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Forecasting EV Transitions under Policy Scenarios in Pakistan using System Dynamics Modelling

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ABSTRACT

The government of Pakistan has announced Electric Vehicle (EV) policies to encourage faster adoption. Such policies set certain targets, but not even 5% of these targets were met as announced in the National Electric Vehicle Policy (NEVP) 2019. The recently announced New Energy Vehicle (NEV) Policy 2025 also lacks evidence-based foundations, with targets that appear ambitious but unrealistic as highlighted by Pakistan Automobile Industry. This research employs System Dynamic Modelling (SDM) to forecast impact of various policies and generate scenarios for wider EV adoption in Pakistan. Four scenarios were set in this paper: scenario 1 (Business as Usual), scenario 2 (Government Support and Finance Policy), scenario 3 (Carbon Trading and Emission Trading System) and scenario 4 (a mixture of policies). In 2020, EV sector was still characterized by its early-stage development, reflecting limited technological advancement and infrastructure readiness. The SDM results indicate that, by 2040, the total number of EVs will amount to 120,000, 202,000, 146,000 and 202,000 under scenarios 1-4, respectively. Findings indicate that, the country's policies, such as financial schemes, play an important role in shaping Pakistan's EV market penetration. The analysis result demonstrates that subsidies and carbon pricing drive significant adoption gains, though integrated policies yield the most substantial impact.

Keywords: Electric Vehicles, National Electric Vehicle Policy, New Energy Vehicle Policy, System Dynamic Modelling, Policy Scenarios, Casual Loop Diagrams

NONMENCLATURE

Abbreviations	
AP	Average Price of Oil
CEC	Cost of Electricity Consumption
CQP	Cabon Quota Price
DPC	Distance per Charge
DPOI	Domestic Price of Oil Imports
ER	Exchange Rate
ETS	Emissions Trading Scheme
FOC	Fuel Oil Consumption
GS	Government Subsidy
ICEV	Internal Combustion Engine Vehicle
IOP	Import Oil Price
MCF	Maintenance Cost of Fuel Vehicle
MF	Mileage of Fuel Vehicle
NAIEV	Newly Added Investment in Electric Vehicles
NEVP	National Electric Vehicle Policy
RE2C	Ratio of EVs to Charging Poles
SDM	System Dynamics Modelling
TCF	Total Cost of Fuel Vehicle
TCE	Total Cost of Electric Vehicle
TNE	Total Number of Electric Vehicles
WTI	Willingness to Invest in EVs

1. INTRODUCTION

The global transition to electric vehicles (EVs) is increasingly recognized as a cornerstone of sustainable transport and climate mitigation strategies. Worldwide, many governments have adopted ambitious targets to phase out internal combustion engine vehicles and accelerate EV deployment. These efforts are underpinned by diverse policy measures, ranging from direct subsidies and tax incentives to regulatory mechanisms such as carbon pricing and emissions trading schemes. Evidence from countries such as Norway, China, and the United States demonstrates that strong and consistent policy frameworks play a decisive role in overcoming market barriers, reducing upfront costs, and ensuring the widespread adoption of EVs [1-3]. Without such interventions, market forces alone often fail to deliver the scale and pace of change required to align with international climate commitments.

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In contrast, Pakistan's trajectory in EV adoption remains slow and uncertain. Despite the introduction of the National Electric Vehicle Policy (NEVP) in 2019 and subsequent strategies, actual market uptake has been modest, with fewer than 20,000 EVs on the road by 2024 [4]. Targets outlined in the NEVP, such as achieving 30% EV sales by 2030, are already considered challenging, given the weak policy enforcement, limited charging infrastructure, affordability constraints, and lack of alignment with energy sector realities [5]. Even the recently announced New Energy Vehicle Policy 2025 illustrates this disconnect [22]: ambitious and optimistic goals are set, but they remain unsupported by quantitative analysis or evidence-based projections, rendering them aspirational rather than actionable. This gap between policy ambition and practical feasibility highlights the urgent need for robust analytical tools to guide decision-making.

Existing research on EV adoption in Pakistan has largely focused on descriptive policy reviews, market surveys, or comparative studies of regional best practices. However, very few studies attempt to capture the dynamic interactions between policies, consumer behavior, infrastructure development, and technology cost trajectories over time. Static analyses, while useful, cannot adequately reflect the reinforcing and balancing feedback that determines adoption trends in real-world contexts. This absence of rigorous modelling creates a critical gap in understanding the long-term effectiveness of Pakistan's EV policy instruments [6] [7].

To address this gap, this research applies System Dynamics Modelling (SDM) to evaluate the impact of different policy interventions on EV adoption in Pakistan. Specifically, it simulates four scenarios: business-as-usual, subsidy-driven adoption, emissions trading scheme (ETS) implementation, and an integrated

Table. 1 Data sources for the elements of SD model [6]

Subsystem	Element/ Variable	Acronyms in Model	Representative Equation	Unit	Data Sources
EV Cost subsystem	Cost of Electricity Consumption	CEC	$TCE = ACE + MCE + CBR + CEC$ (1)	PKR/kWh	[10]
	Electricity price (public)	EP-Public		PKR/kWh	[10]
	Electricity price (private)	EP-Private		PKR/kWh	[10]
	Maintenance Cost of EVs	MCE		PKR/year	[11]
	Mileage of EVs	ME		km	[11] & [12]
FV Cost subsystem	Fuel Oil Consumption	FOC	$TCF = ACF + MCF + FCC$ (2)	km/L	[11]
	Maintenance cost of Fuel vehicle	MCF		PKR/year	[11]
	Mileage of fuel vehicle	MF		km	[13]
	Average price	AP		PKR/L	_
	domestic oil price	DOP		PKR/L	[14]
	domestic price of import oil	DPOI		PKR/L	_
	import oil price	IOP		USD/barrel	[15]
	exchange rate	ER		PKR/USD	[16]
Investment subsystem	Total Number of EVs	TNE	$TNE(t) = TNE(t - dt) + \frac{NAIE}{PCE} - DRE * TNE(t - dt)$ (3)	–	–
	Newly added EVs	NAEV		–	–
	Newly added investment of EVs	NAIEV		–	–
	Depreciation of EVs	DEV		%	[17]
	Total number of Fuel vehicles	TNF		_	_
	Depreciation of fuel vehicle	DFV		%	[17]
	Newly added fuel vehicle	NAFV	$TNF(t) = TNF(t - dt) + \frac{NAIF}{PCF} - DRF * TNF(t - dt)$ (4)	–	–
	Newly added investment of fuel vehicle	NAIFV		–	–
	Willingness to invest (WTI)	WTI		–	[18]
	Ratio of EVs to charging poles	RE2C		–	–
	distance per charge	DPC		km	[11]
Carbon Trading/ Quota subsystem	CO2 emission coefficient of coal	CEC-Coal	$ECO_2 = EC * ME * (CC_{Coal} * CEC_{Coal} * ROC_{Coal} * PrE_{Coal} + CC_{Gas} * CEC_{Gas} * ROC_{Gas} * PrE_{Gas}$ (5)	kg CO2/ton	[19]
	CO2 emission coefficient of natural gas	CEC-Gas		kg CO2/m3	[19]
	Rate of coal consumption	ROC-Coal		g/kWh	[20]
	Rate of Natural gas consumption	ROC-Gas		m3/kWh	[20]
	Conversion coefficient coal	CC-Coal		tce/ton	[20]
	Conversion coefficient natural gas	CC-Gas		tce/m3	[20]
	Proportion of gas-fired electricity	PrE-Gas		%	[21]
	Proportion of coal-fired electricity	PrE-Coal		%	[21]
	carbon quota price	CQP		_	[6]
R&D subsystem	development target	DT	$TL(t) = TL(t - dt) + TIdt$ (6)	%	[6]
	Enterprise R&D intensity	ER&DI		%	
	Total subsidy	TS		PKR	
	Industry-university research cooperation	IURC		%	

subsidy-plus-ETS approach. By examining adoption trajectories up to 2040, the study aims to provide policymakers with evidence-based projections of the relative effectiveness of these strategies, thereby supporting more informed and realistic pathways for transport decarbonization [8] [9].

2. SYSTEM DYNAMIC MODELLING FOR POLICY SCENARIOS

A In this research, SDM was employed to evaluate the long-term impact of policy interventions on EV adoption in Pakistan. The model was designed to capture the dynamic interactions among economic, technological, and policy variables that collectively shape adoption trends. Five key subsystems were incorporated: R&D, Investment, EV cost, ICEV cost, and Carbon Quota. These subsystems reflect the major drivers of market competitiveness, technological progress, and environmental policy in the transport sector.

Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by reference: only relevant modifications should be described.

3. IMPACT OF POLICIES ON EV ADOPTION IN PAKISTAN

To assess the long-term effects of government action on EV adoption in Pakistan, four policy scenarios were simulated using system dynamics modelling. The Scenario 1 case assumes no subsidies or carbon pricing, reflecting current slow adoption. Scenario 2 introduces consumer incentives, tax rebates, and reduced import duties to lower upfront costs and accelerate uptake. Scenario 3 applies carbon prices to manufacturers, indirectly discouraging ICEVs and promoting EVs through regulatory pressure. Finally, Scenario 4 integrates subsidies and ETS, producing synergistic impacts and representing the most ambitious pathway toward Pakistan's transport decarbonization goals.

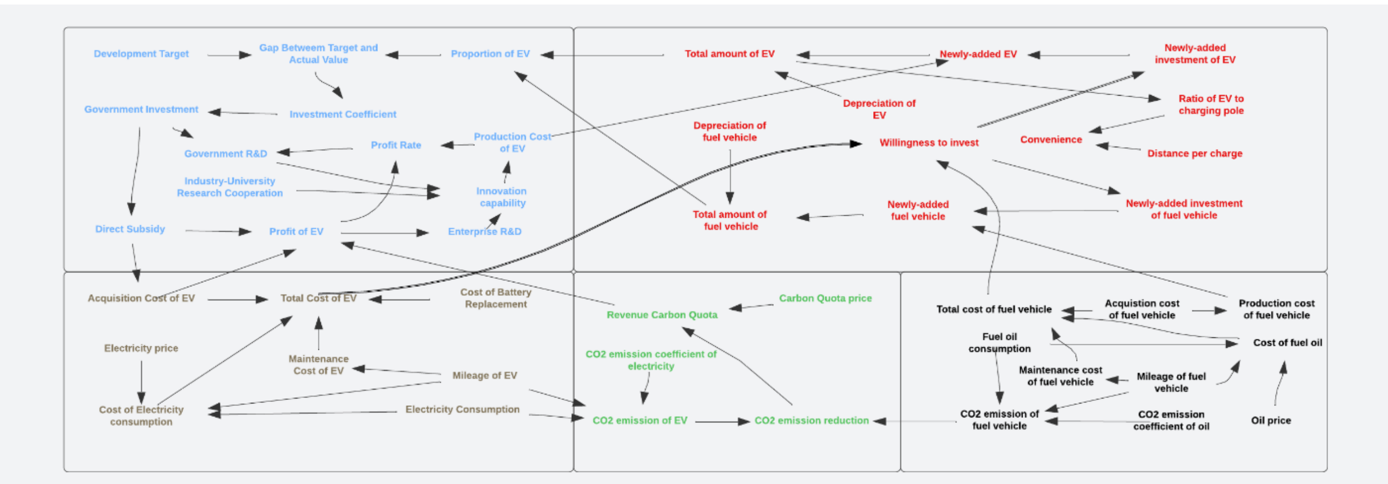

Fig. 1 Closed loop diagram for the SDM

Causal Loop Diagrams (CLDs) as shown in Fig. 1 have been developed to map feedback among variables, where reinforcing loops accelerated adoption through cost reductions, and balancing loops captured constraints such as infrastructure gaps. These CLDs were translated into stock–flow diagrams representing EVs, ICEVs, and charging infrastructure to simulate adoption pathways. The model, built in Stella Architect for 2020–2040, used national and international datasets to ensure contextual accuracy The data variables of each subsystem and relevant equations are shown in the table 1. Policy robustness was tested through sensitivity analyses on subsidies and ETS prices, visualized using response surfaces and scatter matrices. This framework provided evidence-based projections to evaluate Pakistan's transport decarbonization strategies.

Figure 2 illustrates the baseline or Business-as-Usual (BAU) scenario, which assumes no additional government intervention to support EV adoption. In this case, consumer subsidies are set to zero, meaning that buyers receive no direct financial assistance for purchasing EVs. Similarly, the carbon quota price is fixed at zero, indicating the absence of an ETS or any carbon pricing mechanism. As a result, EV adoption follows existing market trends, driven only by global technology cost reductions and consumer preferences. This scenario provides a reference point for comparing the effectiveness of other policy interventions.

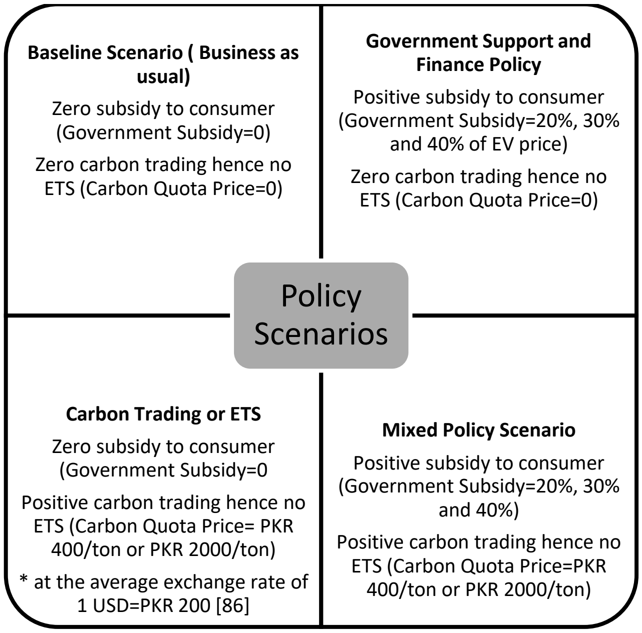

Fig. 2 Assumptions of policy scenarios

4. RESULTS AND DISCUSSION

The SDM simulation results reveal clear differences in EV adoption trajectories under the four policy scenarios between 2020 and 2040.

Figure 3 presents the projected total number of electric vehicles (TNE) in Pakistan under four policy scenarios over the period 2020–2040. The baseline (BAU) scenario assumes zero government subsidy and no carbon pricing (Government Subsidy = 0; Carbon Quota Price = 0), reflecting current trends without policy intervention. As per Economic Survey of Pakistan data indicate that only 300 EVs were registered in 2020, increasing modestly to approximately 15,000 units by 2023–24 [21].

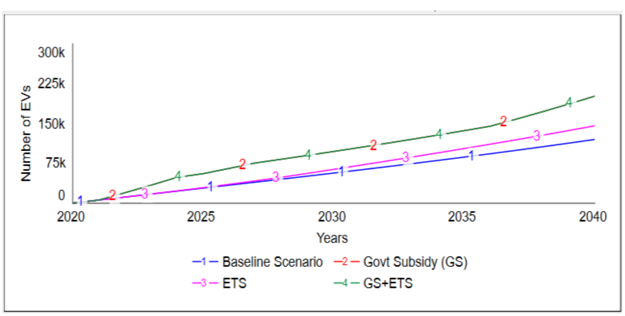

Fig. 3 Total number of EVs under different policy scenarios

The model forecasts that under the BAU scenario, growth remains minimal, dominated by external market factors and declining technology costs. Consequently, the NEVP (2019) target of 30% EV sales by 2030 remains unattainable without proactive policy measures. The ETS scenario introduces carbon pricing for manufacturers, leading to a 21.67% increase in TNE relative to BAU by 2040. However, adoption remains limited due to the absence of direct consumer incentives, demonstrating that regulatory measures alone are insufficient to trigger mass adoption. In contrast, the GS scenario, which incorporates direct subsidies and tax rebates, achieves a 68.33% increase in TNE by 2040 compared with the baseline, emphasising the strong influence of financial affordability on consumer behaviour. The combined GS + ETS policy delivers the most substantial impact, producing the steepest adoption curve through synergistic effects between market-based regulation and fiscal incentives. This dual strategy simultaneously lowers consumer costs and aligns manufacturer incentives with national decarbonisation goals, accelerating EV penetration significantly beyond all other scenarios.

Sensitivity analysis as shown in figure 4 and 5 evaluates variations in subsidy levels of ±10%, ±20%, and ±30% relative to the GS + ETS base case. Results show that a 30% increase in subsidies yields a 56.44% rise in EV adoption by 2040, while a 30% reduction leads to a 21.78% decline. The results shown in Table 2 confirms that subsidy withdrawal produces disproportionately negative effects compared to equivalent increases, underscoring the necessity of sustained financial support for long-term EV market growth.

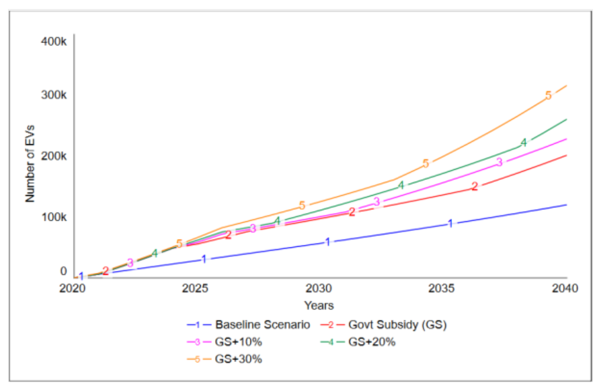

Fig.4 Effect of increasing subsidies on TNE

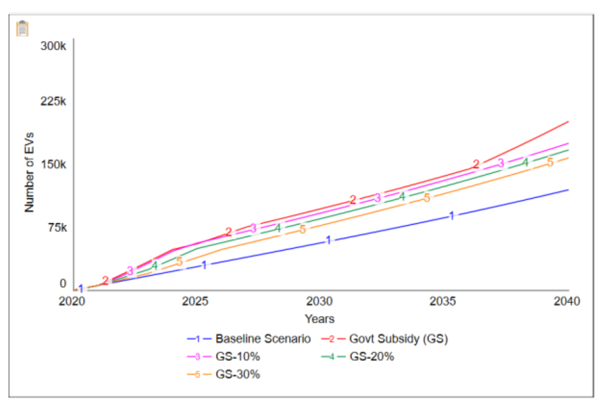

Fig.5 Effect of decreasing subsidies on TNE

Table. 2 Impact of changing subsidy rate on total number of electric vehicles

Year	Baseline (no subsidy)	subsidy	subsidy+10%	subsidy+20%	subsidy+30%
2030	56300	97400	101000	111000	125000
% increase	-	0%	3.69%	13.96%	28.34%
2040	120000	202000	228000	261000	316000
% increase	-	0%	12.87%	29.21%	56.44%
Year	**Baseline (no subsidy)**	**subsidy**	**subsidy-10%**	**subsidy-20%**	**subsidy-30%**
2030	56300	97400	92300	85700	77600
% decrease	-	0%	-5.24%	-12.01%	-20.33%
2040	120000	202000	175000	168000	158000
% decrease	-	0%	-13.37%	-16.83%	-21.78%

These results have significant policy implications. The combined policy scenario shows that synergistic measures yield the highest impact, increasing EV adoption by approximately 150% compared to the baseline and 50% compared to subsidy-only interventions by 2040. Sensitivity analysis suggests that for every additional million USD invested in subsidies, approximately 1,800–2,000 new EVs are adopted, while equivalent reductions cause disproportionate declines. Such integrated, well calibrated and gradual mix of subsidies and carbon pricing offers cost effective and practical pathway to sustainable decarbonization of transport systems.

5. CONCLUSIONS

This study applied System Dynamics Modelling to evaluate the impacts of four policy pathways—Business-as-Usual, Subsidy-Driven, ETS-Driven, and a Combined package—on Pakistan's EV adoption to 2040. Results show that isolated measures yield limited progress: ETS improves uptake modestly relative to BAU, while consumer subsidies generate substantially higher growth. The strongest and most resilient trajectory arises from integrating subsidies with carbon pricing, which aligns consumer affordability with producer incentives and produces reinforcing feedback. Sensitivity analysis results further indicate asymmetric effects: subsidy withdrawal depresses adoption more sharply than equivalent increases stimulate it, underscoring the need for stable, multi-year support. Overall, a coherent mix of consumer incentives, credible carbon pricing, and coordinated charging-infrastructure deployment offers the most effective pathway for meeting national transport-decarbonization goals.

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