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King Abdullah Petroleum Studies and Research Center

Achieving Climate Goals by Closing the Loop in a Circular Carbon Economy

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Key points

- The concept of a circular carbon economy offers a new way of approaching climate goals that implicitly values all options and encourages all efforts to mitigate carbon accumulation in the atmosphere.

- The circular carbon economy differs from the concept of a circular economy in that it focuses exclusively on carbon and energy flows. The 'four Rs' (reduce, reuse, recycle and remove) of the circular carbon economy serve as categories of mitigation options, whereas the 'three Rs' (minus 'remove') of the circular economy are principles to govern the behavior of firms and households.

- The four Rs of the circular carbon economy comprise:

    1. Reduce: energy efficiency, non-biomass renewables, and nuclear power

    2. Reuse: carbon capture and utilization

    3. Recycle: natural sinks and bio-energy

    4. Remove: carbon capture and storage (CCS), direct air capture, and natural sinks

- The concept of a circular carbon economy can further the understanding of system dynamics and interlinkages between mitigation options. For example, increased energy efficiency results in less need for all other parts of the carbon management system. More direct air capture means more direct emissions of fossil fuels are possible while still meeting climate goals. More carbon utilization lessens the need for carbon storage, and so on.

- This systems approach also reveals possible choke points in reaching climate stabilization. For example, achieving climate goals will be difficult without CCS technology. Ensuring that technologies are available, mature, and cost-effective in each part of the circular carbon economy is critical to achieving climate goals at a reasonable cost.

- One of the most cost-effective ways to encourage investment in activities in the circular carbon economy is through emissions trading schemes, which can be implemented at the domestic and international levels. Trading schemes foster cooperation between different parts of the carbon cycle.

- Without such a trading scheme to provide incentives, private firms are unlikely to willingly undertake mitigation activities at scale.

Introduction

On October 30, the Saudi Minister of Energy, Prince Abdulaziz bin Salman, announced at the Foreign Investment Initiative that "the Kingdom of Saudi Arabia offers the concept of a circular carbon economy … Such a closed-loop system, much like what happens in nature, will help restore the balance of the carbon cycle." With this bold new vision for addressing climate change, Saudi Arabia has an opportunity to shift the climate debate, both as part of its presidency of the G20 in 2020 and in the wider international community, toward an approach that explicitly includes and encourages all possible climate mitigation options. As important as renewables are, and as much progress as they have made in recent years, few analysts believe that the world can achieve the Paris Agreement's goal of a balance between sources and sinks by 2050 through renewables alone.[1] The global path toward a carbon balance will inevitably include fossil fuels, and their carbon emissions must be managed. The concept of the circular carbon economy, an outgrowth of the idea of the circular economy, is a useful framework for understanding how all carbon mitigation options can be linked together in a system that achieves the climate goals laid out in the Paris Agreement.

Discussion

Circular economy

The circular economy runs counter to the conventional notion of a linear economy as a once-through system of assumed limitless resources and limitless capacity to absorb waste. At its core, the circular economy is about closing the loop on resource use and protecting the environment. The circular economy can include industrial ecology, where one process takes inputs from the waste stream of another process. It can also include eco-design to reduce resource needs by making longer-lasting products, as well as shifting ownership models (e.g., Uber and the sharing economy) to increase the usage of the products made (Murray et al. 2013). The idea of the circular economy can be represented by the three Rs: reduce, reuse, and recycle. The more that demand for products can be reduced, the fewer resources needed. The more that already-manufactured products can be re-used, the more resource-efficient the economy will be. The more products that are recycled at the end of their useful life, the less the need for raw resources and the smaller the waste stream. Implicit in the three Rs is a hierarchy and priority. Effort should first go to reduce, then what cannot be reduced is reused, and finally what remains should be recycled.

Circular carbon economy

While the resource efficiency gains implicit in the conventional notion of a circular economy directly translate to reduced energy consumption, which in turn results in lower carbon emissions, the primary focus of the circular economy has not been climate change. Researchers and policymakers have recently put forward the concept of a circular carbon economy, which exclusively focuses on the energy/carbon flow through the economy. Its explicit purpose is to manage carbon emissions.

[1]Much debate within the UNFCCC process has been around the terms 'net zero' and 'carbon neutrality'.
In a nod to the language in the Paris Agreement – "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases" – this paper will use the term 'carbon balance' as an alternative to 'carbon neutrality' and 'net zero'.

Rather than focusing solely on reducing or avoiding the amount of carbon that enters the system, the circular carbon economy recognizes the need for a range of carbon mitigation options. One of the circular carbon economy's organizing principles, borrowed from the concept of the circular economy, is the 'three Rs' of reduce, reuse, and recycle, but the circular carbon economy adds a fourth R for 'remove.' These four Rs form the basis for carbon management in a circular carbon economy. The hierarchy of the Rs is nominally the same as in the circular economy, though cost is the ultimate factor in deploying carbon management options. All cost-effective options to reduce emissions entering the system should be pursued.

The following textbox describes each of the four Rs – reduce, reuse, recycle and remove – in the circular carbon economy and the technologies that fall within each.

The four Rs of the circular carbon economy

Note that the icons and bolded terms relate directly to Figure 1, which visually represents the circular carbon economy.

Reduce

'Reduce' represents all of the carbon mitigation options that reduce the amount of carbon entering the system. **Energy efficiency**, both on the supply and demand side, reduces energy consumption and the associated carbon. Similarly, energy supply options that do not emit carbon, such as **non-biomass renewables** and **nuclear power**, also reduce the flow of carbon into the system, though they can indirectly result in carbon emissions during their manufacture, construction, and installation.

Reuse

In the context of the circular carbon economy, 'reuse' refers to **capturing** and using carbon as an input to a chemical or industrial process that converts the carbon to another useful feedstock for industry. **Carbon utilization** fits squarely within the tradition of industrial ecology by 'metabolizing' carbon from a waste to a valuable input. For example, the Saudi Arabian Basic Industries Corporation (SABIC) utilizes its own carbon dioxide (CO_2) waste in the world's largest carbon capture and utilization plant. The plant converts 0.5 million tonnes of CO_2 annually into valuable products such as fertilizers and methanol (Smeets 2019). Researchers are actively developing carbon-to-fuel technology.

Recycle

'Recycle' represents the natural carbon cycle, in which **natural sinks** (e.g., plants, soil and oceans) draw carbon from the atmosphere and then release it again through decomposition and combustion. The carbon is effectively recycled, and the bio-energy subsystem can be considered carbon neutral, as long as an equal amount of biomass grows to replace what is harvested as bio-feedstock (e.g., wood, fuel crops, algae, etc.) for **bio-energy**.

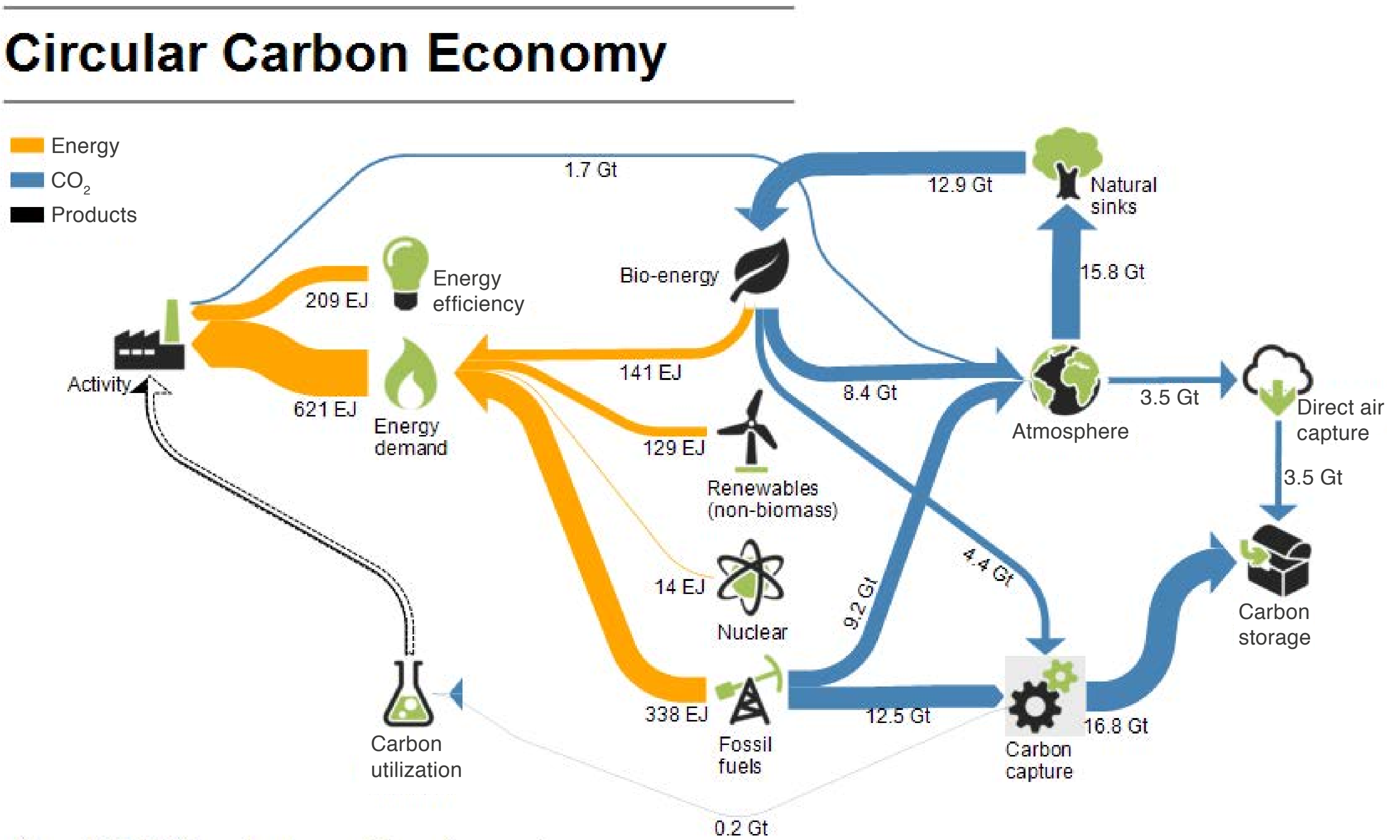
Remove

The final 'R' of the circular carbon economy represents the removal of carbon from the system. **Captured carbon** can be either converted to feedstock, as discussed above in 'reuse,' or removed by **storing** it geologically or chemically. Carbon can be captured directly from industrial processes and points of combustion, but it can also be captured directly from the air with **direct air capture**. Carbon captured from the combustion of bio-energy results in net negative carbon emissions within the **bio-energy** subsystem. Land can also be managed in such a way that it can become a net **natural sink** for atmospheric carbon. Natural sinks, bio-energy CCS and direct air capture can close the loop on emissions elsewhere that may be too difficult or too expensive to capture directly, such as aviation emissions.

The circular carbon economy is a useful construct for understanding how the various carbon reduction options fit together in a system. It reveals how applying more or less of one option requires less or more of another in order to ultimately reach a carbon balance.

Figure 1, below, shows how a global circular carbon economy can be represented as a system of energy and carbon flows, with the arrow sizes representing the magnitude of these flows. The figure is abstracted at a high level as a way to represent the fundamental nature of the system in a simplified view, rather than trying to represent all the possible complex connections that exist in reality. Energy (orange) flows from primary energy sources into energy demand, which is offset by energy efficiency and demand reduction, which in turn flows into activity. Carbon (blue) flows out of bio-energy and fossil fuels to carbon capture and utilization/storage, the atmosphere and direct air capture, or natural sinks and back to bio-energy.

Figure 1. High fossil fuel use in a 1.5°C scenario for 2050.



Sources: TERI 1.5D low carbon transportation policy scenario;
International Energy Agency; KAPSARC analysis.

Figure 1 utilizes a framework based on The Energy and Resources Institute's (TERI's) scenario of meeting the Paris Agreement's goal to limit the average global temperature to 1.5 degrees Celsius (°C) above pre-industrial levels (Zhang, Fujimori, and Hanaoka 2018). The scenario illustrates the possibility of a relatively high level of fossil fuel usage in 2050 that still meets the 1.5°C climate goal. Different assumptions about technology at any point in the system would result in different carbon flows. For example, wide-scale adoption of net-zero energy consuming buildings would reduce the need for energy demand and the flow of carbon into the system. Such buildings combine climate-appropriate design with energy-efficient and smart end-use technologies, alongside on-site or building-integrated solar photovoltaic (PV) generation and solar thermal heat. Higher penetration of renewables and nuclear power would also reduce the need for fossil fuels and reduce the amount of carbon entering the system. Every tonne of carbon not entering the system is a tonne that does not need to be managed.

The carbon utilization value (0.2 gigatonnes [Gt] of CO_2) in Figure 1 comes from a recent estimate of carbon utilization by the International Energy Agency (IEA 2019). This flow of carbon for 'reuse' is low compared with the other carbon flows in the system, but advances in technology could change this outlook. Shell estimates that 5.7 Gt of CO_2 could plausibly be embedded in materials through carbon utilization (Shell 2016). If these estimates turn out to be accurate, carbon utilization could play a significant role in reaching a carbon balance. If, as shown in Figure 1, 5.7 Gt of CO_2 could be utilized, the line running from carbon capture to carbon utilization would grow substantially from its current value of 0.2 Gt of CO_2. In this case, only 11.1 Gt of CO_2 would need to be stored rather than the 16.8 Gt in the original scenario. The economic gains from creating value with 5.7 Gt of CO_2 could be substantial compared with the economic cost of paying to store them.

Recycling carbon via natural sinks and bio-energy is also important. Bio-energy crops can be a much-needed source of income in rural areas. Well-managed land resources can also be a source of low-cost carbon storage. Combining bio-energy with CCS or carbon utilization may prove to be a particularly potent carbon management tool, as carbon removed from the bio-energy system produces net positive carbon reductions from the atmosphere.

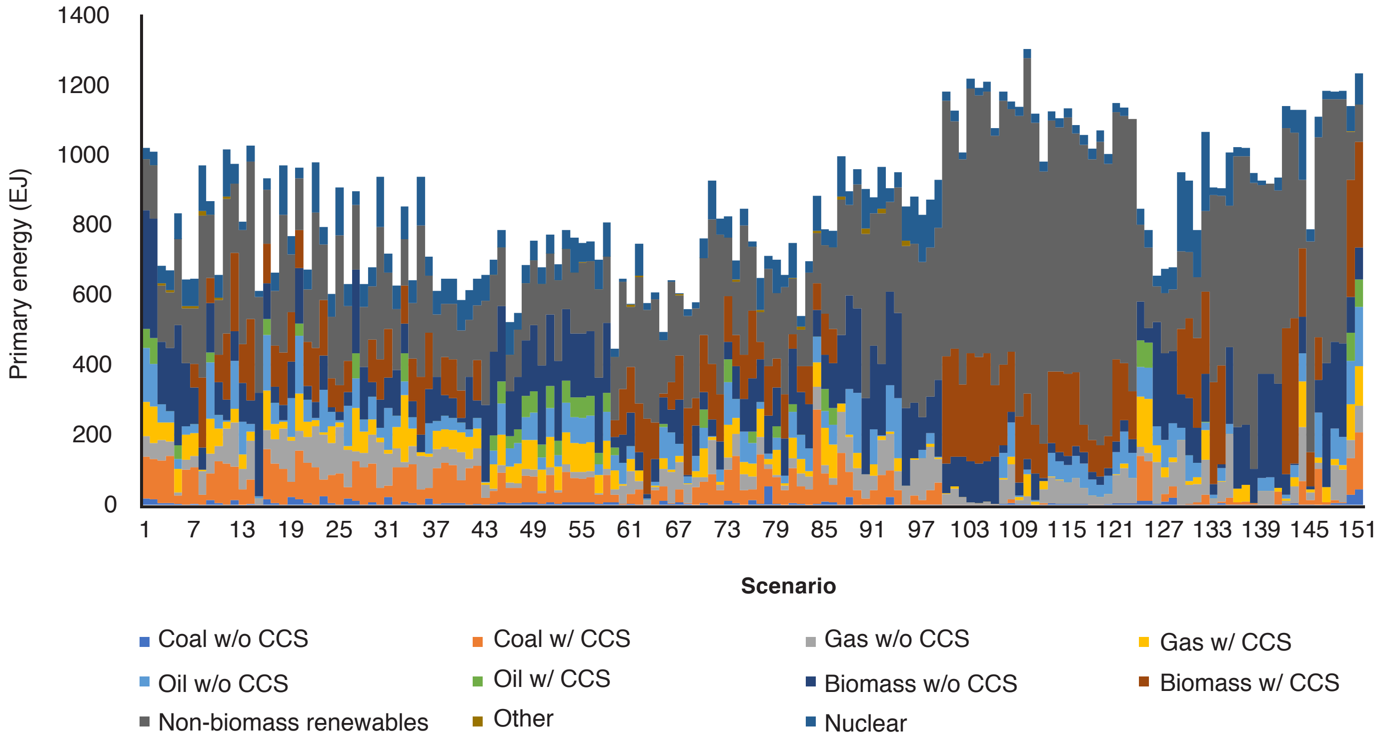
Although 'remove' is the last step in the hierarchy of the circular carbon economy, it is by no means the least important, as it is the final option in managing carbon to reach a carbon balance. Ideally, carbon would be entirely managed within reduce, reuse, and recycle. However, if these fall short, carbon removal could help to achieve the Paris Agreement climate goals. In this sense, carbon removal is the safety net in the path toward climate stabilization. In Figure 1, the amount of carbon removed using direct air capture (3.5 Gt CO_2) is calculated by KAPSARC to equal the carbon emissions remaining in the atmosphere that would need to be captured to reach a carbon balance in 2050. More direct air capture would mean less effort is needed elsewhere in the system. On the other hand, if direct air capture technology fails to reach maturity, the burden on the rest of the system would be greater.

Primary energy mix

If the world ultimately evolves in a way that meets the Paris Agreement's climate stabilization goals, all of the elements (and perhaps some not yet conceived) visualized in Figure 1 will play a role. How much each of the four Rs – reduce, reuse, recycle and remove – contributes depends on many factors, such as the costs and performance of technologies, resource availability based on geography and geology, public acceptance, and enabling policies.

Figure 2 shows the 2050 primary energy mix in exajoules (EJ) for scenarios that result in a 1.5°C to 2°C increase in the average global temperature above pre-industrial levels in 2100. It is taken from the Integrated Assessment Modeling Consortium's (IAMC's) scenario explorer (Huppmann et al. 2018), a database of scenarios that underpins the Intergovernmental Panel on Climate Change's "Special Report on Global Warming of 1.5°C" (SR15) (Rogelj et al. 2018).

Figure 2. Primary energy mix in 2050 for scenarios in IAMC 1.5°C scenario explorer, resulting in a 1.5°C to 2°C increase in the average global temperature above pre-industrial levels in 2100.



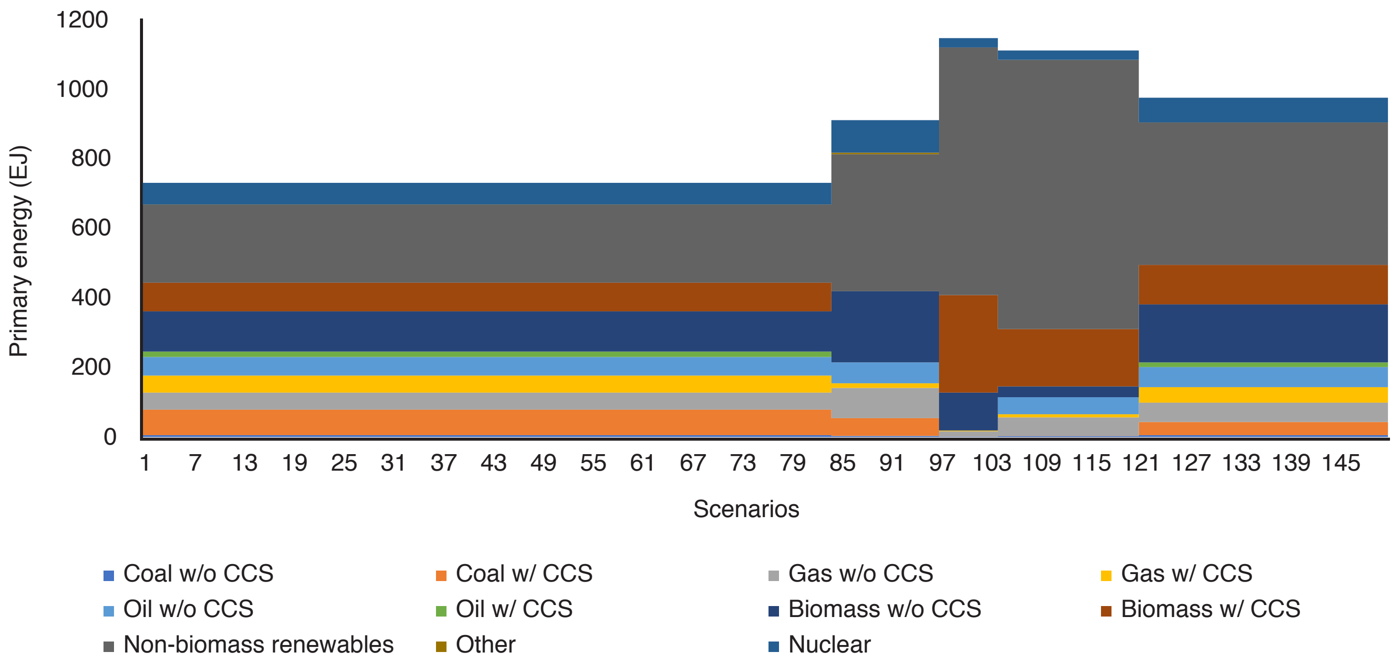
Source: Integrated Assessment Modeling Consortium (IAMC).

The number of scenarios involved makes a visual representation like Figure 2 somewhat difficult to decipher. A cluster analysis that groups or clusters similar scenarios together is helpful in understanding scenario types. Figure 3 shows the results of a clustering analysis using Matlab in which four main clusters containing at least four scenarios each were identified, plus a fifth aggregate cluster that combines several clusters with three or fewer scenarios. These scenarios were grouped by clusters, and their primary energy values were averaged within each of the five clusters. Most of the scenarios fall into a cluster that is well-balanced between all primary energy options, including energy efficiency and demand reduction (scenarios 1 – 84 in Figure 3).

As expected, renewables, both biomass and non-biomass, play a significant role in any pathway toward a carbon balance and climate stabilization. Perhaps less expected is that fossil fuels also play a significant role in most scenarios analyzed. Four out of the five clusters, representing 95% of scenarios, show substantial fossil fuels in the energy mix. Oil, for example, contributes between 50 EJ and 72 EJ of primary energy in 2050 for those four scenario clusters.

Every scenario in the IAMC scenario explorer that results in a 1.5°C to 2°C increase in the average global temperature above pre-industrial levels in 2100 has at least some deployment of CCS technology by 2050. The average share of primary energy with CCS – combining fossil and biomass CCS – across the scenarios is 24%. Eighty percent of the scenarios analyzed result in at least 10% of primary energy with CCS.

Figure 3. Average primary energy mix values in 2050 of six clusters of scenarios in IAMC 1.5°C scenario explorer, resulting in a 1.5°C to 2°C increase in the average global temperature above pre-industrial levels in 2100.

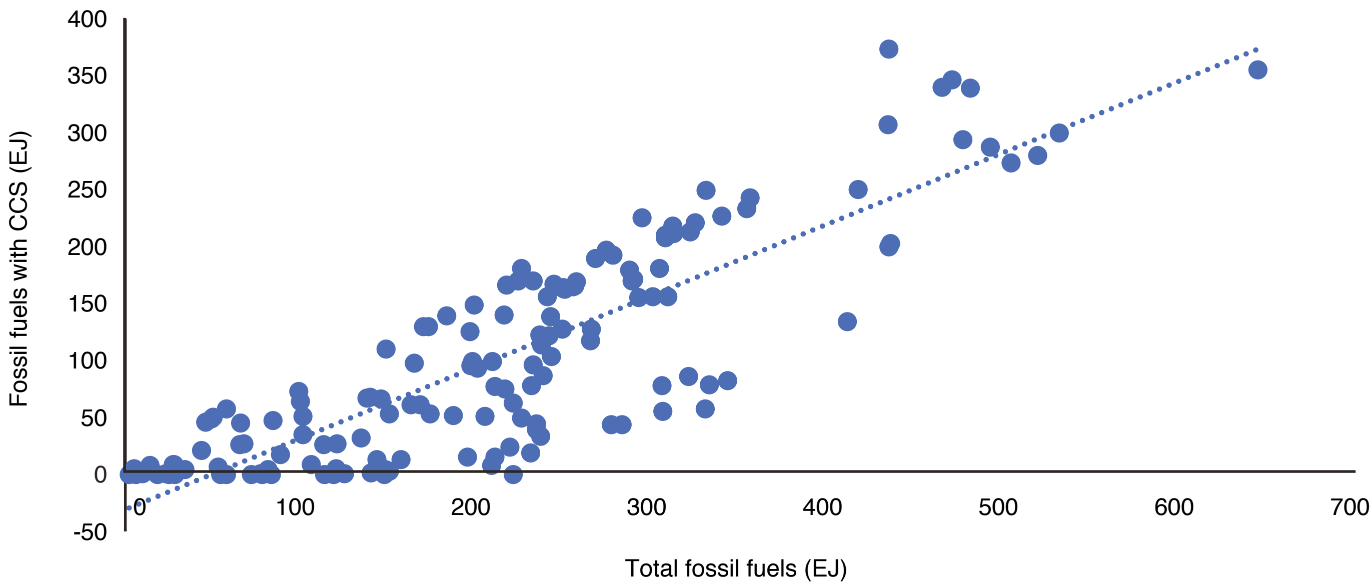


Sources: Integrated Assessment Modeling Consortium (IAMC) and KAPSARC analysis.

The clear relationship between total fossil fuels in the primary energy mix and fossil fuels with CCS shows that CCS enables higher use of fossil fuels. See Figure 4. Based on what we understand today, these scenarios suggest that climate stabilization without CCS is very unlikely. Yet, CCS technology is not being deployed at scale.

Carbon-based fuels are likely to play a significant role in the future global energy mix. As important as it is to reduce carbon by deploying energy efficiency measures, renewables and nuclear power, it is also critical to consider a wider range of options on how we can reuse, recycle, and remove the carbon that will continue to be in the system.

Figure 4. Relationship between total fossil fuels and fossil fuels with CCS in 2050 for scenarios in IAMC 1.5°C scenario explorer, resulting in a 1.5°C to 2°C increase in the average global temperature above pre-industrial levels in 2100.



Source: Integrated Assessment Modeling Consortium (IAMC).

Enabling policies

While the circular carbon economy provides a useful framework for achieving a carbon balance, this is unlikely to happen naturally and organically. Without enabling policies, there will be little incentive to develop and deploy technology. The process of closing the loop in the circular carbon economy will be on-going and evolving over the coming decades. Ultimately, economics and social appropriateness will determine how large a role in the circular carbon economy each element will play. Policies that move investment toward closing the loop on resource use by providing incentives for technologies in all four Rs – reduce, reuse, recycle and remove – promise the greatest likelihood of success. These policies include public-private research and development funding consortiums spanning countries and companies, finance subsidies to offset the risks of unproven technologies, tax incentives, direct capital investment subsidies, results-based financing (e.g., money for each unit of energy produced), among others (Grubb 2004, World Bank Group and Frankfurt School of Finance and Management 2017).

Geographic diversity and comparative advantage mean that companies and countries will gain from cooperating in the effort to close the loop. The diversity of endowments and circumstances among countries offers significant opportunities for efficiency gains from trade. Carbon trading offers a way to close the loop without unduly burdening companies and countries that do not have a diversity of options to reduce, reuse, recycle and remove carbon.[2] At the same time, carbon trading provides an incentive for companies and countries with an abundance of the four-R options to do more than they need to make their carbon emissions balanced. For example, trading gives countries without carbon storage capacity the option to continue to use fossil fuels by paying other companies and countries with storage capacity to store more carbon.

Trading mechanisms can be used in other ways to help technologies reach commercialization. For example, KAPSARC has developed an idea for an innovative mechanism within Article 6 of the Paris Agreement that creates a carbon storage unit (CSU), which is separate from any sort of carbon reduction unit derived from a broader carbon trading system. Pricing carbon removal provides an additional incentive to commercialize storage technology and also facilitates a move away from linear thinking about solely reducing emissions toward circular thinking where both emissions and removals are priced. A recent paper by KAPSARC researchers set out some useful policy building blocks for such an approach (Zakkour and Heidug 2019).

Conclusion

The circular carbon economy provides a useful way to understand a broad range of climate change mitigation options from a systems approach. It reveals the degree to which each element within the system may be able to contribute to the solution, relative to its cost-effectiveness and availability. The circular carbon economy also reveals how choke points in any one of the Rs – reduce, reuse, recycle and remove – can make the carbon flows in the system unmanageable if a key technology is unavailable. For example, climate stabilization is unlikely without CCS technology. Potential choke points, in turn, inform priorities for technology policy. While companies like SABIC are developing technologies for carbon utilization, this is on a very small scale. A significantly larger role for carbon utilization would require substantially more attention and incentives from the policy and business communities. Finally, the circular carbon economy also underscores the value that a carbon trading system has in being able to foster cooperation among companies and countries, close loops through price signals and economic incentives, and drive down overall costs.

[2]Carbon accounting frameworks must underpin both carbon reduction trading and carbon storage trading systems. The veracity of a tonne of carbon reduced or a tonne of carbon stored is essential for trust in any trading system. Rules must balance the streamlining of accounting requirements so as not to discourage activity while maintaining sufficient trust in the framework.

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