies.
- **Serving as a feedstock for industry**: Carbon from biomass and green hydrogen are the main feedstock for production of every bulk chemical product. Enclaves with integrated chain of companies can make use and process one another's products and services.
- **Stimulation of new businesses:** The technical and economic success of hydrogen-based distributed energy systems will stimulate new business ventures. Hydrogen power parks will provide an economic development path for the integrated production of energy services such as electricity, transportation fuels, and heating and cooling.

Societal Impacts of Hydrogen Fuels

The development and use of hydrogen can bring about transformational changes in societal structure. Societies would experience transformational changes as they transition into new communities that are powered by cleaner fuels.

New societies and communities that use hydrogen powered cars, buses, stoves and other residential and commercial heating technologies would emerge changing mindsets for use of hydrogen powered stoves, buses, cars and other equipment.

Environmental Impacts of Hydrogen Fuels

- The use of hydrogen is a long-term option for reducing CO_2 emissions.
- Using hydrogen fuels can ramp up efforts to achieving net zero targets pledged by governments and corporations in the wake of calls for climate action.

- Hydrogen can largely reduce environmental stress or burden as when used to produce energy does not emit CO_2.
- Pollution in urban cities can be attributed to the use of fossil fuels by cars, buses and trucks for hauling goods among others. The use of hydrogen will reduce pollution levels in cities and urban centres which has become a key concern for many governments and local authorities.
- Hydrogen warming impact - Climate consequences of hydrogen application relative to fossil fuel strongly depend on time horizon and leakage rate (Ocko et al. 2022)

4.2.3 Digitalization and Artificial Intelligence

4.2.3.1 Technology information and application

Digitalization/Artificial Intelligence are enablers of new/emerging industries or business at scale. Ye, J, (2021) described digitalization as the application of digital technologies (e.g., sensors, networked devices, cloud data storage, analytics) to physical equipment and systems to reducing energy use and carbon emissions across the economy, including in the power, transportation, buildings, industry, and agriculture sectors. It also includes the application of smart grid, smart meters and block chains that could enable new/emerging businesses.

It involves the collecting more and high-quality data about the physical world using sensors, analysing data with algorithms or Artificial Intelligence (AI), and turning the resulting information into actions that can help increase productivity and efficiency. Digital technologies can also help using digitalization to achieve decarbonisation. The technology can enable communications between electricity generators and consumers and implement flexible demand response strategies to better align use with resources.

Additionally, Electric Vehicle (EV) charging can be optimized using digital technologies, helping the grid to operate more efficiently with less total power required. Likewise, digital devices can provide system operators with information. Electricity system are rich in data and have great potential for AI. AI can help to develop new technologies, improve forecasts of demand and renewable energy, optimise grid management or enhance system monitoring.

4.2.3.2 Economic Impacts of AI/Digital Technologies

Generally, digitalization/artificial intelligence can generate wide positive economic benefits. The economic returns are achieved through the employment creation, improve quality of life and enabling adoption of green technologies. Digitalization/artificial intelligence can also contribute to the duel of benefit of economic growth and reduction of greenhouse gas emissions. In the energy sector, the application of AI/digital technologies has the versatility to improve wind and solar generation forecasts and help the grid maximize.

4.2.3.3 Societal Impacts of AI/Digital Technologies

AI/digital technologies could deliver e-health services to 1.6 billion people across the developing and developed world. Smart agriculture will boost yields by 30%, avoid 20% of food waste and could deliver economic benefits worth $1.9 trillion. At the same time, smart agriculture could reduce water needs by 250 trillion litres and abate 2.0Gt CO_2e.

4.2.3.4 Environmental Impacts of AI/Digital Technologies

AI/digital technologies to increase carbon abatement by 20% (Inderwildi et al 2020). AI technologies are likely to be more effective and could raise carbon abatement to 30%. Real-time traffic information, smart logistics, intelligent lighting and other ICT enabled solutions could abate 3.6Gt CO_2e, including abatement from avoided travel (SMARTer2030, ICT Solutions 21st Century Challenges). Smart manufacturing, including virtual manufacturing, customer centric production, circular supply chains and smart services could abate 2.7Gt CO2e.

5. Conclusions and Possible Recommendations

Focus: This section will cover, among others, the major findings in the technical paper, policy recommendations for consideration by KCI and final conclusions.

5.1 Key findings

5.2 Recommendations

5.3 Conclusions