**Solution to Energy Crisis**

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April 8, 2023

Sector coupling refers to the integration of different sectors, such as the electricity, heating, and transportation sectors, to achieve greater efficiency, grid stability/flexibility, and sustainability in energy systems. Traditionally, these sectors have operated independently, with separate infrastructure, technologies, and regulations. However, as the world transitions to a low-carbon economy and seeks to reduce greenhouse gas emissions, there is a growing recognition that greater integration and coordination between sectors are necessary. For example, sector coupling can involve using excess renewable electricity to power electric vehicles or heat houses, rather than relying on fossil fuels. It can also involve using waste heat from industrial processes to generate electricity or provide heating and cooling for buildings.

The economics of sector coupling, also known as “P2X”, is a complex topic that involves multiple parameters affecting the operation and business models of these technologies. The basic idea behind sector coupling is to convert excess available electricity into another energy carrier which is required or can be more easily stored than electricity. This can be done through power-to-gas (P2G), which is the process to use renewable energy to produce green hydrogen through electrolysis, through power-to-liquids (P2L), which is a process to use excess electricity to generate methanol or synthetic diesel, likewise, power-to-vehicles (P2V) is a process to use excess electricity for the transportation sector to charge electric vehicles (EVs), power up the mass transit and convert railway to the electric rail system. One of the main economic benefits of sector coupling is its potential to avoid curtailing renewable energy sources (RES) in specific hours when production exceeds demand, by exploiting available power at no cost. In some cases, sector coupling can be used to convert excess electricity into another form of energy that can be sold on the market, generating additional revenue streams. In the case of Pakistan, power coupling can be used as a potential solution to solve the capacity payments and potential of excess electricity supply due to increasing rooftop solar and commercial variable renewable energy (VRE) projects. This article explores the advantage and prospects of various types of sector coupling.

As the world transitions to a low-carbon economy and seeks to reduce greenhouse gas emissions, there is a growing recognition of greater integration and coordination between sectors.

Firstly, the Power-to-gas (P2G) has several potential benefits, including its ability to store excess electricity for long periods, convert electricity into hydrogen gas for various uses, and avoid curtailing renewable energy sources. This makes P2G an effective solution for seasonal storage, which is important for balancing supply and demand in power systems with high shares of renewable energy sources. Another benefit of P2G is its ability to convert excess electricity into hydrogen gas, which can be used as fuel in various sectors such as transportation or heating. Hydrogen gas can also be used as a feedstock for industrial processes such as chemical production. P2G can also help avoid curtailing renewable energy sources when production exceeds demand. By converting excess electricity into hydrogen gas, P2G provides an additional revenue stream for renewable energy producers and helps reduce greenhouse gas emissions by avoiding the need to curtail renewable energy production. Overall, P2G has the potential to provide additional flexibility options for power systems and help ensure a continuous matching between demand and supply. However, there are also challenges associated with implementing P2G, such as low roundtrip efficiency due to losses during conversion and storage, and technical and economic barriers to integrating different energy sectors. P2G for the case of Pakistan can be effective in terms of economic benefits like import substitution of fuels, stabilization of the electric grid, and incentivization of VRE. The environmental benefits include an increase in decarbonization and GHG emissions.

The second type of sector coupling is Power-to-liquids (P2L) which also has several potential benefits. One of them is the P2G, which is its ability to store excess electricity for long periods. This also makes P2L an effective solution for the seasonal storage of electricity. Another benefit of P2L is its ability to convert excess electricity into liquid fuels such as methanol or synthetic diesel. These fuels can be used in various sectors such as transportation or heating and can help reduce greenhouse gas emissions by replacing fossil-based fuels. P2L can also help avoid curtailing renewable energy sources when production exceeds demand. Likewise, by converting excess electricity into liquid fuels, P2L just like P2G provides additional revenue earning for renewable energy producers. Overall, P2L has the potential to provide additional flexibility options for power systems and help ensure a continuous matching between demand and supply.

Power-to-vehicles (P2V) has several potential benefits. One of the main benefits is its ability to shift the additional power demand from peak hours to off-peak hours. This can help improve power network operation by reducing the strain on the grid during peak hours. Another benefit of P2V is its ability to provide a flexible and efficient way of storing excess electricity. Electric vehicles (EVs) can be charged during periods of low demand and discharged during periods of high demand, providing a valuable storage option for renewable energy sources. P2V can also help reduce greenhouse gas emissions by replacing fossil-fueled vehicles with EVs. By using excess electricity to charge EVs, P2V provides an additional revenue stream for renewable energy producers and helps reduce greenhouse gas emissions by avoiding the need for fossil fuels. Overall, P2V has the potential to provide additional flexibility options for power systems and help ensure a continuous matching between demand and supply. However, there are also challenges associated with implementing P2V, such as the need for time-of-use tariffs or a third-party player that directly controls the charging process based on specific requests from users. Additionally, customers should be able to set some charging targets based on their needs while keeping some room for unpredictable early needs to use their cars.

Sector coupling is an emerging solution that can provide additional flexibility options for power systems compared to traditional technologies for providing energy balance services. Traditional technologies include electricity storage, transmission networks, fossil-based dispatched energy, and demand response and/or management programs. While these technologies can help balance supply and demand in power systems, they may not be sufficient to ensure a continuous matching between demand and supply required to operate power grids. Sector coupling involves converting excess electricity into another energy carrier that can be stored for later use or used in other sectors such as transportation or heating. This can be done through power-to-gas (P2G), power-to-liquids (P2L), or other conversion processes. The converted energy carrier can then be used to balance supply and demand in the power system. One potential advantage of sector coupling over traditional technologies is its long-term storage capabilities. P2G or P2L can be used to store excess electricity for days or even months when needed. Additionally, sector coupling can help avoid curtailing renewable energy sources when production exceeds demand. However, there are also challenges associated with implementing sector coupling. The transformation process generally has low roundtrip efficiency due to losses during conversion and storage. Additionally, there may be technical and economic barriers to integrating different energy sectors. Overall, while both traditional technologies and sector coupling have their advantages and disadvantages, sector coupling could provide additional flexibility options for power systems and help ensure a continuous matching between demand and supply.

However, there are also political and economic challenges associated with implementing sector coupling. The transformation process generally has low roundtrip efficiency due to losses during conversion and storage. Additionally, there may be technical and economic barriers to integrating different energy sectors. For example, the infrastructure required for P2G or P2L may not be available in all regions. The economics of sector coupling also depends on factors such as capital expenditures (CAPEX), operational expenditures (OPEX), and the number of annual operational hours required for each application. For many applications, operational hours remain a critical issue due to the high prevalence of CAPEX over OPEX. Moreover, the political dimension of retiring fossil fuels, particularly coal is the major challenge. Overall, while sector coupling has the potential to provide additional flexibility options for power systems and help ensure a continuous matching between demand and supply, further research is needed to fully understand its potential benefits and challenges in different contexts. Policymakers should consider sector coupling as part of a broader strategy to decarbonize the energy system and increase its resilience.

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