KAPSARC
مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

18th IAEE European Conference

67. Circular Carbon Economy – 7th cycle of concurrent sessions

The Circular Carbon Economy Technology Roadmaps:

A Methodology for Net-Zero

Noura Y. Mansouri, Ph.D. - Fellow I, Climate & Sustainability, KAPSARC

On behalf of the team,

Fateh Belaid, Ph.D. - Fellow II, Climate & Sustainability, KAPSARC

Aljawhara Al Quwayid - Senior Research Associate, Climate & Sustainability, KAPSARC

26/07/2023

Outline

- Literature Review on Technological Innovation
- Understanding Technology Roadmaps
- Technology Roadmaps Development Process
- The Circular Carbon Economy
- The Circular Carbon Economy Technology Roadmaps

Literature Review on Sustainability Transition

- **Technological Innovation Literature**
  - Innovation and Economic Development
  - Sustainability Transition
  - Evolutionary Economics
  - Technological Innovation
  - Technology Readiness

Evolutionary Economics

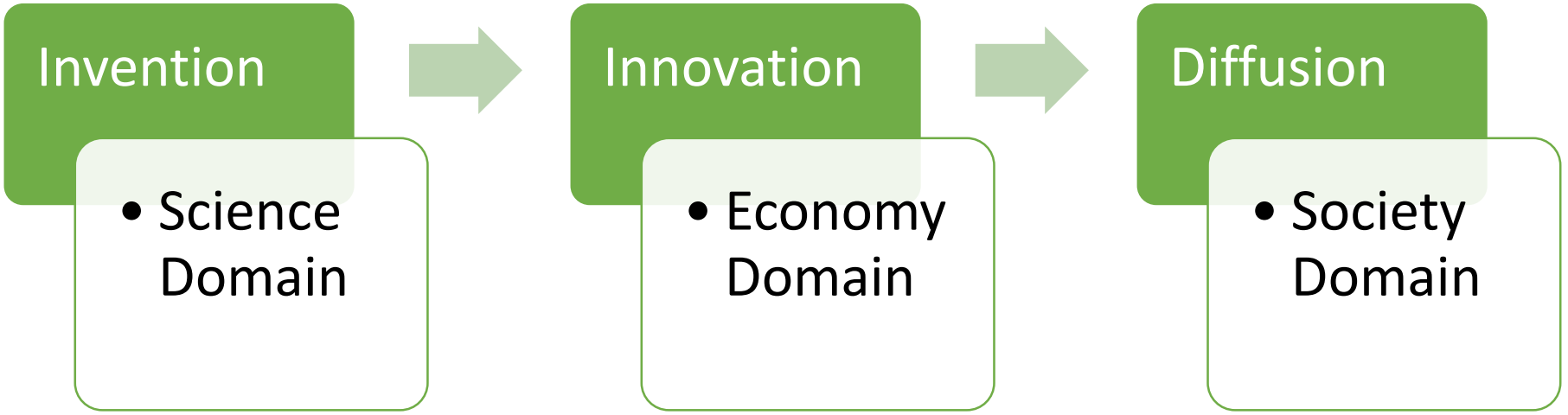
- **Behavioral and experimental economics, view economic agents as diverse, boundedly rational, and socially interactive. They depart from the traditional neoclassical assumption of perfectly rational agents and emphasize the importance of considering cognitive limitations, social interactions, and individual heterogeneity in understanding real-world economic phenomena. These perspectives have led to innovative theories and empirical research, enriching the economic discipline and influencing policymaking.**
- **Joseph Schumpeter in the first half of the 20th century**
- **Nelson and Winter in 1982**

Complexity

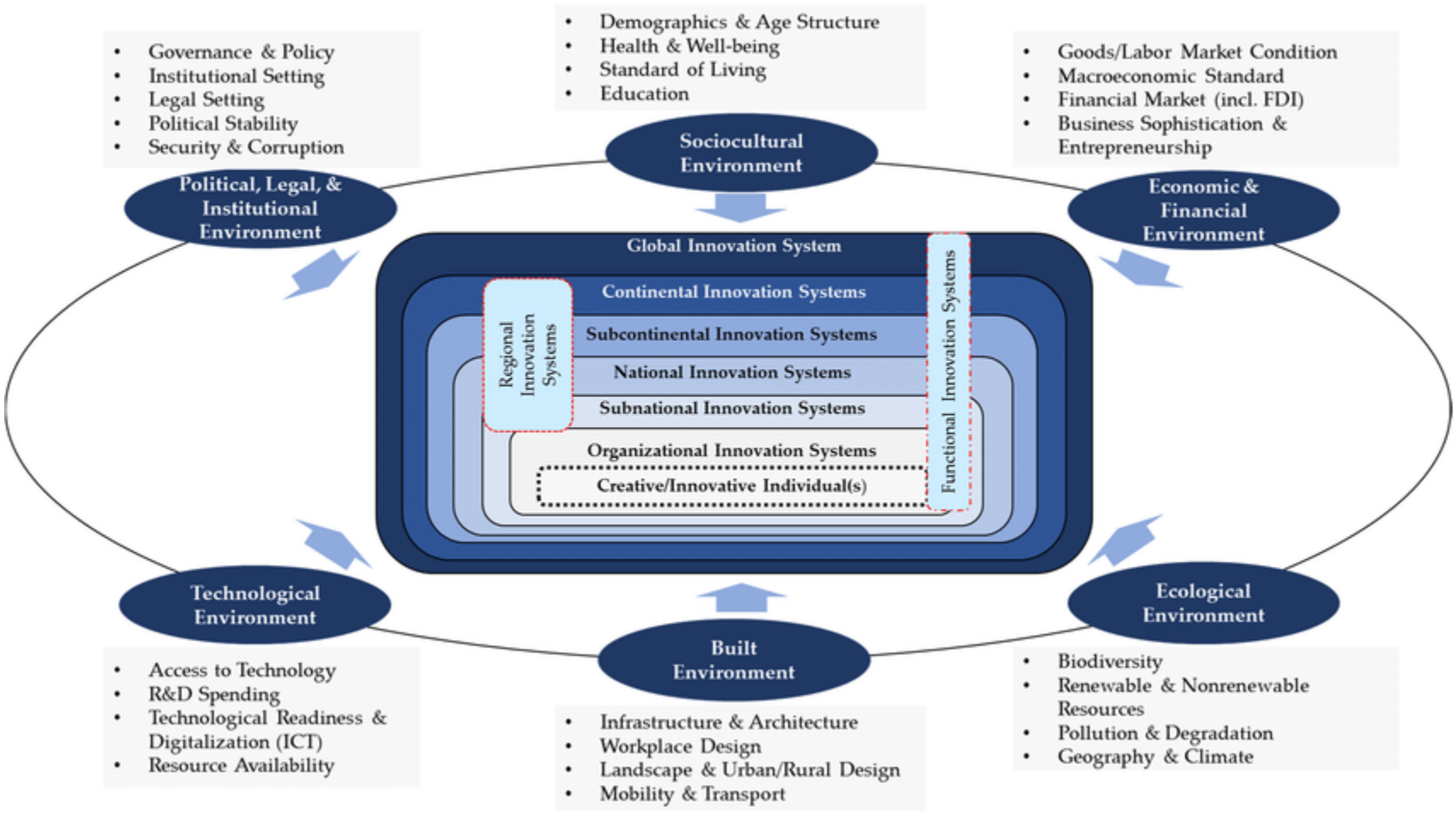
Economic Dynamics

Bounded Rationality

Schumpeterian Innovation

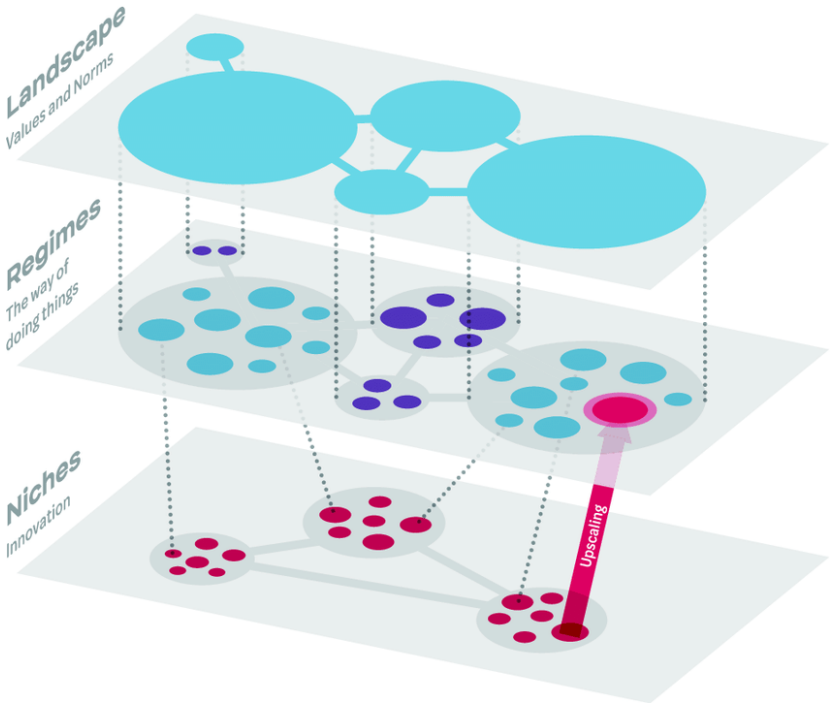


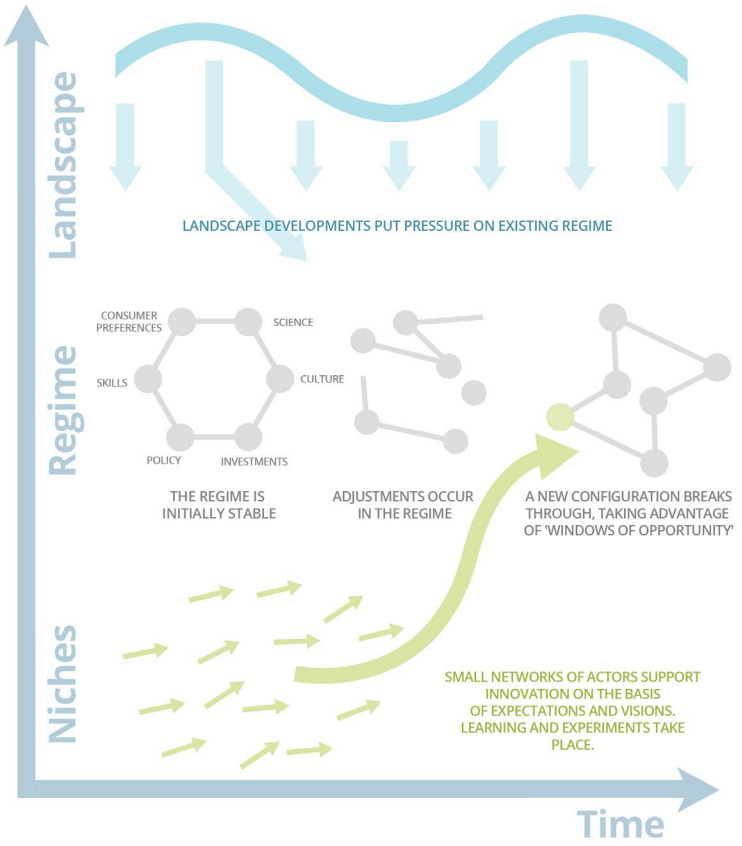
Innovation Systems View



Source: Satalkina and Steiner, 2020.

Literature Review





The multi-level perspective (MLP) has emerged as a fruitful middle-range framework for analyzing socio-technical transitions to sustainability.

Source: Based on Geels (2002)

The multi-level perspective (MLP)

A central tenet in MLP is the stabilizing influence of a socio-technical regime, defined as "*the coherent complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures*"
(Rip and Kemp, 1998, p. 338)

Technological Regime

TABLE 1: DIFFERENT APPROACHES TO THE CONCEPT OF TECHNOLOGICAL REGIME

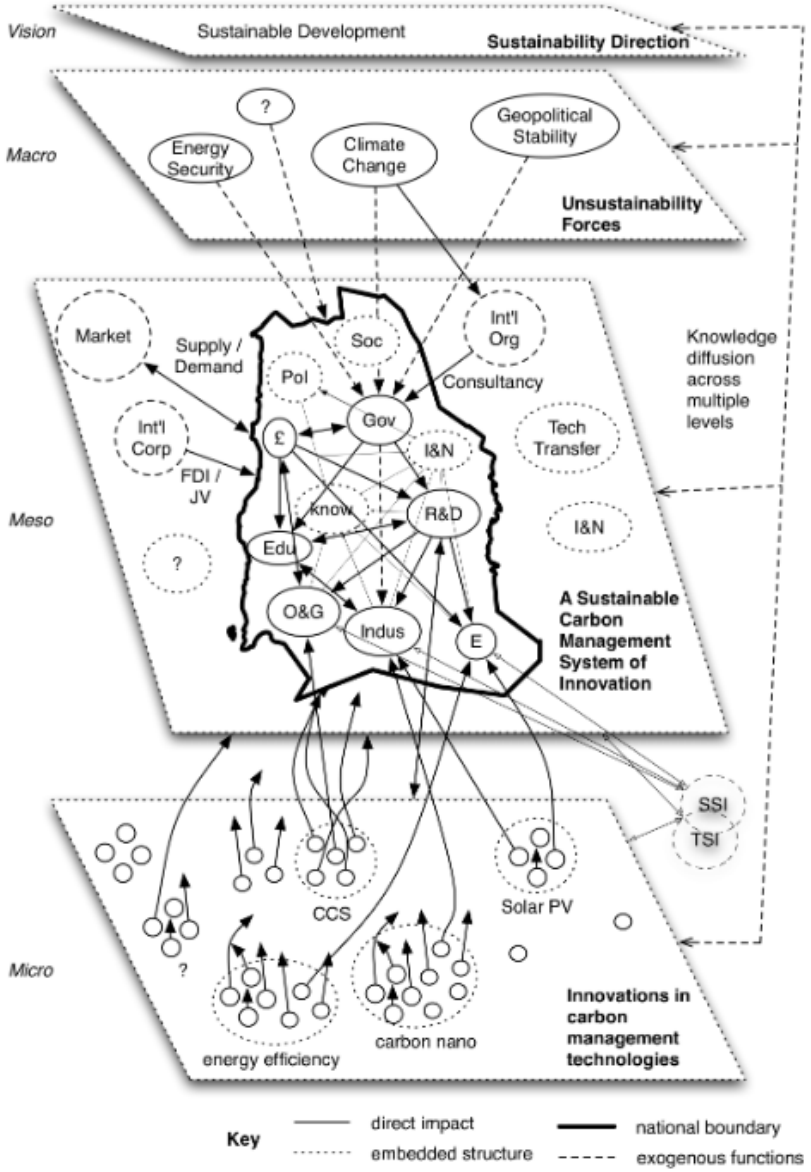
Scholar	Notion	Dimensions	Major Focus
Dosi, [6]	Technological paradigm/ Technological Regimes	• Accumulativeness • Uncertainty	The focus is on explaining "continuity" and "discontinuity"
Nelson and Winter [17, 32]	Technological regime	• Technological **opportunity** • Technological **appropriability**	Concentration on the role of technological environment in determining the intensity of innovation, the degree of industrial concentration and the rate of entry. By Technological regime, the main focus is on the cognitive aspects of dynamics of natural technological trajectories [16, p. 50].
Sahal [25]	Typology of innovation	• the frequency of technological progress	
Acs, and Audretsch, [33, 2]	Nature of relevant technology	• Level of being routine or entrepreneurial (the innovative activities) • The information asymmetry between entrepreneurs and incumbents (due to the nature of knowledge base)	Focus on the differences between industries in terms of patterns of entry and exit due to the fact that how routine is the innovative activities in that industry.
Rip and Kemp [24]	Technological regimes[1]	Noting special	The focus is on rules that are specific for a particular technology
Malerba and et al [28, 13, 14]	Technological regimes / Learning Regimes	• Technological **opportunity** • **Appropriability** of innovation • **Cummulativeness** of technological advances • **Properties** of the knowledge base	The main focus is on attributing differences between sectors to the specifications of knowledge base of each sector.
Godoe, [8].	Innovation regimes	• Level of cooperation between actors in the process of innovation • Standardization of technologies	To explain the innovations in the telecommunication industry
Poel [22]	Technological regime[2] / innovation patterns[3]	• the function of that technology (artifact) • The configurations, design concepts, technical features and parts of that technology (physical properties of artifacts)	"how these innovation patterns enable and constrain the emergence of radical innovations that transform technological Regimes". Among them, he focuses on rules that govern design and development of technology

[1] By Technological Regime he refers to "rule-set or grammar that is characteristic for the development of a technology and that guides not only the search activities of engineers, but also the actions and interactions of the other actors involved in technical development." [24]
2 By Technological Regime, Poel "refers to the rules that guide the design and further development of a particular technology. Such rules result in incremental and cumulative patterns of technical development." [22, p. 49]
[3] "The term 'innovation pattern' refers to the constellation of roles and the division of labor among actors with respect to the initiation and the development of

Source: Mehrizi, 2008

Example: A Saudi sustainable carbon management system of innovation

- A schematic proposed framework for a sustainable carbon management system of innovation using MLP, transition theories and innovation system approach



Source: Mansouri, 2013

Understanding Technology Roadmaps

- ***"A Technology Roadmap (TRM) serves as a coherent basis for specific technology development and transfer activities, providing a common (preferably quantifiable) objective, time-specific milestones and a consistent set of concrete actions; developed jointly with relevant stakeholders, who commit to their roles in the TRM implementation."***

- Background paper on technology roadmaps, UNFCCC Technology Executive Committee, TEC/2013/5/5.

- ***"Is a dynamic set of technical, policy, legal, financial, market and organizational requirements identified by all stakeholders involved in its development. The effort shall lead to improved and enhanced sharing of and collaboration on all related technology-specific RDD&D information among participants. The goal is to accelerate the overall RDD&D process in order to deliver an earlier update of the specific energy technology into the marketplace."***

- The IEA definition of a technology roadmap

Understanding Technology Roadmaps

- TRMs are technology-specific roadmaps intended to support the development of a specific type of technology.
- Literature review on past and existing roadmaps would be summarized and would inform the roadmapping process
- Tracking of milestones and goals of technologies would inform the global TRM
- Rigorous empirical analysis of existing, relevant, empirical data for TRMs
- Increased communication with stakeholders, and consensus-building through surveys, interviews and workshops would inform local and global roadmaps
- Identifying best practices to be incorporated by stakeholders
- Proposing specific, time-related and action-oriented policy recommendations
- Individuals involved typically include technical experts, policy makers, energy analysts and university researchers, who come together to outline performance targets, pathways, priorities and time frames for the research, development, demonstration and deployment (RDD&D) of a technology.
- It engages and aligns diverse stakeholders in a common course of action
- Manage and implement an effective energy technology roadmap process relevant to their own local circumstances and objectives.
- Help national and local policymakers and industry to develop strategies that accelerate the deployment of low-carbon energy technologies worldwide.
- Creating conditions for deployment

Typical Roadmap Audiences

- national government decision makers in ministries of energy, environment, industry, natural resources and infrastructure
- national government decision makers in ministries of finance or economics
- state/provincial and local policy makers and national regulators
- energy sector decision makers, particularly from industries that produce or consume large amounts of energy (e.g. electricity, natural resources, agriculture and energy-intensive industry)
- leading scientific, engineering, policy, social science and business experts involved in researching specific energy technologies and the supporting policies and financing mechanisms needed to accelerate commercialization
- NGOs engaged in research and advocacy in low-carbon energy

Circular Carbon Economy Technologies across the 4 R's

Reduce

Energy Efficiency
- Combined Cycle
- EE Standards
- HVAC

Alternative Energy
- Non-biomass Renewables
- Nuclear power
- Fuel switching
- Synthetic fuels

Reuse

- Synthetic fuels
- Fertilizers and urea
- Methanol and chemicals
- Polymers
- Concrete (CO_2 chemically reacted)

Recycle

- CO_2-Enhanced oil recovery
- Super-critical CO_2 applications (power)
- Concrete (CO_2 physical storage)
- CO_2-Enhanced water recovery

Remove

- Natural sinks (e.g., afforestation, soil and oceans)
- Bio-energy CCS (BECCS)
- Direct Air Capture with Storage
- CO_2 capture (mobile)
- CO_2 Transport
- Geological Sequestration

- ✓ This project provides a techno-economic analysis of energy innovations and technology roadmaps that span across the 4 R's to assess its technical feasibility and economic viability to contribute to meeting climate targets in a cost-effective and timely manner.
- ✓ The project offers in-depth understanding of the CCE framework and its 4 R's pathways and their challenges and opportunities.

UNFCCC

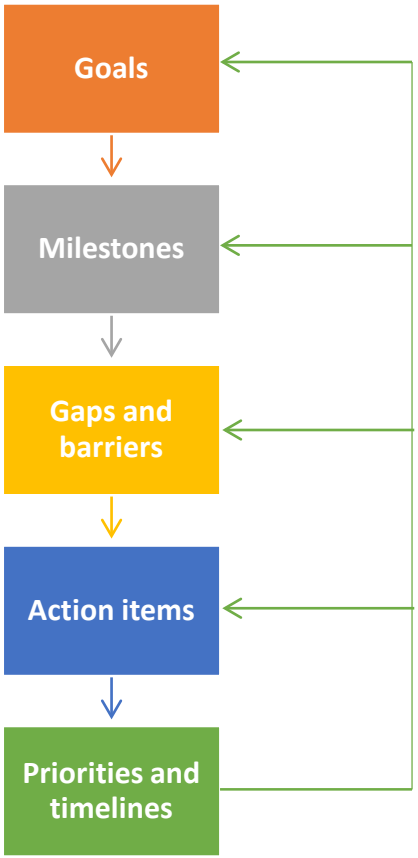
The background paper (2013) reported on the use of technology roadmaps (TRMs) related to climate change mitigation and adaptation technologies. The study of TRMs is motivated by the UNFCCC Conference of the Parties (CoP) request to the Technology Executive Committee (TEC) to catalyse the development and use of TRMs as facilitative tools for action on mitigation and adaptation

Recommendations

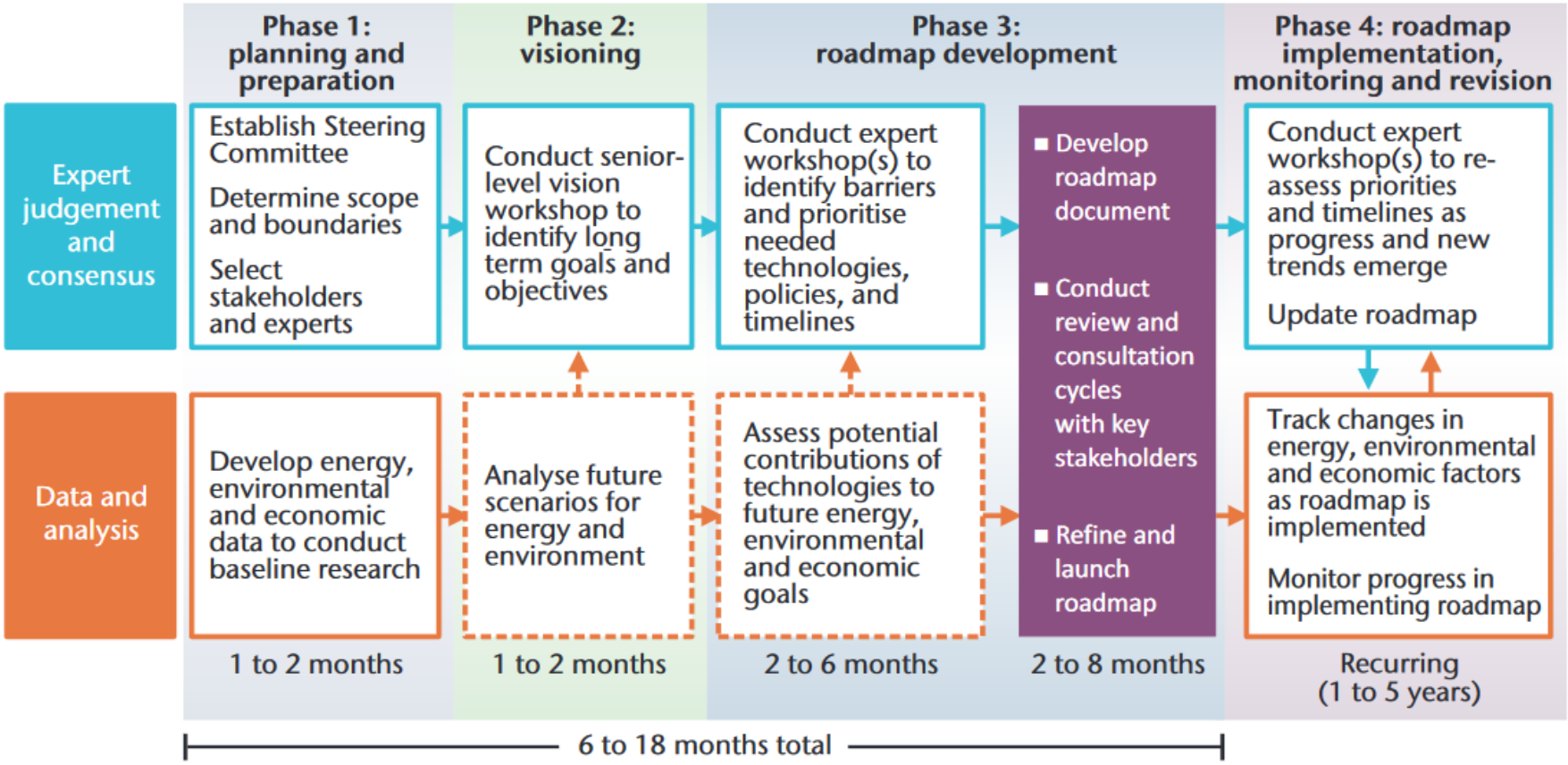
The following key recommendations, based on the analysis conducted for the background paper, are:

- Guidance and good practice should be disseminated in order to improve the quality and consequent contribution of TRMs to climate change mitigation and adaptation technology development and transfer.
- The TEC should further explore the perspectives for promoting TRMs for adaptation technologies.
- The TEC should promote the use of TRMs in developing countries; to this end, it could work towards developing cost effective TRM methods and guidance to improve the use of TRMs in and for Non-Annex I countries and provide training or capacity building on TRMs.
- The role of TRMs in integrating with other existing technology transfer efforts should be further explored by the TEC. This includes Technology Needs Assessments (TNAs) and Technology Action Plans (TAPs), and National adaptation Plans of Action (NAPAs) and Nationally Appropriate Mitigation Actions (NAMAs).

Key elements of a successful roadmap



Roadmap process outline



Note: dotted lines indicate optional steps, based on analysis capabilities and resources.

The roadmap development process

Phase I	Planning and preparation
Phase II	Visioning
Phase III	Roadmap development
Phase IV	Roadmap implementation and adjustment

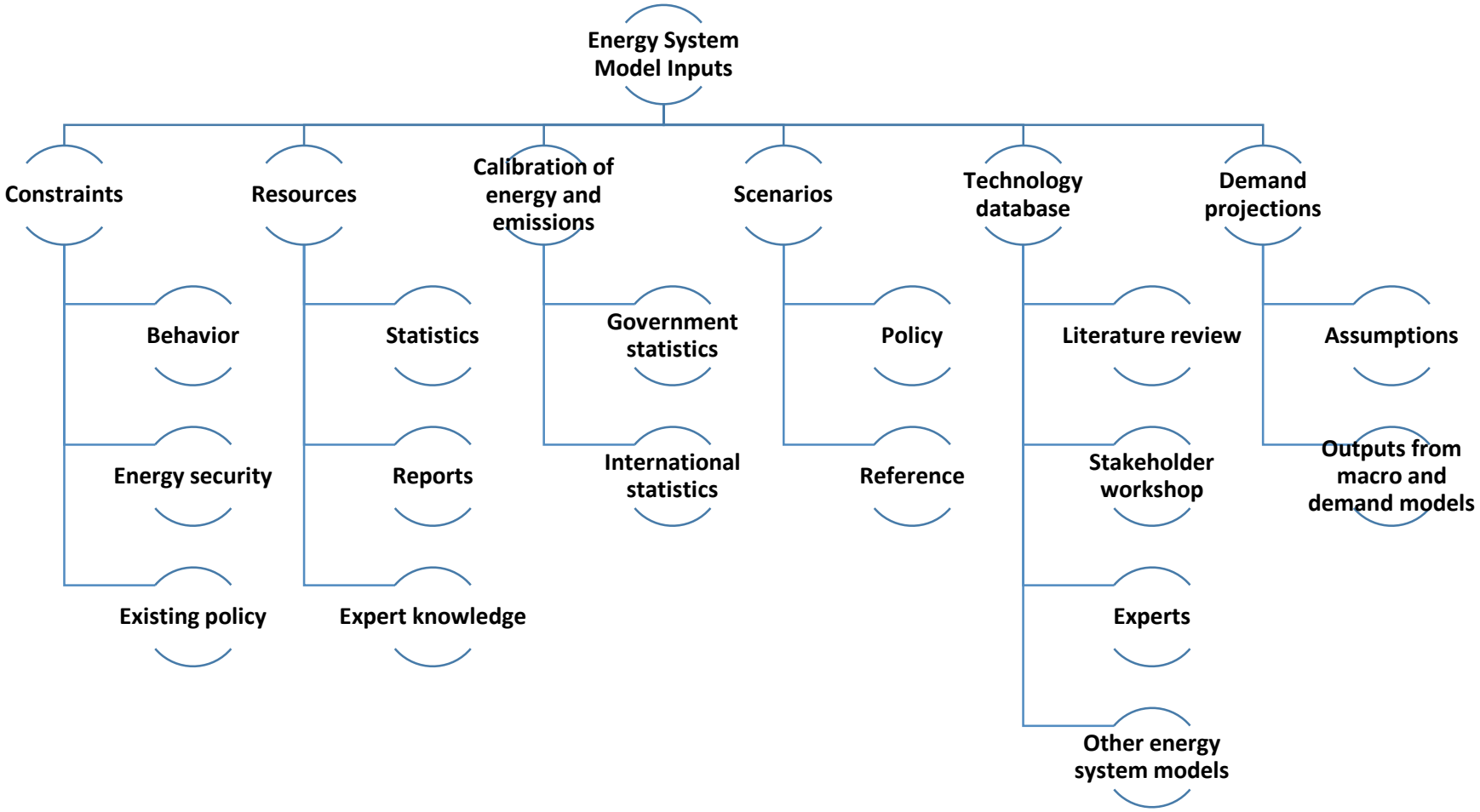
Phase I Planning and preparation

- **Ensure leadership commitment**
  - Leadership commitment will ensure
    - Stakeholder participation and commitment
    - Hold accountable stakeholders on the progress of the roadmap
    - Guiding the update and review of the roadmapping process
- **Appoint Steering Committee**
  - Steer the direction toward what is deemed important globally and locally
- **Develop a Statement of Purpose and Scope**
- **Conduct Baseline Research**

Phase II Visioning

- **Setting a vision is the process of defining the desired pathway for a technology's deployment.**
- **Modelling and Scenario Analysis to define possible future states.**
- **Modelling assesses fundamental data on national population growth, shifting projections on natural resources and economic growth to suggest different energy futures and environmental consequences of those futures.**
- **Hold a Vision Workshop(s)**

Phase II Visioning

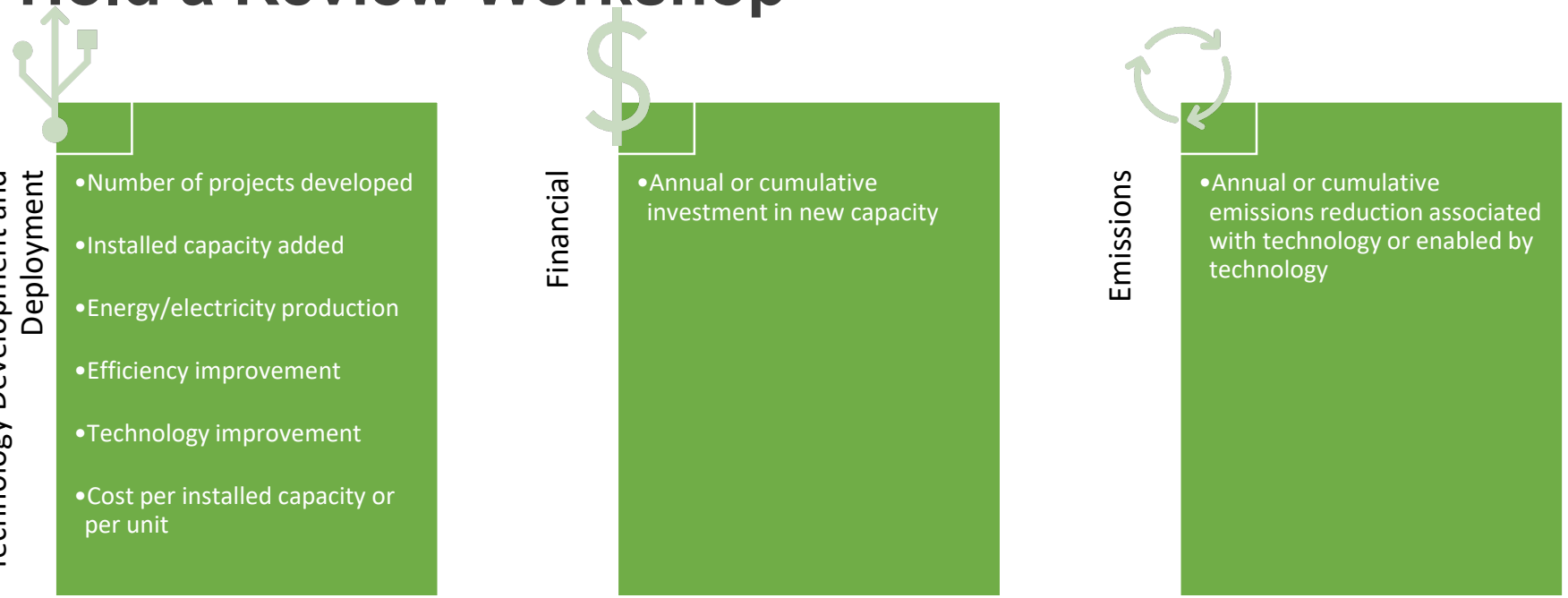


Phase III Roadmap development

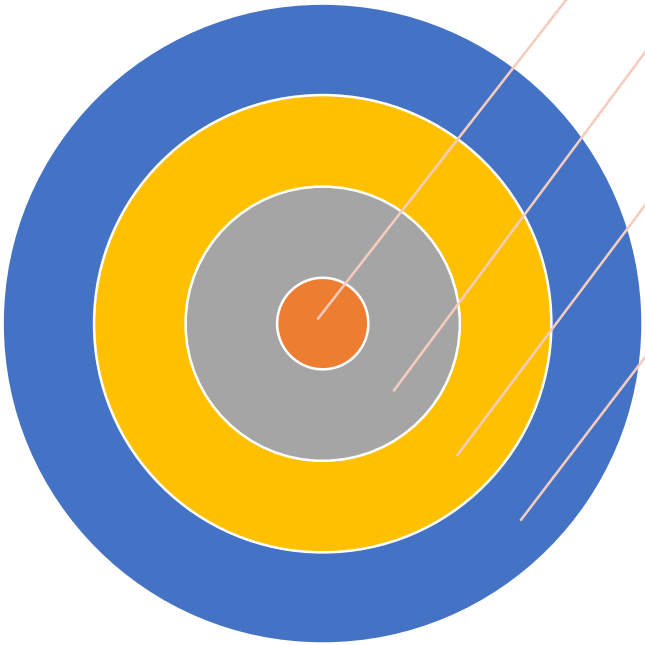
- **Hold a Roadmap Workshop(s)**
- **Prepare the draft roadmap document**
- **Conduct a roadmap review**
  - First Review
  - External Review

Phase IV Roadmap implementation and adjustment

- **Launch the roadmap**
  - Begin implementation
  - Monitor progress and adjust the roadmap
- **Hold a Review Workshop**



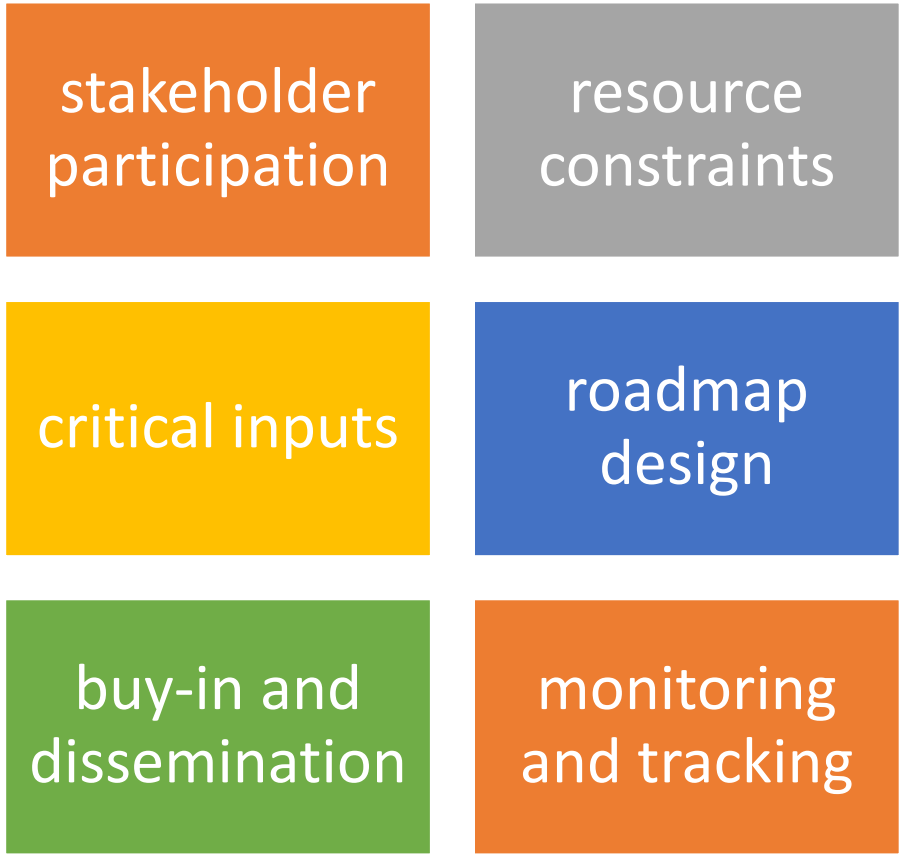
Stakeholders Involvement



Lessons learned: Roadmap implementation and revision

- Approach roadmapping as a “living process” that continues past the roadmap’s initial publication.
- Plan a successful roadmap launch to build awareness and create momentum needed to stimulate action.
- Designate the roadmap implementation body early in the process.
- Monitor key energy, environmental and economic indicators to track progress.
- Conduct regular roadmap revision workshops to adapt roadmap goals and priorities to changing circumstances.

Key Factors for Roadmaping

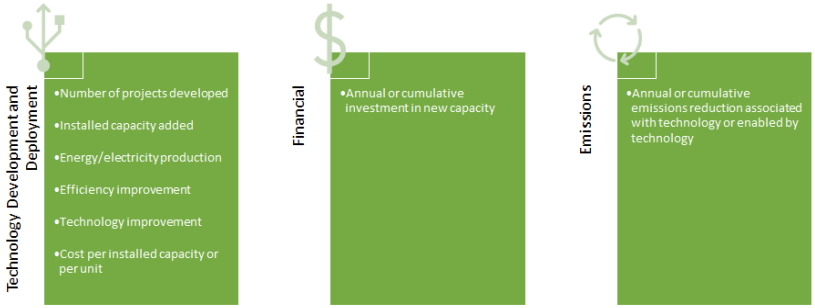


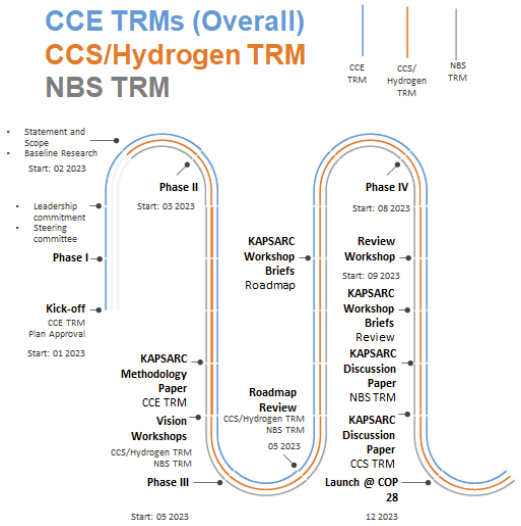
TEAM: NOURA MANSOURI, FATEH BELAID, ALJAWHARA AL QUAYID, WOLFGANG HEIDUG;
SP TEAM: ALAA ALARFAJ, LINAH AL HAMDAN, SHETTY PAVITHRA

Technology Roadmaps for Advancing the Global Circular Carbon Economy

This project aims to develop The Circular Carbon Economy (CCE) Technology Roadmaps (TRMs) – through:

- ✓ Identifying performance targets, pathways, priorities and timeframes for the research, development, demonstration and deployment of a particular CCE technology
- ✓ Creating a *first-of-a-kind* real-time dashboard showcasing the global and local technology roadmap of each of the CCE technologies that's updated and *revised* continuously
- ✓ Creating an account of existing projects of each CCE technology
- ✓ Assessing the investment requirements for the deployment of technologies
- ✓ Identifying *technical, policy, legal, financial, market* and *organizational* requirements for each CCE technology as identified by stakeholders





"A Technology Roadmap (TRM) serves as a coherent basis for specific technology development and transfer activities, providing a common (preferably quantifiable) objective, time-specific milestones and a consistent set of concrete actions; developed jointly with relevant stakeholders, who commit to their roles in the TRM implementation."

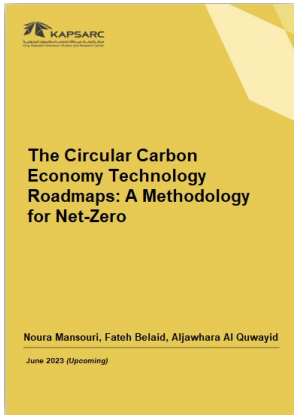
TEAM: NOURA MANSOURI, FATEH BELAID, ALJAWHARA ALQUAYID, WOLFGANG HEIDUG;
SP TEAM: ALAA ALARFAJ, LINAH AL HAMDAN, SHETTY PAVITHRA

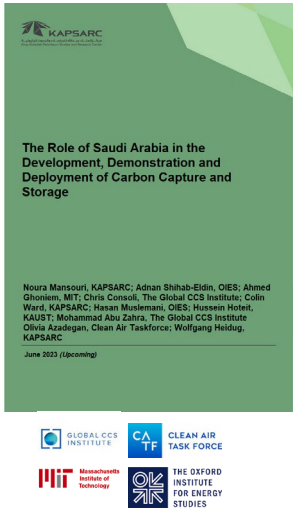
Expected Methodological Contribution:

- Technology Roadmaps are rooted in the sustainability transition literature, here, we propose the CCE-TRM as a net-zero methodology that builds on the CCE framework and contributes to the TRM through a stakeholder-informed process. The outcome could inform Saudi policymaking, namely, providing a technology deployment strategy for a transition towards carbon circularity and neutrality.

Driving Questions for each CCE-TRM:

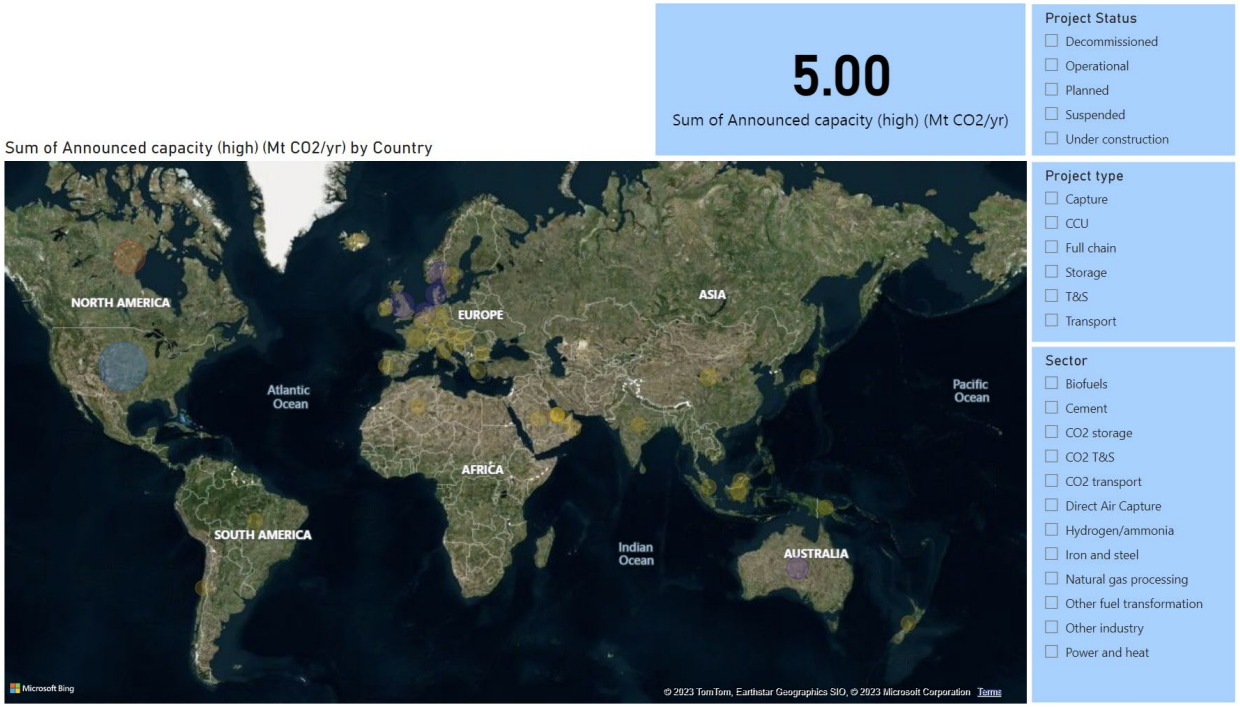
- How can we create a technology momentum?
- What is the potential of CCE-TRM technologies for carbon circularity and neutrality?
- What are the associated costs, risks, and benefits?
- What are the barriers to deployment?





The CCE-TRM Dashboard (*Sample*)

TEAM: NOURA MANSOURI, FATEH BELAID, ALJAWHARA ALQUAYID, WOLFGANG HEIDUG;
SP TEAM: ALAA ALARFAJ, LINAH AL HAMDAN, SHETTY PAVITHRA



CCE TRM Project: The Carbon Removal TRMs

- **Carbon Capture Utilization and Storage (CCUS) has a negative connotation given its association with hydrocarbons, therefore, 'packaging' the first set of TRMs as 'carbon removal' including CCS, (blue) hydrogen and NBS would be perceived in a more positive light, particularly in COP 28.**
- **The Carbon Removal TRMs include:**
  - Carbon Capture and Storage (CCS) TRM
  - Direct Air Capture (DAC) TRM
  - Nature-based Solutions (NBS) TRM
  - Hydrogen TRM
- **Carbon Removal Technology Roadmaps (TRM) identifies, in a first-of-a-kind live *roadmapping* online platform, a detailed scenario for the technology's development, demonstration and deployment by 2050.**
- **It builds on existing efforts globally and capitalize on open-source databases**
- **Through engaging with key stakeholders from the government, industry and research community to demonstrate CCS at scale and pace around the world in a variety of settings.**
- **To describe and analyze actions needed to accelerate CCS deployment to levels that would allow it to fulfil its CO2 emissions reduction potential.**

Major Research Questions

- Where are we in the technology?
- What are the current projects?
- What are the current applications?
- What's the potential for carbon circularity and neutrality?
- What are the associated costs?
- What are the associated risks and benefits?
- How can we accelerate the technology's deployment?
- What is the technology prospects in the near future?
- What are global goals or milestones for the technology?

Expected Contributions

- **The roadmap concludes with a set of near-term decisive actions that stakeholders will need to take to achieve the roadmap's vision.**
- **Tracking the development of the technology globally.**
    - Technology Activity and Live Project Interactive Map
- **A *first-of-its kind* live platform**
- **Independent and scientific assessment**
- **Sample Action List:**
    - reach a broadly supported international agreement on a global response to climate change
    - build capacity that will enable the delivery of CCS at the scale, time and magnitude necessary
    - construct a number of large-scale demonstration facilities
    - ensure an active sharing of knowledge on the experience gained

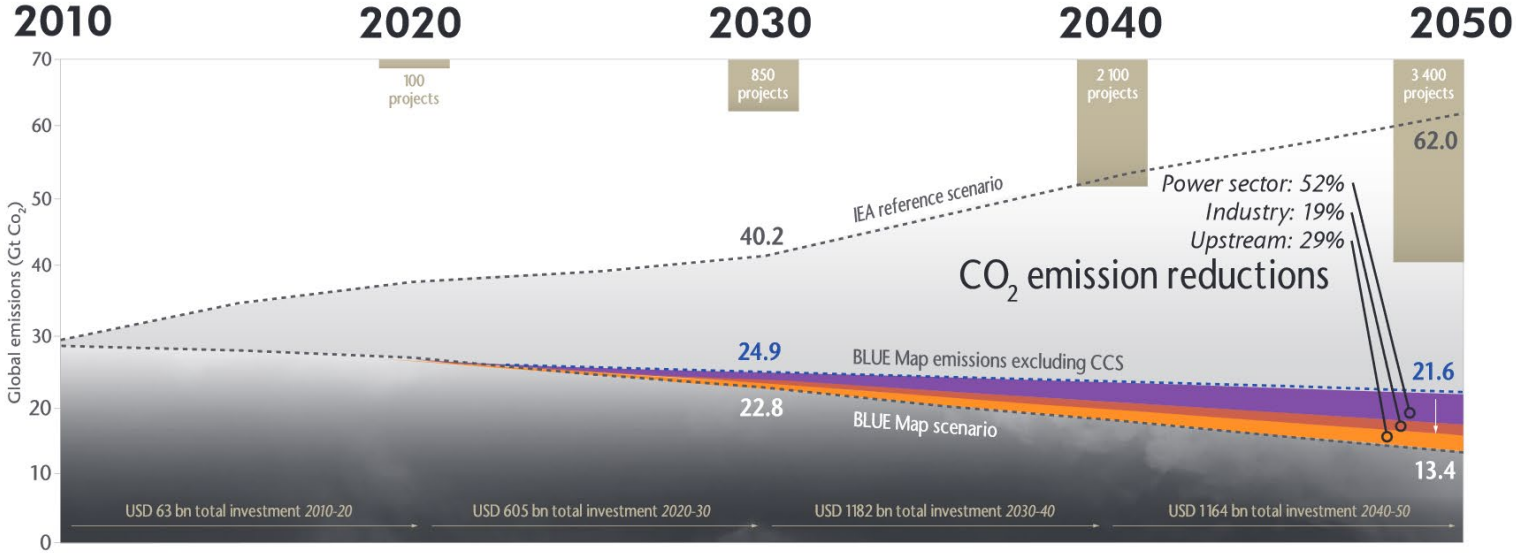
Example of CCS Roadmap, IEA (2009)

CARBON CAPTURE AND STORAGE ROADMAP

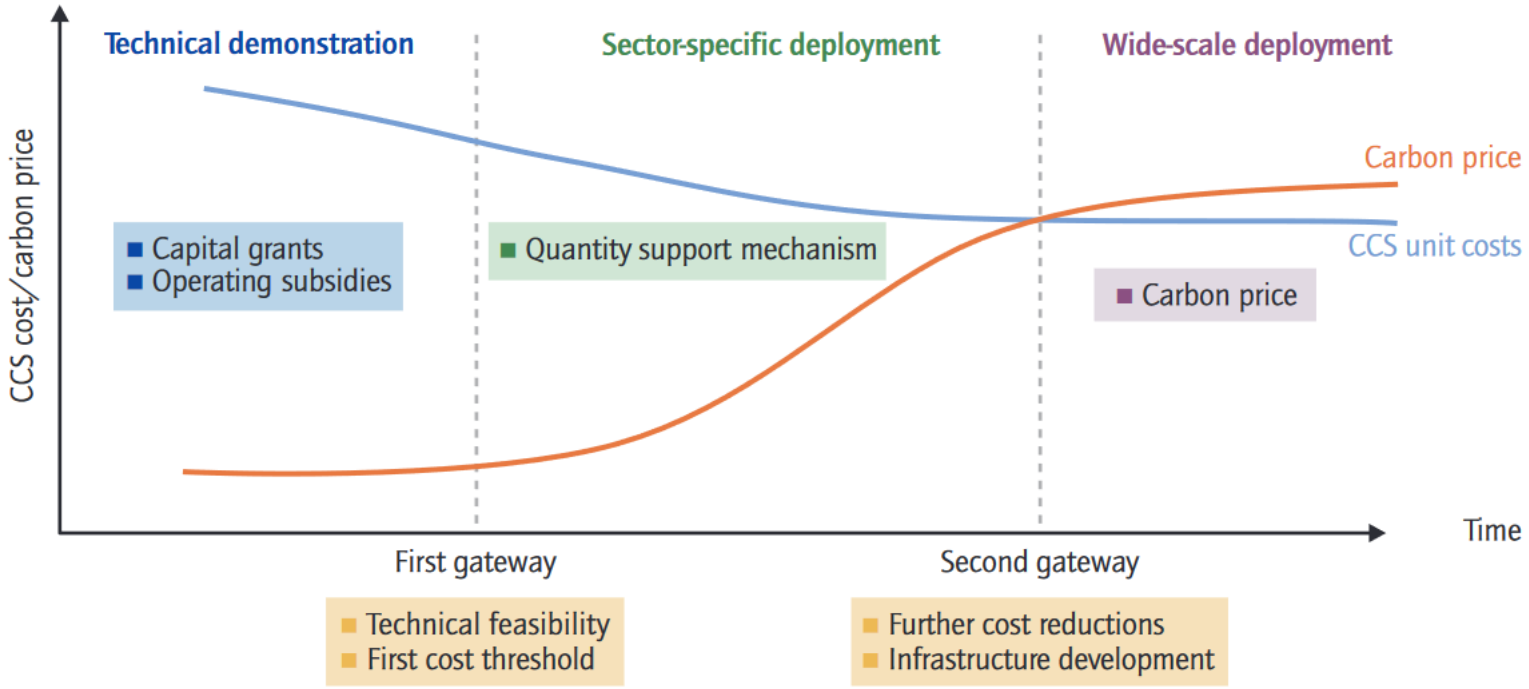
International Energy Agency

CCS contribution in BLUE Map by sector 2010-50

Total CCS contribution to the BLUE Map scenario is 8.2 $GtCO_2$ avoided in 2050.
This is 19% of the total mitigation effort needed.



Example of CCS Roadmap, IEA (2012)



Source: IEA, 2012f.

References

Background paper on Technology Roadmaps, UNFCCC Technology Executive Committee, Fifth meeting, March 2013

https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEM_TEC_meetings/d8024d9b950f43d594fc17fd22b5477a/df75c7bbbd2e4daa8f2f8eba203d33de.pdf

IEA, April 2014 “Technology Roadmap: A Guide to development and Implementation”

https://www.iea.org/reports/technology-roadmap-a-guide-to-development-and-implementation

IEA CCS Technology Roadmap, IEA 2009

Energy Technology Perspectives 2008, IEA 2008

Energy Technology Perspectives 2010, IEA 2010

IEA/CSLF report to the Muskoka G8 Summit: Carbon Capture and Storage – Progress and Next Steps. Prepared in cooperation with the Global CCS Institute. IEA 20105760 J. Lipponen et al. / Energy Procedia 4 (2011) 5752–576110 Author name / Energy Procedia 00 (2010) 000–000

The Status of CCS Projects, Interim Report 2010, Global CCS Institute 2010.
http://www.globalccsinstitute.com/downloads/general/2010/The-Status-of-CCS-Projects-Interim-Report-2010.pdf

IEA (2009) CARBON CAPTURE AND STORAGE ROADOAP
https://iea.blob.core.windows.net/assets/dc2df219-519c-466a-9a4b-ca4e6de58399/CCS_roadmap_foldout.pdf

Liliya Satalkina and Gerald Steiner (2020), Digital Entrepreneurship and its Role in Innovation Systems: A Systematic Literature Review as a Basis for Future Research Avenues for Sustainable Transitions, Sustainability, 1 April 2020

Mansouri, Noura (2013) Carbon Management for Sustainable Development: An examination of potential transition paths for the Saudi Arabian ‘national system of innovation’ towards a cleaner energy economy, Queen Mary University of London, Oct. 31, 2013. Available [Online]:
http://qmro.qmul.ac.uk/xmlui/handle/123456789/8575