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Policy as a catalyst in shaping mobility sector transition for developing countries

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Abstract

This paper presents a modified technology innovation system (MTIS) approach applicable to developing countries. Evidence collected over three decades 1992–2022, shows how policy plays a catalytic role in managing multidimensional low-emission mobility transitions in developing countries such as Pakistan. This paper follows policy and the network of actors, institutions and technology in compressed natural gas (CNG)-based mobility transition in Pakistan. Event-based analysis helped in mapping the development of respective functions, which is later validated by expert consultation. Between 1992 and 2002, deliberate policies for early adoption were put in place to strategically manage a desired transition path. This involved providing guidance and knowledge diffusion through demonstration to increase entrepreneurial activities and market formation. The accelerated diffusion during the take-off period during 2003–2012 was due to the entry of private businesses and multinational companies speeding up entrepreneurial activity and market-formation functions. However, there was a clear policy-driven roll-back and deceleration during 2013–2022. Policies designed to ban CNG licence issuance and renewal resulted in detrimental effects on market and entrepreneurial activities. Social struggle arising from roll-back is now caught in a dilemma if policy innovation will lead to re-emergence of CNG or will support a new transition cycle through the emergence and adoption of electric vehicles in the mobility space of Pakistan. Rapid shifts in the global landscape of innovation and market conditions are creating a need for the effective handling of cascading transition management in developing countries. This paper outlines how lessons learnt from Pakistan's CNG-MTIS can help in shaping electric vehicle MTIS not only in Pakistan, but also in many other developing countries. It is recommended that, in order to manage cascading transitions in developing countries, new approaches and strategies for reskilling, retraining and redirecting finances to address stranded assets be employed. This can mitigate the negative impacts on those affected by transformation and create an environment for a just transition that restores trust in policy and accelerates transformative change.

1. Introduction

Global assessments have highlighted the need for transformative changes to decarbonize economic activities everywhere, including the transport sector (SLOCAT 2021, IPCC 2022, UNEP 2022). Roy and Some (2022) argued that complete avoidance of all mobility is impractical, as it is a 'service' that connects an interdependent human society by bridging the point of demand to the point of supply. Therefore, it is essential to understand how this 'unavoidable mobility' should be sustainably managed. Understanding how transition is shaped by national policies, which includes national specificities, such as stages of development, changing natural resource endowments, economic wealth, as well as the involvement

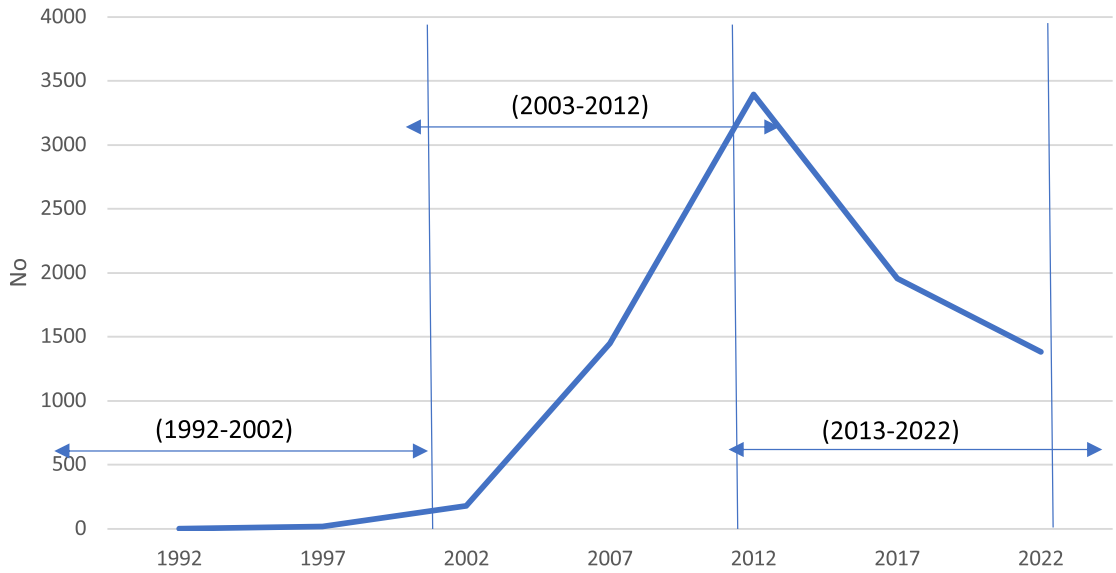

Figure 1. Number of CNG filling stations during 1992–2022. Drawn by authors using data from various sources (oil and gas regulatory authority (OGRA, Pakistan) data for active stations and (Khan and Yasmin 2014)).

of and coordination among different actors (Dubash *et al* 2022, IPCC 2022), helps in identifying and gauging the drivers, opportunities, costs and challenges of such transitions for scaling up and replication. In developing regions, transport-related emissions are rising faster and are expected to rise further in the future. This trajectory contrasts with the situation in Europe and North America, where growth in passenger and freight transport is comparatively more moderate (Jaramillo *et al* 2022). A frequently asked question is, among other social actors, how governments can help in reducing transport energy demand (Jaramillo *et al* 2022). It is important to understand how policy can play an important role in managing multidimensional strategic transformative change in increasing the share of electromobility and low-carbon mobility options. A policy-driven transition towards green technology has occurred in the Netherlands (Suurs *et al* 2010). Understanding the issue from a developing country perspective can provide new, deeper insights for accelerating transition (Butt and Singh 2023). We consider the case of Pakistan (SM1.1) in this paper.

In Pakistan, since 1992 there has been a clear policy-driven process for creating a move away from oil to compressed natural gas (CNG)-based cheap, domestically available cleaner fuel for passenger transport, as reflected in the number of CNG filling stations (figure 1) and the carbon intensity of the sector (figure 2).

This empirical evidence helped us in deciding the stages of the transition, which we discuss in detail in section 2.

From this perspective, this paper tries to answer:

- How government policy can play a catalytic role in deciding technology choice and strategically managing multidimensional transition in mobility service provision through low-carbon fuel-based technology in a developing country context using a case study of Pakistan covering the period 1992–2022.
- How do the various dimensions in the technology innovation system (TIS) framework work in shaping the transition path for developing countries?
- What are the roles of various social actors through various phases ?

This paper contributes significantly on multiple fronts. Firstly, it provides an argument for why the application of the standard TIS framework for developing country context needs to be modified. Secondly, the paper throws light on how policy frameworks can play a critical role in developing countries by deciding on early adopters' roles and thus creating an enabling environment for market development, thereby accelerating the participation of various social actors in infrastructure expansion and technology diffusion. Third, it delineates actions by actors and essential functions crucial for strategically managing the multidimensional transition to low carbon growth. Fourth, the study points out how, for developing countries, there can be overlapping transitions due to internal and external factors and how policy can become critical in providing directionality in transition. Finally, the paper introduces a methodological improvement in the comparative analysis of transition stages by estimating the area under the polygons.

Section 2 outlines the analytical method used in this paper. Section 3 provides the detailed results and section 4 includes a discussion of Pakistan's CNG modified technology innovation system (MTIS), highlighting the role of actors, institutions and

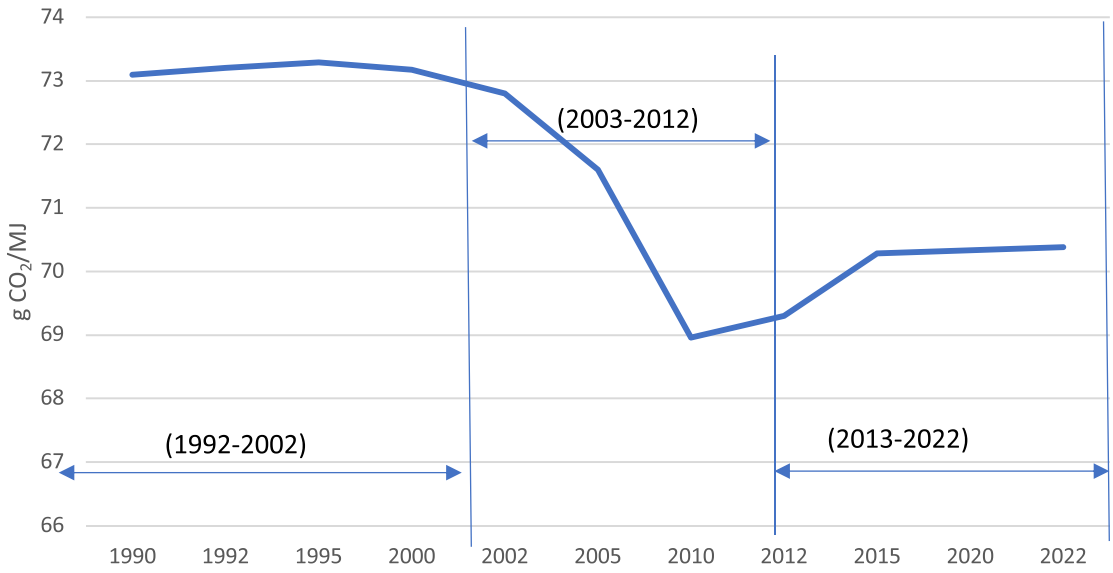

Figure 2. Carbon intensity of road transport in Pakistan during 1992–2022. Drawn by authors using data from the IEA database.

technology through the development of seven functions of the TIS at three stages (decision for early adoption, take-off, roll-back) for CNG-based transport transition in Pakistan, along with a comparison with the Netherlands' automotive natural gas (ANG) TIS. Concluding remarks are presented in section 5.

2. Method: application of the TIS framework

To understand the policies, interventions and actors involved in the CNG-based mobility sector transition in Pakistan, we adopt a multidimensional transition framework (Bergek *et al* 2008, Suurs *et al* 2010, Tigabu *et al* 2015b, Tigabu 2017, Esmailzadeh *et al* 2020) by applying the TIS approach (Jacobsson and Johnson 2000, Hekkert *et al* 2007, Suurs and Hekkert 2009, Wieczorek 2014, Markard 2018, Roy *et al* 2018, Höhne and Roy 2021). The TIS focuses on the roles played by diverse actors, interconnected networks and institutions, coupled with a holistic approach, and has the capacity to offer universally applicable insights (Tigabu *et al* 2015a, 2015b, Tigabu 2017). The TIS methodology is considered as an important framework within the domain of transition studies, primarily due to two reasons: first, the rise of innovative technologies stands at the core of socio-technical transitions. Numerous emerging technologies are constantly challenging conventional technologies, organizational norms and institutional setups. Second, a plethora of contemporary empirical studies utilizing the TIS approach have scrutinized technologies, such as renewable energies and alternative vehicle technologies, that are intrinsically linked to sustainability goals. Literature on the TIS approach has focussed on the intricate micro-level mechanisms underpinning the formation of a TIS. This particularly involves establishing connections with the actor-centred paradigms prevalent in the realm of policy analysis (Sabatier 2014). A frequent criticism aimed at the TIS framework revolves around its limited perspective, insufficient consideration of contextual variables, internal focus and neglect of the broader contextual dynamics of the innovation system (Markard and Truffer 2008). Specifically, there have been assertions that the TIS methodology could potentially overlook the emergence of supplementary or rival technologies within its contextual sphere, as well as the intricate dynamics of competing for supremacy against established technologies. Being aware of these criticisms and given the knowledge of realities in developing countries, particularly Pakistan, we contextualized the method and have classified the barriers into two categories, internal to TIS function—related to actors, institutions and market related to technology—and external to the TIS—e.g. any new emerging competing TIS, which is electromobility (EV-TIS) in our study. We have given special attention to the fact that developing countries require technology transfer rather than initiating an innovation process (Pueyo and Linares 2012). Developing countries in their updated nationally determined contributions (NDCs), mention common challenges and demand a heightened focus on technology transfer mechanisms (e.g. Government of Bangladesh 2021, Government of India 2022, Government of Thailand 2022).

Literature in the context of developed countries mentions four transition stages within the function of the TIS, as presented in supplementary material (SM 1.2). In this paper, to capture the developing country specificity, we combine the first two stages: emergence and early adoption. This decision is based

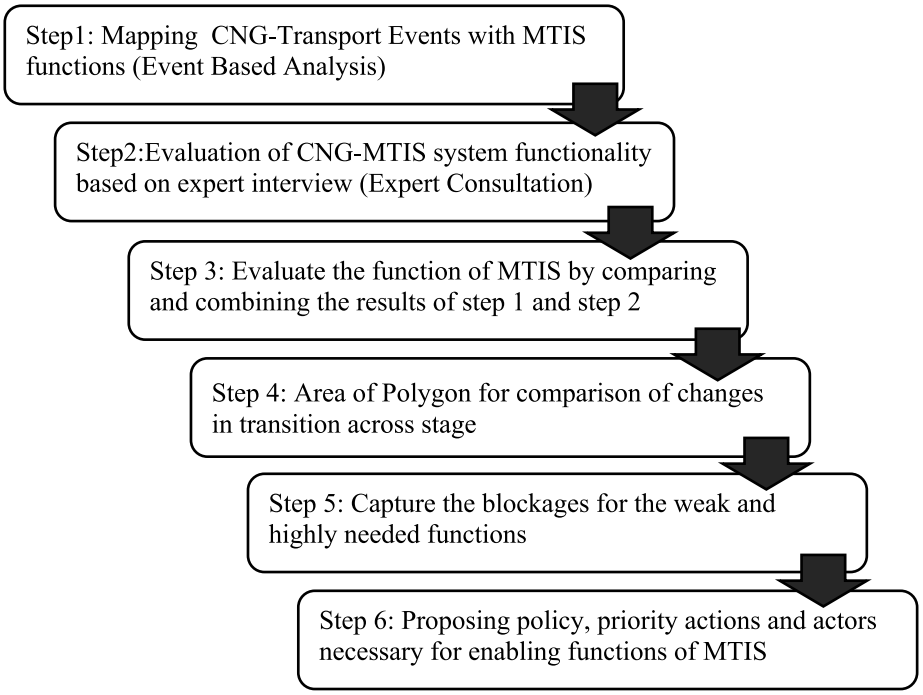

Figure 3. Flow chart of the MTIS methodology.

on the recognition of a fundamental theoretical argument that, due to lack of innovation finance and capacity, developing countries are lagging behind in terms of low carbon technology development (Blanco *et al* 2022). Thus they are 'following' through technology transfer or trade and not 'leading' by innovation. The advantage for developing countries in adopting a follower role in the deployment of low carbon technology is that there is no need to invest significant time and resources in the emergence stage of the technology. By following the established innovation chain, including the critical effort zone, there is no need for extensive trial and error (Hernandez *et al* 2019) to reach maturity and then to find early adopters of the technology. Instead, as a 'follower', a mature low carbon technology can be adopted by skipping the emergence stage. For the follower, the crucial step is to initiate a 'decision for early adoption' of commercial-scale or demonstration-scale technology, thereby taking first-mover advantage among peers and leapfrogging (Mohammed *et al* 2020). In the past, during the introduction and roll-out of clean development mechanism projects for developing countries, China, India and Brazil were able to reap the maximum benefit over their peers in terms of mobilizing projects and fund transfer (Li and Lin 2021) by taking first-mover advantage. This fundamental difference in the roles of developed and developing countries in low carbon innovation dominates the technology transfer argument in multiple international assessments (Ockwell *et al* 2010, Khor 2012, Blanco *et al* 2022) and negotiations. This allows us to modify the TIS by defining and generalizing it for developing countries using 'three' stages of transition instead of the conventional 'four'. The first stage being the 'decision for early adoption' for developing countries – the decade of 1992–2002 for our case study country Pakistan. The second stage is the diffusion stage (hereafter called 'take-off') – the decade of 2003–2012. The decade of 2013–2022 is the 'roll-back' stage. These three stages are reflected very clearly in figures 1 and 2 in section 1. Additionally, by mapping specific decades to different stages, we aim to offer a historical narrative of technological development and the impact of policies in a developing country context. We followed six steps (details are in supplementary material (SM1.2) to assess the CNG-MTIS function, as shown in figure 3.

3. Results

Step-wise results based on event-based analysis and expert consultation are presented in this section. The functional accumulation mentioned in section 2 is utilized to analyse the development of individual functions of the MTIS.

Step 1: Event-based analysis

Figure 4 is a visual representation of the historical development of the seven functions of the MTIS in Pakistan, through three phases: early adoption (1992–2002), take-off (2003–2012) and roll-back (2013–2022). The highest number of events (27) is recorded in the take-off decade (2003–2012) (see SM2 and SM3), which aligns with observations by Khan and Yasmin (2014) that activities in CNG technology space peaked during 2003–2012.

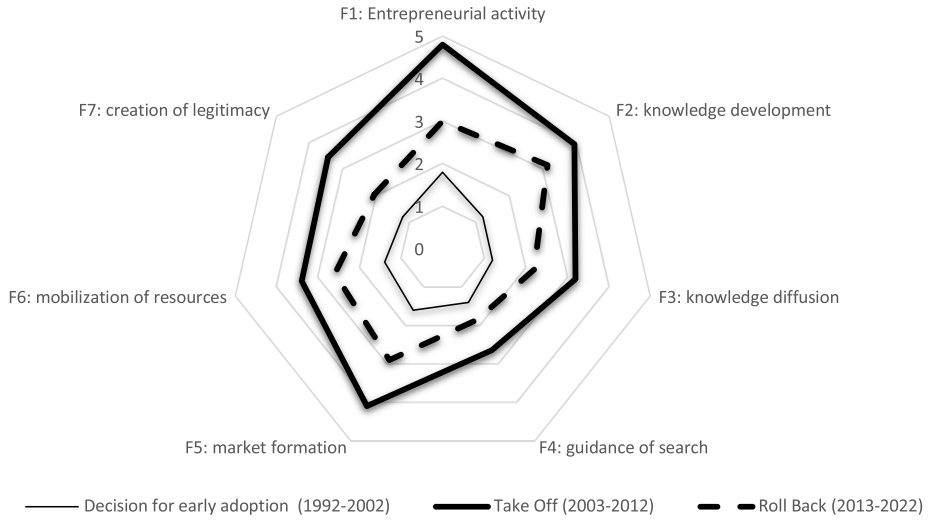

Figure 4. Step 1: evaluation of Pakistan CNG-based transport 1992–2022 MTIS through event-based analysis.

During the 'decision for early adoption' stage (1992–2002), the entrepreneurial and market-formation functions took the lead compared to the others, while the creation of legitimacy, knowledge development and knowledge diffusion functions were the weakest. In the next decade (2003–2012), referred to as the 'take-off' phase, entrepreneurial activity reached its peak. Knowledge development and market-formation functions also improved significantly. The functions of knowledge diffusion, search guidance, mobilization of resources and creation of legitimacy also showed improvement compared to the previous decade, although they remained weaker compared to other functions. The decade 2013–2022, labelled as the 'roll-back' phase, is visibly characterized by the shrinking activities in the CNG-MTIS. This resulted in reductions in the *capability* and *capacity* of the system. Entrepreneurial activity was reduced due to policy roll-backs by the government, such as imposing a ban on issuance/renewal of licences for CNG stations, limiting the production of CNG kits only for export purposes and removal of CNG cylinders in public transport. The exit of relevant actors led to a notable decline in entrepreneurial activity, driven by unfavourable policies. This, in turn, led to a corresponding decrease in the functions of creation of legitimacy, resource mobilization, market formation, and guidance for search and knowledge diffusion, knowledge development has been shrinking at a much slower pace compared to other functions (figure 4).

The comprehensive 30 year policy landscape in Pakistan is summarized in figure 5.

Step 2: Expert consultation

Many actors were associated with CNG's decades-long transition; for instance, private parties, the All Pakistan CNG Association (APCNGA), researchers and a government CNG-specific organization. The experts selected for the consultation in this study are individuals affiliated with the actors involved in CNG technology in Pakistan.. They are from the key institutions of CNG technology, as follows: (1) the Hydrocarbon Development Institute Pakistan (HDIP); (2) the Oil and Gas Regulatory Authority (OGRA) representing the government; (3) the APCNGA representing private parties in CNG businesses; and (4) researchers identified during a review of published literature (SM4 and SM5).

Figure 6 shows that, in the early adoption phase, market formation and mobilization of resources were the most developed, followed by knowledge development, knowledge diffusion and entrepreneurial activity. The creation of legitimacy function was the least developed, according to the experts. In the take-off phase (2003–2012), the experts saw significant growth in all seven TIS functions compared to the decision for the early adoption phase. The market formation and mobilization of resources showed the highest development, followed by the creation of legitimacy and entrepreneurial activity. Experts felt the least-developed function in this decade was knowledge diffusion.

In the roll-back phase (2013–2022), the experts reported a decrease in the development of all seven TIS functions. Entrepreneurial activity, knowledge development, knowledge diffusion, market formation and mobilization of resources functions shrunk beyond the levels observed in the decision for the early adoption phase. The guidance for search and creation of legitimacy functions also decreased compared to the take-off phase, but still managed to survive the decline beyond the decision for early adoption phase.

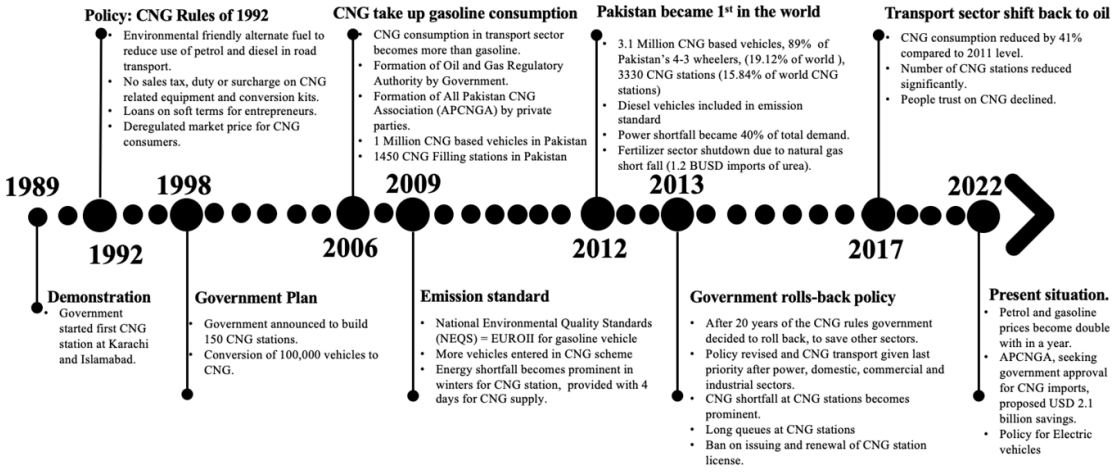

Figure 5. Evolution of the policy landscape around the CNG-based mobility system in Pakistan.

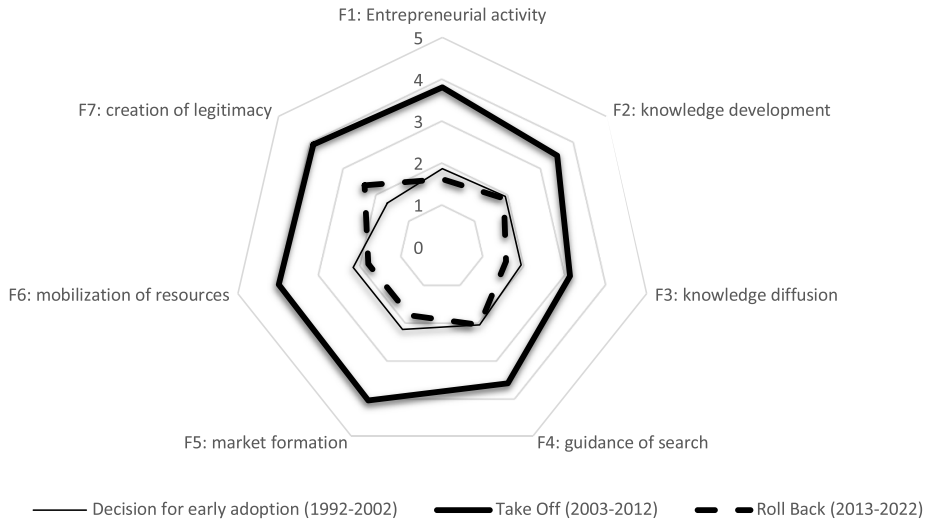

Figure 6. Step 2: evaluation of Pakistan CNG-based transport 1992–2022 TIS through expert consultation.

Step 3: Combining the results of event-based analysis and expert consultation.

When we compare (figure 7) the results from event-based analysis with those from the expert consultation analysis, the main messages are similar, which strengthens the findings from the event-based analysis.

During the decision for early adoption phase, entrepreneurial function and market formation were stronger among other functions due to favourable policies and incentives for new investors in the CNG market. However, the function of legitimacy was found to be the weakest due to the lack of knowledge development and diffusion. The absence of a consistent direction and clear vision on the part of the government also hindered the development of legitimacy. The area of the polygon (for the estimation method, see SM6) was also the smallest, showing that it is trying to gain ground to expand the process.

During the take-off phase, the area of the polygon shows the largest increase in coverage. Entrepreneurial activity was near the highest and near the boundary, with a significant increase in the number of CNG stations, investments and employment in the sector. The functions of knowledge development and market formation also improved due to standardization and training efforts by various organizations. The functions of knowledge diffusion, guidance and search, mobilization of resources, and creation of legitimacy also showed improvement but were still weaker as compared with the other functions.

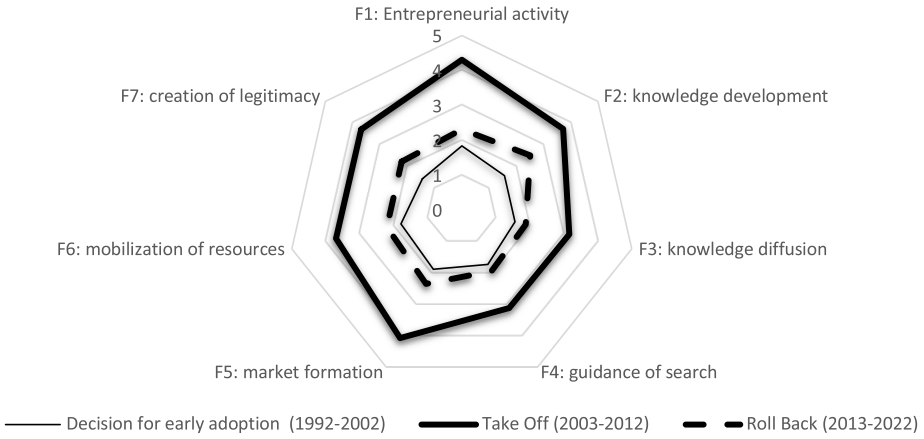

Figure 7. Result of step 3: combination of event-based analysis and expert consultation analysis.

The roll-back phase shows a shrinking coverage with smaller polygon size with a decline in the CNG-MTIS due to withdrawal of favourable policies. This decade showed a decrease in entrepreneurial activity due to a government ban on new licences and renewals for CNG stations, which discouraged new entrants and resulted in the exit of existing actors. The number of CNG stations decreased and the investments in the sector reduced, leading to a shrinkage of the CNG-MTIS compared to the take-off stage, but it did not collapse to a central point or below the decision for the early adopter stage.

The results reveal a consistent pattern in the development of all functions, with a decision for the early adoption stage followed by maturity in the take-off decade and a subsequent shrinkage in the roll-back period, as depicted in figures 4 and 6. However, expert consultations suggested that certain functions had shrunken significantly beyond the decision for the early adoption stage. Notably, the creation of legitimacy function exhibited less shrinkage in comparison to event-based analysis, which can be attributed to the recent energy crisis in the country, resulting in a price hike of 272% for petroleum products, with prices rising from Rs. 100.11/Ltr in June 2020 to Rs. 272/Ltr in March 2023 (PSO 2023). This provided an opportunity for the APCNGA to float a proposal for saving $2.1–$2.5 billion in energy imports through the revival of CNG with lignified natural gas (LNG) imports (Siddiqui 2022, Tribune 2022).

Step 4: area under the polygon for comparison of extent of transition across stages

Using the method developed to quantify the area under the polygon (for details SM1.2) specified in equation 1, we can compare the extent of transition across three stages. The estimated values are 0.35 sq. units, 30.93 sq. units, 1.29 sq. units for early adoption, take-off and roll-back respectively (table 1). The change from a smaller value to a larger value represents progress in the expansion of the transition process with improvements along the dimensions of the MTIS functions.

Table 1. Area under polygon for CNG-MTIS.

Transition stages	Emergence	Take-off	Roll-back
Area under polygon	0.35	30.93	1.29

Source: estimated by authors.

$$\text{Area under polygon} = \frac{1}{2}\left|\sum_{i=1}^{6}(x_i y_{i+1} + x_7 y_1) - \sum_{i=1}^{6}(y_i x_{i+1} + y_7 x_1)\right| \quad (1)$$

where, (x,y) are the Cartesian coordinates of a vertex of the polygon

$$x = r \times \cos\theta \text{ and } y = r \times \sin\theta.$$

r is the radius of the vertex from the origin of the polygon and θ is the angle of the vertex.

As shown in figure 8, the functions in the roll-back stage are stronger than for the decision for early adoption stage, so the area for decision for early adoption polygon is smaller than that for roll-back. Detailed results are provided in SM 6.

Step 5: Capture the blockages for the weak and enabling/highly needed functions.

The results demonstrate that all functions during the decision for the early adoption decade (1992–2002) were weaker than in the take-off decade. Nonetheless, the creation of legitimacy functions was one of the least-developed aspects, primarily due to the absence of relevant actors such as civil and environmental societies, and a lack of sufficient lobbying for CNG-based transport (for details see SM7). This is also reflected in the area under the polygon. During

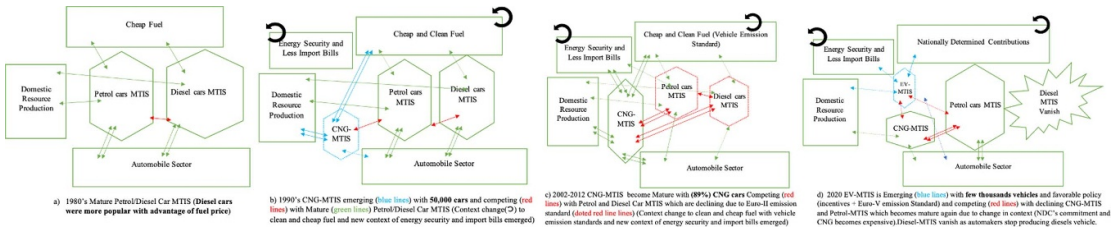

Figure 8. Pakistan transport sector parallel EV-MTIS developments and competition from external factors.

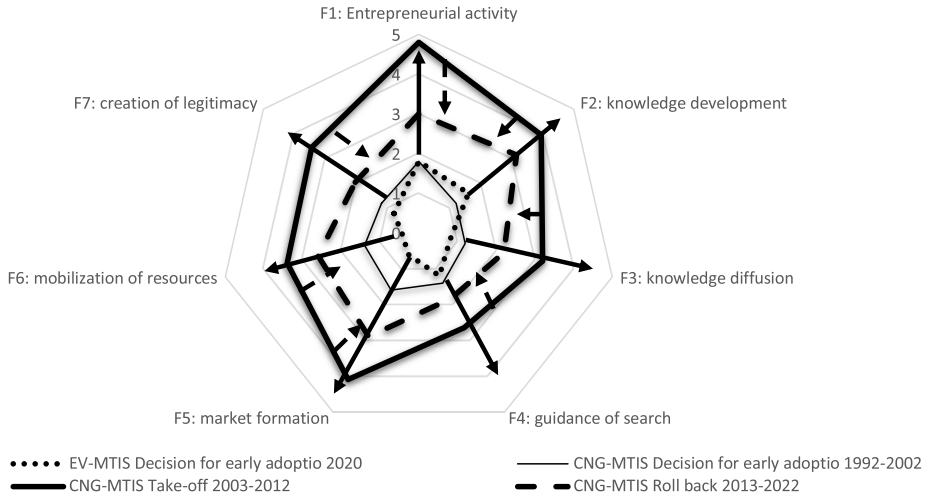

Figure 9. CNG-MTIS vis-à-vis EV-MTIS (outwards arrows represents the future expansion possibilities of EV-MTIS and inward arrows shows the contractionary policies of CNG-MTIS).

the take-off decade (2003–2012), although all functions expanded, the least-developed function was guidance and handholding support. In the roll-back phase, one of the key blocking mechanisms was the lack of clear and consistent policy support from the national government. This resulted in uncertainty, making it more challenging for organizations to make long-term investments in R&D or commercialization efforts, and slowing down the pace of technological progress. In the roll-back decade, two functions, knowledge diffusion and hand holding by policy targets and guidance, became the weakest. The imposition of a ban on CNG station licence issuance/renewal was the major blocking mechanism for all functions of the CNG-MTIS, resulting in a lack of new knowledge development and discouraging the generation of new knowledge from universities, R&D and industries, and reduced knowledge diffusion. This is a clear signal of the government's planned lack of interest in further support for the development of CNG-based transport in Pakistan. This may be due to several reasons. The most plausible seems to be a preference for the development of a parallel EV-MTIS due to landscape-level changes arising in response to national and international commitments to climate action (Butt and Singh 2023), as depicted in figure 8.

The present study depicts, taking the example of Pakistan, how the mobility sector in a developing country context is trying to respond to a series of fast-changing transitions emerging in the global landscape. As the transition to the CNG-driven mobility sector started in developing countries, global-level innovation in technology matured and made it possible for adoption by Pakistan. India also adopted CNG in many states (Patankar and Patwardhan 2017, Krelling and Badami 2021). The current roll-back phase in CNG-MTIS and the shift in focus towards electric vehicle (EV)-led transition is also policy driven (figure 9). A distinctive feature of decision for early adoption of the EV-TIS compared to the CNG-MTIS is the knowledge development function, which is more advanced in the former, as can be seen by the shapes of the respective polygons.

The entrepreneurial activities and guidance for search functions show similar scores for both CNG-MTIS and EV-MTIS. This is because, like for CNG, the government has set targets for all types of vehicles including two wheelers (which was absent in CNG-MTIS as technology was not available to make it possible towards decision for early adoption) in its EV policy (table 2). Manufacturers of e-two wheelers are emerging in Pakistan after policy implementation as

Table 2. Pakistan electric vehicle targets.

EV penetration target	Medium-term 2025	Long-term 2030	Ultimate 2040
Two- and three-wheeler	500 000	50%(900 000) of new sales	90% of new sales
Four-wheeler	100 000	30%(60 000) of new sales	90% of new sales

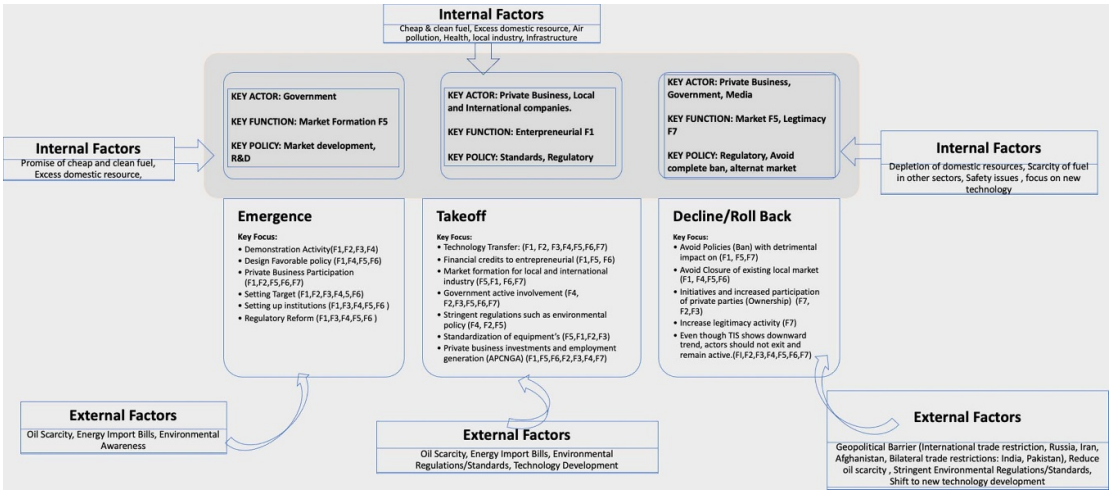

Figure 10. Priority actions/actors/functions needed for development of a successful TIS for new emerging technologies.

technology matures. Entrepreneurial activities characterized by technology manufacture and installation, as well as the entry of new firms such as Vlektra and Jolta Electric in the two-wheeler market, Sazgar in the three-wheeler market, and MG motors and Nur in the four-wheeler market, respectively, are similar to before. On the other hand, the knowledge development score is higher for EV-MTIS. A Scopus search of peer-reviewed articles using the keywords 'Electric Vehicle' and 'Pakistan' yielded 47 articles, 41 of which were published in the last 5 years (2019–2023). Furthermore, the search guidance for EVs is better, as the government has set more aggressive targets for all types of vehicles in its EV policy (table 2), in contrast to CNG which was initially introduced for four-wheeler passenger vehicles and three-wheelers and later encouraged for public transport and buses. However, the market formation and mobilization of resource functions of the EV MTIS are less developed, possibly due to Pakistan's recent economic crisis, which resulted in import bans (including EVs), energy crises and power shortfalls (Zamir and Yep 2022, Shah 2023).

The areas under the polygon for the decision for early adoption stage (event-based) for CNG-MTIS (1992–2002) and EV-MTIS (2020–2023) are 2.55 sq. units and 0.84 sq. units, respectively. It needs to be noted that CNG-MTIS is shown for one decade while for EV-MTIS it is only for 2.5 years. Progress is evident in all functions except for knowledge development. This can be due to the high upfront cost and ongoing negative discourse on awareness and safety issues with EVs (Halsnæs *et al* 2023). Moreover, CNG-MTIS, although facing roll-back, has not yet collapsed and could create a market barrier. The CNG-MTIS market expansion from the very beginning facilitated a faster push to the take-off stage through the entry of many actors into the market.

Step 6: policy, priority actions and actors necessary for enabling functions of the MTIS

In summary, as shown in figure 10, the CNG-MTIS results show that during the decision for early adoption phase, priority actions should focus on demonstrating new technologies and implementing policies that support market formation and entrepreneurial activities. In contrast, the take-off phase requires actions such as more stringent emissions standards for competing fuels, promoting national and international collaboration, facilitating investment, and standardizing and certifying supply chains (e.g. it was for CNG kits and cylinders). However, the roll-back phase involves imposing bans on various activities, including renewal and issuance of CNG station licences, public transport and new manufacturing units, which could negatively impact the TIS by hindering entrepreneurial and market formation. Policymakers need to weigh the costs and benefits of such actions and identify alternative strategies to achieve their goals while minimizing negative impacts on the MTIS. SM8 provides a detailed list of priority actions and their impacts (direct and indirect) on MTIS functions to promote the development of the MTIS during each

phase along with key actors and major policy focus recommendations.

4. Discussion

Pakistan's case study shows that once the decision for early adoption of CNG technology was taken, entrepreneurial functions and market formations were driven by the CNG Production and Marketing Rules 1992, a policy for easy loans, and the removal of tax and import duties (Khan and Yasmin 2014). Developing countries are trying to follow the international low-carbon transition path and sometimes lack incentive to create national legitimacy functions in the absence of long-term visions (Bergek *et al* 2008, Wieczorek 2014). The government's obligation to convert all government vehicles to CNG (NGV Global 2006) played a significant role in initiating the process.

The lack of long-term vision through creation of legitimacy clearly was reflected in the roll-back period (2013–2022) of CNG. It may also be interpreted as a deliberate decision by policy makers to take early mover's advantage in the global electromobility trend at a time when there is growing resource depletion pressure on domestic CNG sources, which triggered the need for a planned roll-back without leaving it to unmanaged social struggle. One can argue that, in the later years of the third decade, CNG policies, although perceived as inconsistent for further growth of CNG, align with the government's goal of reducing use of CNG in the transport sector given the declining supply of domestic CNG. Despite the active presence and maturity of all actors involved in entrepreneurial activity, the government's announcement to roll back the CNG-based transport policy due to scarcity of natural gas resources (Government of Pakistan 2013, Boone 2013) became a dominant driver. While parallel policies encouraging natural gas use for the domestic, industrial, power and fertilizer sectors started creating new dynamics in these sectors, momentum was lost in the transport sector. The government's policy of imposing a ban on new licence issuance for vehicles and renewal for CNG stations for transport fuel resulted in the exit of existing actors, both national and international, and discouraged new entrepreneurs from entering the mobility sector CNG-related business. As a result, the number of CNG stations declined from around 4000 to 1958 from 2011 to 2020 (OGRA 2021). The news media began reporting negative events, such as a decrease in the number of stations, CNG crises and accidents, and bans on multinational companies such as Landi Renzo, which created a barrier to growth (Ahmad *et al* 2014, Bhutta 2014, Crisis24 2021, OGRA 2021, Republic World 2021, Siddiqui 2021).

Comparative analysis of Pakistan's CNG-MTIS (1992–2022) and the Netherlands's ANG-TIS (1970–2007) (for details see SM9) shows some interesting contrasts. As leaders in innovation, the impetus for innovation in ANG-TIS was driven by entrepreneurial activity during its emergence (1970–1989) (Suurs *et al* 2010) in Pakistan. As a follower of market-ready innovations, the expansion of the market was driven by government-led policy. It is a good example for developing countries of how the widescale favourable policy innovations in Pakistan have created public acceptance and trust, leading to an influx of new entrepreneurs into the CNG business. The clear price advantage of CNG (50% cheaper than gasoline and diesel) encouraged its adoption by new users. The decision for the early adoption phase of the CNG-MTIS in Pakistan and the emergence followed by the early adoption phases in the ANG-TIS in the Netherlands had different sets of key actors, for obvious reasons (see figure 11). The emergence of the ANG-TIS in the Netherlands through innovation was driven more by EU environmental issues and oil scarcity, while in Pakistan it was more driven by domestic factors, an abundance of domestic natural gas reserves as cheap, clean alternate fuels for the transport sector when the need for low carbon development was rising, new CNG-based technology, and mature infrastructure. Agents of change for the Netherlands were entrepreneurs, whereas in Pakistan, it was the government playing the dual roles of decision-maker and policy-maker for market formation, as shown in figure 11.

In the second decade of take-off (2003–2012), it was again a government institution, in collaboration with other actors such as the APCNGA, that boosted entrepreneurial activities, facilitated market formation and promoted knowledge development. These drove all other functions of the CNG-MTIS. Hence, entrepreneurial activities can be identified as the driving force behind innovation in the take-off decade. In contrast, the take-off period of the Netherlands ANG-TIS between 2005 and 2007 was driven by market formation and search guidance. After a decline between 1990 and 1999 and re-emergence between 2000 and 2004, the entry of new actors, such as municipalities and provincial governments, air quality standards regulations, local market development, financial incentives, and oil scarcity, boosted the ANG-TIS. The agent of change for the Netherlands's take-off was market formation, while in Pakistan, it was entrepreneurs (Suurs and Hekkert 2009) as shown in figure 11.

The roll-back (2013–2022) of the Pakistan CNG-MTIS was forced by domestic resource scarcity while in the Netherlands ANG-TIS (1990–1999), roll-back was forced by liberalization of gas companies (Suurs and Hekkert 2009), as shown in figure 11. In both

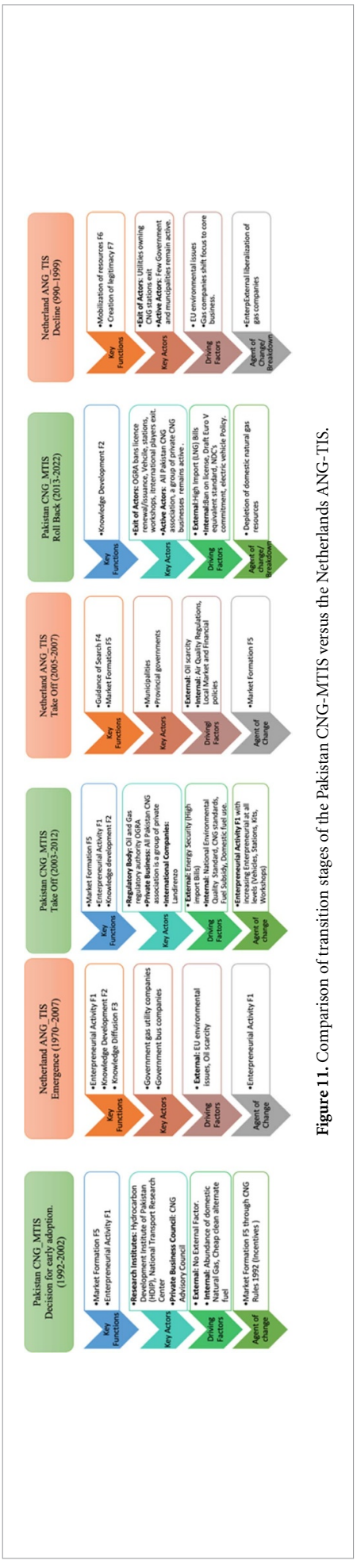

Figure 11. Comparison of transition stages of the Pakistan CNG-MTIS versus the Netherlands ANG-TIS.

countries, changes in the gas sector led to roll-back. While in Pakistan a depleting domestic gas supply led policy makers to roll-back, in the Netherlands gas companies in a deregulated market moved back to concentrate on their primary business. For instance, after merging with the energy provider Nuon, ENW, which owned a major portion of the existing ANG refuelling infrastructure, gave up on the plan and sought to sell their refuelling stations in Velsen, Haarlem, Alkmaar and Amsterdam. Project cancellations resulted in the exit of actors and gave ANG technology a bad reputation among future users.

5. Conclusion

This study is intended to show how, on a global zero carbon transition path, developing countries as latecomers in the innovation chain can accelerate transformative change through government decisions for early adoption of new mature technologies. The example that has been used here is from the mobility sector in Pakistan, but is applicable to developing countries as they are as a group negotiating for technology transfer and adoption to shift development in the near term on a sustainable development trajectory (Lecocq *et al* 2022, IPCC 2023). Examining the revised NDCs of various developing countries (Government of Thailand 2022, Government of India 2022, Government of Pakistan 2021, Government of Pakistan 2021, Government of Bangladesh 2021) reveals common elements, such as a focus on technology transfer and adoption (SM 1.1). Specifically, there is a shared emphasis on designing incentive mechanisms in the form of international finance to support technical assistance and technology transfer funds for purchasing intellectual property rights for free distribution of clean technologies to accelerate decarbonization.

The application of the modified TIS framework is customized to represent the technology adoption and leapfrog characteristics of developing countries, as technology followers, where long innovation chains can be avoided. The analysis of the CNG-MTIS in Pakistan shows that, in developing countries, policy-driven low carbon transition management is possible and policy can be a major enabler even if cascading transitions need to be managed. Government policy changes can enable several functions in a multidimensional transition process. This can be achieved by establishing appropriate context-specific incentives for market expansion, entrepreneurial activity, knowledge processing, development and dissemination, resource mobilization, and legitimacy. Institutional support or advocacy through civil society engagement agencies can provide directionality and influence the transition process expansion in a time-bound manner. The decision for early adoption need not only be in one sector, it can be in multiple sectors depending on national needs and priorities and would need coordinated actions with a variety of social actors, thus creating a movement within society.

The roll-back phase of CNG in Pakistan is a good example that demonstrates how policies can be managed in the face of cascading innovations to welcome a new superior innovation. The case here is electromobility, by rolling back the preceding transition. However, it also illustrates that when the period for roll-back aligns with new emergence, improved articulation can mitigate social struggles. During the third decade (2013–2022) of the CNG-MTIS, unlike the decision for early adoption stage (1992–2002), it seems that in the roll-back stage there was less prior planning, and thus articulation from the government led to social struggle. Our findings show that the drastic withdrawal of policy support in very short time without prior articulation or consultation with the CNG sector supply chain left the latter with uncertainty in terms of business outcome and the CNG infrastructure in which they invested, which are becoming stranded assets. This contributed to confusion in the market expansion of EV-MTIS functions, as trust in policy was undermined. Good policy practices from the CNG-MTIS could be used to facilitate a smooth EV transition. However, the situation with the latter has one more layer of complication that needs to be realized and incorporated into policy framworks. The EV-MTIS in stage 1 needs a smooth policy-driven roll-back of the CNG-MTIS through planned articulation to maintain investors' support and trust in policy. By implementing properly planned retraining processes and compensation mechanisms, CNG-MTIS investors could smoothly transition into the market expansion process of the EV-MTIS, which could be a win–win outcome. In the ANG-TIS in the Netherlands, gas companies involved in transport sector infrastructure development had the flexibility to swiftly revert to their original gas business. In Pakistan and many developing countries, there is a need for supportive guidance for managing cascading transitions. However, instead of managing this transition with broader societal change, driven by national and international commitments, the government is focusing on pushing EV technology as a clean and economical fuel (Engineering Development Board 2020, Shakeel 2022, Butt and Singh 2023). It needs to be recognized that the CNG-MTIS came with many win–win options and positive enabling factors. The introduction of new activities, new infrastructure, new business opportunities and jobs created optimism within the economy, which generated social acceptance. However, the emergence of EV has surprised incumbents and causing disruptions among certain segments of society, which has not been adequately explored in recent literature (Butt and Singh 2023). Therefore, focusing only on consumer need fails to address the just transition issue and could delay the process. The same is

true for many developing countries as they all will need to face the challenge of cascading transitions. For example, India, Bangladesh and Thailand, who recently adopted EV policies, share similarities with Pakistan in terms of their vehicle markets. In India, two-wheelers constitute 75% of the total vehicle fleet, while in Thailand, they make up approximately 60% and in Bangladesh, the figure is around 80%. They also have CNG vehicles that were introduced around a similar time period through policy interventions and now moving towards EV. It is necessary to consider the inclusion of individuals or entities adversely affected within the CNG-MTIS framework. Targeted measures such as reskilling, retraining, redirection of finance, compensation for stranded assets and rehabilitation for losers in the newly emerging system could restore trust in policy. This, in turn, can facilitate a sustainable fast transition towards long-term transformation through the EV-MTIS. Therefore, TIS dynamics management, especially in a complex situation where roll-back of one is cascading/overlapping with emergence of another new technology, can be handled through a just transition framework and managed with limited social struggle. While CNG technology has historically dominated the market for four-wheeler and three-wheeler passenger cars in Pakistan, due to the entry of local manufacturers like Jolta Electric, MS Group and Vlecktra (Talal 2022), EV penetration in these markets needs special attention. The number of e-two wheelers is 18 000 and there are 2000 e-cars (Jamal 2023). EVs have made headway in the two-wheeler category, a segment not covered by the CNG-MTIS, and make up around 82% of Pakistan's passenger transportation (Pakistan Bureau of Statistics 2022). This aspect could contribute to a smoother transition in the near term.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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