The Role of Electric Vehicles in Road Transport Decarbonization: Exploring Environmental Impacts and Policy Implications through a Systematic Literature Review of System Dynamics Approaches

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Abstract

The systematic review examines the use of system dynamics models to decarbonize road transport with electric vehicles (EVs). The study assesses model structures, components, functions, and their environmental and policy implications across 31 selected journal articles. The review finds that many papers lack quantitative aspects and do not adequately validate their models, potentially limiting our understanding of policy impacts. It highlights that models often focus on policy variables for market penetration and decarbonization, overlooking holistic perspectives. Coordinated policies are crucial for effective EV adoption. The review calls for greater transparency in reporting and emphasizes the importance of understanding the time component of models. It stresses the need for model validation to ensure practical relevance. Additionally, the study suggests that EVs can reduce global greenhouse gas emissions but face various challenges. Policy tools like purchase subsidies can boost EV demand. The review underscores the necessity of a mix of policy instruments and regulatory requirements to promote EV adoption and carbon emissions reduction. It advocates a comprehensive approach involving investment, incentives, marketing, and regulation. Future research should consider holistic models, explore EVs' role in Africa, and investigate emissions reduction at the mode of transportation level.

Keywords: road transport; decarbonization; electric vehicle; emission reduction; policy implication; system dynamics; systematic literature review.

1. Introduction

1.1. Decarbonizing the Transport Sector

Decarbonization of the road transportation is imperative to achieving an overall reduction in global carbon emissions. The transport sector is responsible for 26% of the global energy consumption [47]. Carbon dioxide (CO_2) emissions from the transportation sector are currently the second largest source of greenhouse gas (GHG) in the world, accounting for 22% of total emissions [39]. Fuel combustion is one of the significant sources of anthropogenic CO_2 emission, and the relationship between transportation and air pollutants has been exposed in the literature [50]. The sector will also drive future energy consumption and CO_2 emissions [69], and reducing carbon dioxide emissions is becoming more significant in the sustainability of transportation systems, influencing social, economic, and environmental aspects [38]. For many countries, reliance on foreign energy resources creates a fiscal pressure and countries who are the signatory of the Paris agreement are further motivated to reduce carbon emissions arising from the transportation sector.

The road to decarbonisation and achieving net-zero extends beyond the industrialised nations in the global north to emerging and developing countries in the global south. Getting to net-zero by 2050 is a dynamic process that underscores the importance of energy system transformation, technological breakthrough, and collaboration [36].

Plug-in electric vehicles (PEVs), both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), have emerged as a viable and attractive solution to reducing the greenhouse gas emissions from the transport sector. Even though internal combustion engine vehicles [ICEV] continue to be used worldwide, the number of electric vehicles (EVs) continues to capture the market in most developed countries. EV technologies are termed to be more eco-efficient due to their high potential to minimize the externalities arising from road transportation [40].

Electric Vehicles (EVs, henceforth), by virtue of their "zero-tailpipe-emission" play a significant role in reducing this carbon emission. The substitution of internal combustion engine (ICE) vehicles with EVs in the fleet has the impressive potential to reduce greenhouse gas (GHG) by one-half to two-thirds in 2030 [33]. EVs are proposed as a long-term solution to the harmful effects of traditional transportation, especially on the environment [56]. However, GHG emissions reduction depends on the successful penetration of EVs in the road transport segment. EVs have emerged in the market worldwide and are viewed as a promising option towards road transport that is less carbon intensive, less polluting and less oil dependent [55]. Fortunately, it has been argued that the adverse impact of transport sector emission can be reversed through usage of EV for various reasons. First, EVs are less carbon intensive, less polluting and less oil dependent. These vehicles neither emit tailpipe pollutants, CO_2, nor nitrogen dioxide. EVs also reduce nation's dependence on imported petroleum [8, 32, 43, 47]. Second, they offer cheaper maintenance: since the number of EVs engine elements is smaller, the maintenance cost of the vehicles and the cost of the electricity required is much lower in comparison to maintenance and fuel costs of traditional combustion vehicles. Third, energy efficiency: EVs are more efficient than traditional vehicles. The energy cost per kilometer is significantly lower in EVs than in traditional vehicles [32, 59]. EVs fed by renewable energy show an overall efficiency up to 70% [35, 70].

However, figuring out the real-time and actual impacts of introducing EVs in any market and examining the policy implications require employing a better research approach and modelling. In the literature, there are various modelling tools used in the transport sector such as agent-based modelling and diffusion-rate models [46, 66, 34, 64]; stochastic models and Monte Carlo methods [44]; Times-based modelling [55]; and, mixed-integer linear programming [62]. These models, however, are not holistic to inspect the electric vehicles' decarbonization contribution for three basic reasons. First, they do not provide the level of detail and are not explanatory and informative enough for policy makers. Second, many of these models include quantitative dependencies, which appear to be able to handle deterministic equations, by integrating multiple variables in a complex system environment. Unfortunately, these models lack the ability to represent the full context of the problem, since they do not incorporate feedback, delays, and non-linearity [63]. Third, the complexities that are inherent in electricity value chains are non-linear in nature and they require unconventional modeling methods, such as system dynamics. It is therefore, important to use a holistic method that can capture the dynamism and complexity of the transport energy system. Significant number of researches worldwide on carbon emission reduction from the transportation sector have applied and suggested the system dynamics approach.

In the transportation sector, the applicability of this method dated back to 1994 when Abbas and Bell (1994) published the first study on the subject. Abbas and Bell (1994) compared SD with the traditional transport modelling and simulation approaches, pointing out that SD is a useful tool to support policy analysis and decision-making in transport systems. In particular they suggested the approach would be well suited to strategic policy analysis and as a support tool for decision making. In essence, transportation systems are complex, they often involve a number of different stakeholders or agents which results in feedbacks with different time lags between the responses of each type of user. System dynamics models offer a whole system approach to transport planning and with this different perspective the importance of these feedbacks and lagged responses can be demonstrated to policy makers.

The literature reveals that system dynamics approach is the best approach to modelling the transport sector problems because the feedback and linkages these models are able to capture are useful for identifying complex interactions within the transport system. With the recent interest around the world in the promotion of electric vehicles, it is not surprising that modelling their uptake has been a hot topic in the application of system dynamic models. System dynamics is a good fit to these types of problems [61]. Furthermore, assessment of the energy consumption and carbon emissions emanated from the road transport sector is a complex problem as it includes current and future state of a multitude of interconnected parameters such as population and economic growth, travel distances, traffic congestion, fuel prices, electricity availability, share of transportation modes, consumers' acceptance, and government policies. Given these realities, the literature recommends system dynamics (SD) approach to systematically examine the impacts of various electric vehicle penetration rates on the end energy use and associated carbon emissions reduction simulations under multiple economic, environmental, and social targets and policy scenarios. Considering the importance of decarbonizing the transport sector through penetration of electric vehicles and SD's contribution to its dynamic analysis, the absence of a systematic review dedicated to this problem motivated this study.

Previous works have reviewed the literature on low-carbon transportation of different technologies and research methodologies. Up to this date and knowledge of the author, no systemic literature review is made on the application of system dynamic modelling to analyzing the role of EVs in reducing carbon emissions in the road transport sector. It is tempting to ask how has the dynamic aspects of road transport decarbonization through electric vehicles systems been modeled using the system dynamics approach. What is the trend and pattern of the SD modelling of role of EVs in the road transport decarbonization in different parts of the world? What methodological lessons and research areas can be drawn for further applications and researches in the developing world, particularly Africa?

It is, therefore, against to this background that this paper aims to offer a review on the field to be able to comprehend the current situation of scientific research on the application of SD in the analysis of role of EVs in reducing emissions in the road transportation sector.

Specifically, it aims to set out which aspects of road transportation research have applied system dynamics since the paper by Abbas and Bell. It also aims to highlight whether the studies have made use of the qualitative causal loop approach, the quantitative stock-flow modelling approach, including the equations and scenario analysis and validation. Finally, it aims to identify what research is still necessary to improve the representation of decarbonization pathways with SD models.

The remaining part of the paper is organized as follows. Section 2 presents the methodology employed to perform the review. Section 3 details the search parameters used to browse through the data, science mapping analysis performed, actual search results, highlighting the core journals, publication over time, and across country. Section 4 presents the results and content analysis carried out with the relevant articles in the field. In section 5, conclusions and implications of the review and research gaps are drawn.

1.2. Basics of System Dynamics (SD)

System dynamics, developed by Jay Forrester of MIT in the late 1950s, has emerged as a modeling tool for analyzing large scale complex systems. It is based around causal loop diagrams that simulate and analyze relationships and mathematical modeling of stocks and flows [63]. It incorporates both qualitative and quantitative techniques, making it highly versatile tool of analysis [58].

System Dynamics (SD) has been used for more than half a century for a wide variety of applications due to its unique 'systems' perspective and capability to address the fundamental structural causes of problems arising in complex dynamic socio-economic systems. The major strength of the SD modeling approach is the 'open structure' of the models making them flexible for input parameters and structural modifications. This advantage is especially beneficial in the transport sector which is represented by complex connections between system elements, feedbacks, non-linearity, and time delays [60].

From a methodological point of view, the system dynamics model composes three main elements: causal loop diagrams (CLD), stock and flow diagrams (SFD), and equations (E) representing the relationships between the variables [63].

I. *The Causal Loop Diagram (CLD)*: It is a qualitative and graphical representation of variables and their joint linkages. These linkages are depicted through feedback loops, both negative (balancing) and positive (reinforcing) feedback loop. Feedback loops are best defined as closed sequences generated by causes and effects triggered between variables. In particular, reinforcing loops connect variables that are positively linked: for each increase in one variable within the loop, the growth generated in the linked variables originates an additional increase in the first variable. For balancing loops: the increase in the value of one variable causes changes in the values of the linked variables which results in a decrease in the value of the first variable.

II. *Stock and Flow Diagrams (SFD)*: SFD are made up of four elements: stocks, flows, auxiliary variables, and connectors. Stocks are cumulated quantities given by the difference between the inflow and the outflow of a process. They can refer accumulations of goods, money, customer orders, etc. over time. Flows can be physical, economical or informational quantities that either increase (inflows) or decrease (outflows) the value of a stock. Auxiliary variables can be either constant or variable over time. Connectors represent the relationships between the previous mentioned three elements.

III. *Equations of the SD Model (ESD)*: These can be either algebraic or differential in nature, they are independent from one another, and are functions of the state of the system in the previous time steps. They define for instance the values of flows joining two stocks or the stock levels.

System dynamics uses a top-down approach and directly incorporates systems thinking to describe, model, simulate and analyze the nature and working of complex systems [51]. It is used to represent complex systems so as to analyze their dynamic behavior over time [68]. Moreover, system dynamics are descriptive models which are commonly used to provide information on what would happen in case a policy is implemented at a specific point in time and within a specific context. It aims at understanding what the main drivers for the behaviour of the system, which in turn requires identifying properties of real systems, such as feedback loops, nonlinearity and delays, via the selection and representation of causal relations existing within the system analysed [65].

When systems contain balancing and reinforcing loops then a dynamic equilibrium may be reached. While qualitative models are useful in describing the structure of a system and a dynamic hypothesis, most decision makers then wish to see some quantitative results. Here the approach is based on linking differential equations but is presented to the user in terms of "stocks" and "flows" via a stock-flow diagram which keeps the model transparent and easy to understand [61]. Most importantly, Ref. [63] suggests that the usability of the system dynamics technique for policy and decision makers requires further investigation that focuses on the context of each country.

Within the suite of systems methodologies, SD offers additional capabilities for informing intervention design and policy-making in comparison to soft systems methodologies by integrating qualitative and quantitative elements to represent soft behavioural variables, and engaging decision-makers in the process of testing policies or intervention strategies based on real-world circumstances [53].

Early applications of system dynamics were in business management but over the past few decades it has been applied to other areas, including government policy, healthcare, the automobile industry and urban studies [63]. The application of causal loop diagrams (which set out the causal links between concepts) may be used to bring out the "mental models" (how people think a system works) of different stakeholders and therefore help remove any barriers to implementation of a given policy. System dynamics approaches are becoming increasingly used in a hierarchical manner which allows systems and policies to interact across space and time. The holistic approach is well suited to the transport problems we now face.

2. Methodology of the Paper

In the paper, a Systematic Literature Review (SLR, henceforth) approach is employed. All relevant studies from the literature are exhaustively identified through a systematic search and screening of electronic database and tracking backward citations of relevant studies. Papers eligible for inclusion in the analysis are those whose research methodology is systems dynamics to the evaluation of electric vehicles penetration in the transportation sector word wide. Triangulation method has been employed to ensure acceptable level of reliability, validity, sensitivity and objectivity in the selection of articles.

The SLR is a rigorous approach to conducting a stand-alone literature review. Stand-alone literature reviews can and are conducted with varying standards of rigor, ranging from little more than an annotated bibliography to scientifically rigorous syntheses of a body of primary research. Ref [45] defines SLR as a systematic, explicit, comprehensive, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners. It is essential to verify the state of a particular research field [73]. The SLR not only allows integrating quantitative data between studies, but it also summarizes the findings of a given field [74]. Therefore, this method is not just a review of existing writings because it assesses existing contributions and identifies gaps in the literature that can be explored in future studies [76]. There are several approaches in the literature to perform the SLR. Ref [71] and [76] perform the SLR through eight-step procedures. In a similar way, Ref [71] applied a procedure composed of ten steps. Regardless of the number of steps, the SLR is composed of three main phases: planning the review; conducting the review; and reporting and disseminating results [77]. This paper has adopted the procedure for systematic literature review proposed by [72], as illustrated in Figure 1.

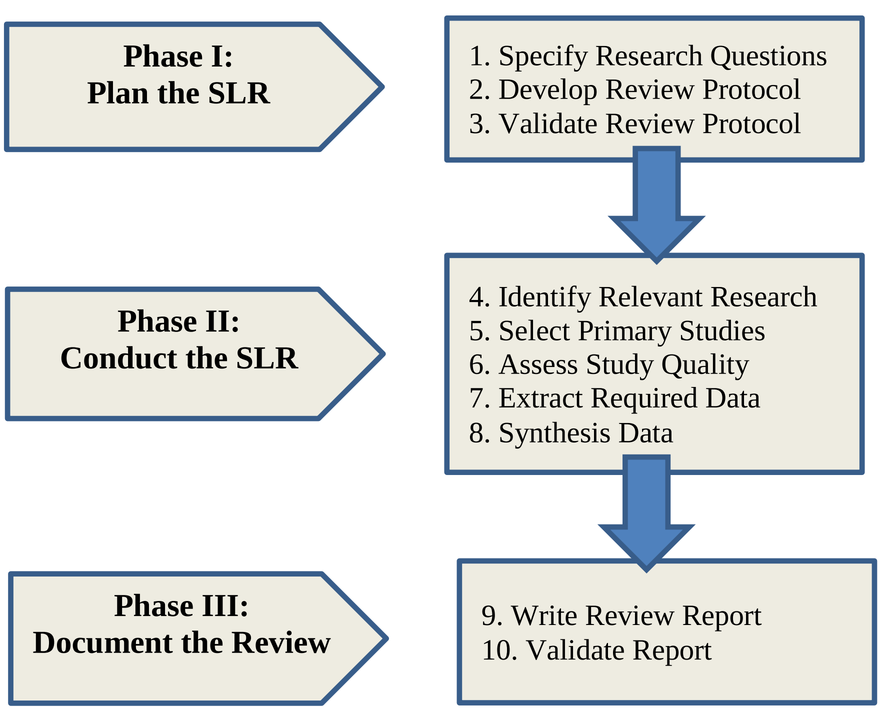

Figure 1: Systematic Literature Review (SLR) process: adapted from [72].

The reasons for doing the SLR are identified in the planning phase. In addition, the objective and the steps of the research are defined at this stage [75]. According to [72], the papers related to the theme are identified and evaluated in the second phase (conducting review). In addition, data collection and synthesis are carried out at this stage. Finally, the report, presenting the results obtained in the research, is developed in the third phase [76].

3. The Systematic Literature Review (SLR)

3.1. Search Strategy, Inclusion and Exclusion Criteria

In the first phase of the process, the set of terms used in the search for papers is identified. In addition to the basic terms in the title of the SLR, I have conducted an analysis of the keywords of three papers published on the topic on international journals. Thus, to identify studies that assessed, through SD, the role of electric vehicles in road transport decarbonization, the following combination of keywords is chosen:

"System Dynamics" AND "Electric Vehicle" AND "Transport" Transportation AND "Emission Reduction" Emission Pollution

The logical (Boolean) operators "OR" and "AND" were applied to facilitate the combination of keywords and the selection of papers. To force the search that the results should exactly include certain words or phrases, we put them under quotation "System Dynamics"

And, in order to check robustness of the search technique and results obtained, we have used different combination of key words arranged in different format using the Boolean operators. The following broader search terms are used and finally we got the same papers selected despite the large number of populated papers in the search result.

"System Dynamics" AND "Road Transport" OR "Transport" OR "Transportation" AND "Emission Reduction" OR "Emission" OR "Decarbonization" AND "Electric Vehicle" OR "Electric Car" OR "Electric Bus"

The portfolio was built in 28th February 2023 using the Google Scholar database covering the available online journal. Books, conference proceedings and unpublished documents, including thesis, are excluded. The search has put neither time nor geographical constraints or restrictions. In order to identify the maximum number of SD applications in the role of EVs in road transport decarbonization, no restriction is set about the year of publication. In addition, due to the importance of decarbonized transportation for the development of any country, the paper did not make a specific geographical delimitation. Criteria such as journal rankings were not used for exclusion purposes because this review aims to give a comprehensive overview of the system dynamics models of transport decarbonization through electric vehicles. Moreover, other databases were not used to avoid repeated papers in the portfolio, considering that Google Scholar makes all electronic resources available [41]. The selection, however, follows the relevance ranking of Google Scholar search results.

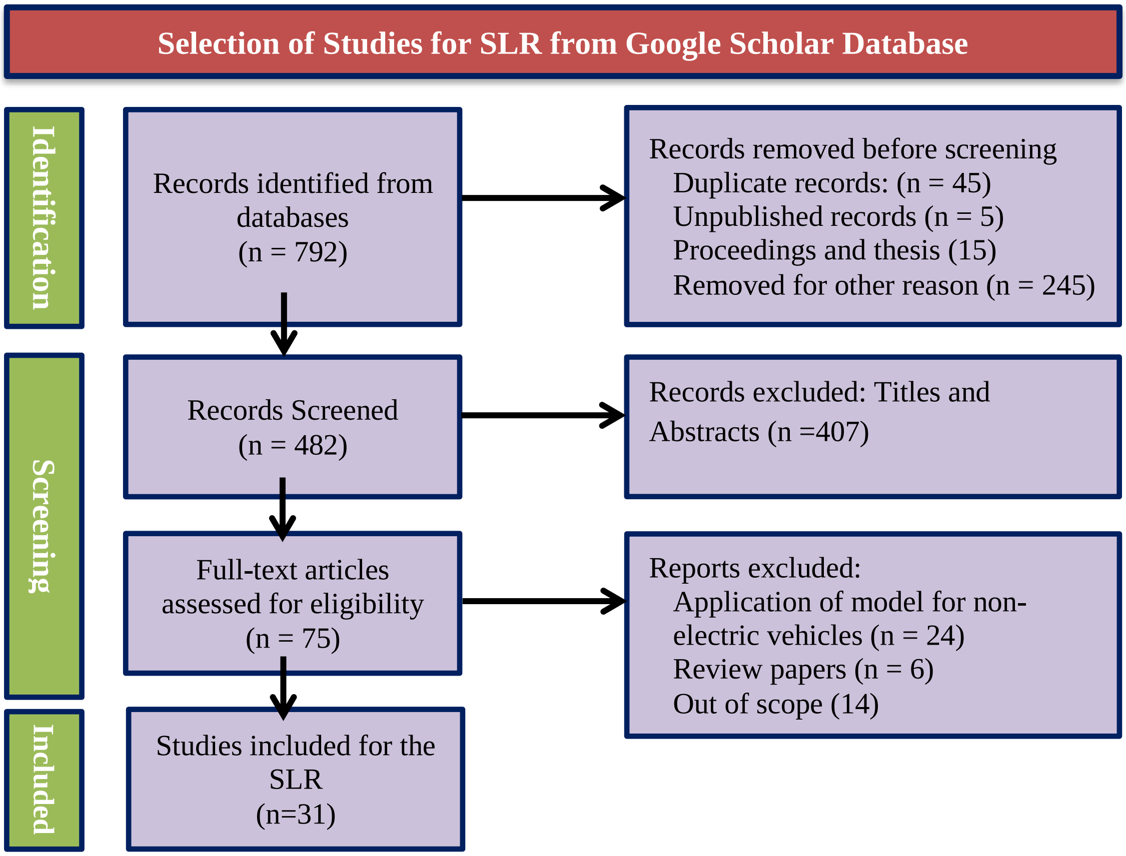

Figure 2: PRISMA method of flow diagram of the systematic literature review [54]

Also, only papers in English were included. Articles eligible for inclusion were those that described applications of system dynamics modeling to evaluating the role of EVs in the decarbonization of the road transportation sector worldwide. Studies excluded at the title, abstract and keywords screening. Thus, papers that did not use SD to analyze the role of EVs in the decarbonization of the road transportation sector are excluded. Figure 2 shows the flow diagram of the identification, screening and selection process of papers for the SLR based on the PRISMA[1] guidelines.

The first search resulted in 792 documents. The documents were then filtered by language (English), document type (articles), and research areas (environmental science, social science, business and management), and resulting in 482 articles to be further evaluated. In the screening step, the paper has applied inclusion criteria to select papers containing system dynamics models regarding the contribution or role of electric vehicles in emission reduction or decarbonization of the road transport sector, which resulted in 407 exclusions and 75 publications being assessed for eligibility.

In the second screening step, despite citing electric transport, a few studies were identified concerning hydrogen based vehicles or other forms of vehicle transportation were disregarded for the review by applying the exclusion criteria. Papers that discussed other forms of decarbonizing the road transportation are also excluded through the exclusion criteria. A total sum of 31 studies that address the main theme of this research, i.e. the role of EVs in emission reduction or decarbonizing the road transport

[1] *Preferred Reporting Items for Systematic Reviews and Meta-Analyses*

sector using the SD approach, remained in the folder to be reviewed. The description of the selected papers, synthesis data and analysis are discussed in the following sections.

3.2. Synthesis Data

Microsoft excel is used to undertake the synthesis data, It allows us to visualize patterns and trends in the literature based on data in the papers. Among the included papers in the bibliographic portfolio, the first two papers that used system dynamics as a tool for examining the role of electric vehicles in decarbonizing the road transportation were published in 2010. The highest number of publication is recorded in 2020, with a total of 8 papers followed by 2022 with 6 papers (figure 3). It is worth mentioning that the search for papers was carried out in the last week of February 2023. In the month of January and February of 2023 alone, it was published almost the same number of studies published in 2010 and 2013. This information shows that SD is being used increasingly to evaluate sustainable road transportation policies.

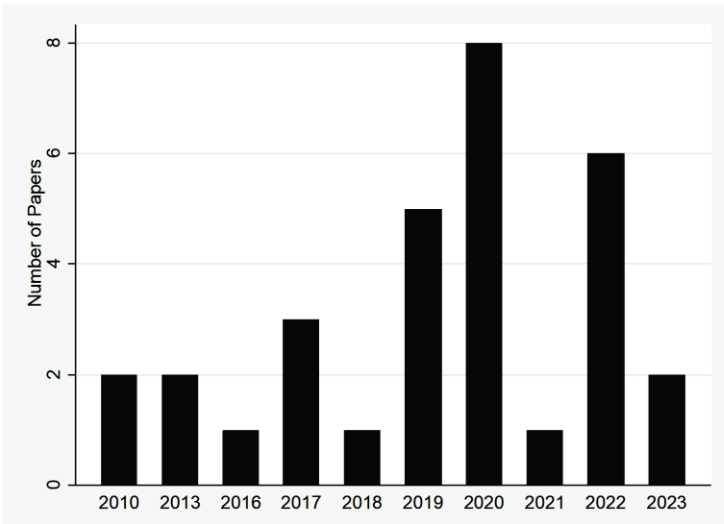

Figure 3: Distribution of papers based on the year of publication

One interesting point that could be raised at this point is that the greatest number of publication is recorded at the year when covid-19 pandemic has hit the world and drastically changed our life style. Though the impact of Covid-19 on publications should be studied, there is a high possibility that this is because of the lockdown measures taken by governments across the world.

Table 1 - Journals with the greater number of publications in the SLR

No.	Name of Journal	Number of Papers
1	Sustainability	3
2	IEEE Access	3
3	Technological Forecasting and Social Change	2
4	World Electric Vehicle Journal	2
5	Environmental Science and Pollution Research	2

The papers included in the bibliographic portfolio are distributed in 24 scientific journals. Among them, Sustainability and IEEE Access stand out with the highest concentration of papers (three publications each). Journal of Technological Forecasting and Social Change, journal of World Electric Vehicle Journal and journal of Environmental Science and Pollution Research also stand out with two papers each (table 1). The remaining journals have only one publication each.

Table 2: Publishers with the highest number of publications in the SLR

No.	Name of Publisher	Number of Papers
1	Springer	8
2	Elsevier	6
3	MDPI	6
4	IEEE	3

Regarding the publishers, Springer stands out first with 8 papers, followed by Elsevier and MDPI with 6 articles published each. IEEE is also on top of the list of publishers with 3 publications (Table 2). A total of 12 publishing companies have participated in the publication the studies.

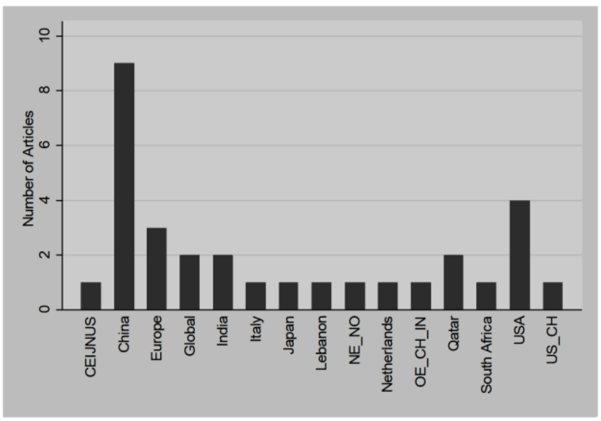

Figure 4 - Geographical distribution of included paper

(Note: OE_CH_IN means OECD China & India; NE_NO means Netherlands and Norway; CEIJNUS means China, European Union, India, Japan, Norway and the United States of America; US_CH means USA and China

Regarding the country where the study has been conducted, China is the country with the largest number of publications with 9 papers, followed by USA with 4 papers. Additionally, in the group case studies of the articles, China and USA appear 3 and 2 times, respectively (figure 4).

4. Results and Content Analysis

4.1. Description of SD Model Components and Sub-Models

Table 3 presents the selected studies, their simulation period, SD software used, and whether or not the model's diagrams (causal loop diagrams and stock and flow diagrams) and equations were fully or partially presented, and whether or not model's validation test is undertaken.

In terms of model's presentation, majority of the papers (18 papers) have presented the three basic components of the SD model (some partly): causal loop diagram (CLD), stock-flow diagram (SFD) and equations of the SD model (ESD). Five papers have shown the CLD and ESD, while three papers presented the SFD and ESD of the model (Table 3).

Vensim, Stella, Matlab, Ventity and AnyLogic are the five types of SD software used in the analysis of the papers, where Vensim is the most commonly employed software (thirteen articles), followed by Stella with three articles. And, two papers have used Matlab. Eleven articles did not mention or specify the type of software that has been used in their analysis.

The length of the simulation period is mentioned by almost all, except one, papers. The longest simulation period is 100 years (21st century) selected by one paper, followed by 70 years by one study, 55 years by two studies, 50 years by one, 47 years by another one and 44 years by five studies. The most common length of simulation periods are 30 years and 40 years selected by 5 papers each. The shortest simulation period is five and seven years used by one paper each (Table 3).

Model validation is an important step in the development of any SD model. Given this fact, only 22 papers (70.97%) have explicitly mentioned that they have carried out model validation, while the remaining 9 papers did not specify or mentioned whether or not they have conducted model validation (Table 3).

Table 3: Synthesis SLR of studies that applied SD

Index	Authors' Name	Simulation Period	SD Model Presentation	SD Software	Model Validation
1	Wen & Wang (2022)	2020 - 2060	SFD & ESD	Vensim	Yes
2	Abdullah et al. (2022)	2020 - 2050	CLD, SFD & ESD	Stella	Yes
3	Barter et al. (2013)	2010 - 2050	CLD, SFD & ESD	Not Specified	No
4	Li et al. (2023)	2010 - 2030	CLD, SFD & ESD	Not Specified	Yes
5	Zheng et al. (2019)	1990 - 2030	CLD, SFD & ESD	Not Specified	Yes
6	Golroudbary et al. (2022)	2010 - 2030	SFD & ESD	AnyLogic	Yes
7	Kamal et al. (2020)	2010 - 2050	CLD, SFD & ESD	Ventity	Yes
8	Watabea et al. (2019)	2016 - 2060	ESD only	Not Specified	No
9	Harrison & Thiel (2017)	1995 - 2050	CLD & ESD	Vensim	Yes
10	Chen et al. (2023)	2010 - 2030	CLD, SFD & ESD	Not Specified	Yes
11	Haddad et al. (2017)	2010 - 2040	SFD & ESD	Vensim	Yes
12	Onat et al. (2016)	1980 - 2050	CLD, SFD & ESD	Vensim	Yes
13	Pillay et al. (2020)	1993 - 2040	CLD, SFD & ESD	Stella	Yes
14	Vilchez et al (2013)	2000 - 2050	CLD only	Not Specified	No
15	Zolfagharian et al. (2020)	2016 - 2046	CLD, SFD & ESD	Not Specified	No
16	Saraf & Shastri (2022)	2020 - 2050	CLD & ESD	Matlab	Yes
17	Xue et al. (2020)	2008 - 2023	CLD, SFD & ESD	Vensim	Yes
18	Idjis & Attias (2018)	2010 - 2050	CLD & ESD	Not Specified	No
19	Xiang et al. (2017)	2015 - 2040	CLD, SFD & ESD	Vensim	Yes
20	Esmaeili et al. (2022)	2020 - 2049	CLD & ESD	Matlab	Yes
21	Walther et al. (2010)	2009 - 2021	CLD, SFD & ESD	Vensim	No
22	Pautasso et al. (2019)	2018 - 2030	CLD, SFD & ESD	Vensim	Yes
23	Zhou et al. (2020)	2017 - 2052	CLD, SFD & ESD	Vensim	Yes
24	Chen et al. (2022)	2010 - 2030	CLD, SFD & ESD	Not Specified	Yes
25	Deuten et al. (2020)	2010 - 2017	CLD, SFD & ESD	Vensim	Yes
26	Barker & Scrieciu (2010)	2000 - 2100	Unspecified	Not Specified	No
27	Vilchez & Thiel (2020)	1995 - 2050	CLD, SFD & ESD	Vensim	Yes

28	Kushwah & Tomer (2021)	Not Specified	CLD only	Stella	No
29	Vilchez & Thiel (2019)	2015 - 2050	ESD only	Vensim	Yes
30	Li et al. (2019)	2015 - 2020	CLD, SFD & ESD	Vensim	Yes
31	Bi et al. (2020)	10 Years	CLD & ESD	Not Specified	No

Note: CLD = Causal Loop Diagram, SFD = Stock-Flow Diagram, and ESD = Equation of the SD model

Besides, the articles have employed various sub-models or methods (table 4). Among them are: energy-economic sub-model and carbon-emission sub-model [1]; energy supply sub-model, fuel production sub-model, electricity grid sub-model, and vehicle sub-model [3]; transportation sub-model, environmental sub-model, economic sub-model, and social sub-model [12].

The Powertrain Technology Transition Market Agent Model (PTTMAM) is employed by [9] to create scenarios related not only to market conditions but also policy strategies. The PTTMAM includes the most significant EU regulation related to the control of manufacturers regarding new fleet emissions. PTTMAM is a comprehensive SD model covering the EU car and light commercial vehicle markets. It models the interactions among four agent groups: users, manufacturers, infrastructure providers and authorities [25]. In the model, CO_2 emission targets set by the authorities have a strong impact on manufacturers' decisions to support certain powertrains and their associated attractiveness for users and profitability for infrastructure providers [27], while the same study uses the Transport, Energy, Economics, Environment (TE3) model to simulate EV uptake in China, India, Japan and the US. Ref [29] has used the PTTMAM to analyze the effect of altering purchase incentives. It helps understand policy options and market trends with a particular focus on electro-mobility [29]. Also, the energy-environment-economy model at global level (E3MG), which is a large-scale, non-linear macro-econometric simulation method, is employed to assess the implications of a low-stabilization target of 400ppm CO_2 equivalent by 2100, assuming both fiscal instruments and regulation [26].

Furthermore, life cycle assessment (LCA) method has been used by [6] so as to present a global scale analysis of environmental cost of using rare-earth-elements (REEs) in green energy technologies. It has been performed using system dynamics modelling integrated with life cycle assessment and geo-metallurgical approach. Also, an integrated dynamic life cycle sustainability assessment (LCSA) model is utilized to analyze the environmental, economic, and social life cycle impact as well as life cycle cost of alternative vehicles in the US [12]. Life cycle assessment (LCA) has been adopted primarily for studying environmental impacts in terms of greenhouse gas emissions and energy consumption [22]. A life cycle model is also used to evaluate the synergistic effect of the four emerging technologies (wireless charging technology, shared mobility services technology, autonomous driving technology & battery electric vehicle technology) on the payback time of GHG emissions of infrastructure and vehicle burdens [31].

The GREET (greenhouse gases, regulated emissions, and energy use in transportation) model is used to adapt the life-cycles of emission rates from energy sources [6]. The fuel resource properties were rapidly estimated by a well-to-tank life-cycle analysis using GREET's software to estimate the well-to-tank CO_2 emissions, because these were not available [7]. A combination of both IPCC's calculation methods of carbon emissions in transportation industry "top-down" macro-calculation method and "bottom-up" micro-calculation method are employed in Ref [10].

On another article, the CTEGER model (China's transportation energy consumption and GHG emission reduction model) is used to simulate the reduction of GHG emissions from the replacement of gasoline and diesel vehicles with BEVs and PHEVs [5]. The same study has also applied the well-to-wheel (WTW) method to derive the life cycle GHG emission coefficients (LCGEC) of gasoline, diesel, and kerosene from four processes, namely, extraction, refining, pipeline transportation, and usage [5].

Another model called ForFITS (For Future Inland Transport Systems), a comprehensive modelling tool based on the system dynamics approach, used to assess mitigation scenarios at a national level [36]. The method uses demographic and socio-economic data and assumptions, including policy inputs, to model transport activity which it then converts into estimates of fuel consumption and CO_2 emissions [11].

On the other hand, econometric techniques have been also applied by a few of the researches. The energy demand for the transport sector is endogenously determined by a consumer's vehicle choice characterized by the multinomial logit model (MNLM) [8]. An MNLM compares various attributes of different vehicle options and comes up with purchase probabilities [16]. It also uses the autoregressive exogenous (ARX) model, a form of time series model, is used for fitting the equation relating ethanol production capacity from molasses and lingo-cellulosic biomass to the profit earned by these bio-refineries with time delays [16]. Ref [5] uses error correction models (ECMs) to describe the short-term dynamic relationship among the variables. It also uses the autoregressive distributed lag (ADL) model to project the transport output value, and co-integration equations to establish long-term relationships and elasticity among the variables [5]. Many factors affect the purchasing of electric vehicles and modelled using the logit regression [20].

Besides, Theil's inequality method is used to compare the model fit to historical behaviour and identify potential improvement. The method decomposes the mean square error (MSE) amongst three components: error due to bias; unequal variation between the simulation and the data; and unequal co-variation [25]. The same study has also used loop knock-out, or loop deactivation methods for exploring relative effects of feedback loops. By means of loop knock-out analysis, dominant structure of the model is explored to see to what extent it causes sales of EVs in 2030 and 2050 in the Netherlands and Norway [25].

Additionally, a consumer discrete-choice model is widely used to study consumers' purchase decisions and estimate the market share of alternatives. So, it is applied here to calculate the market share of EV, representing the proportion of consumers who choose to buy an EV in any given year [4]. Also, the vehicle cohort modelling (VCM) is used to provide a comprehensive vehicle fleet stock as a good representation of the real world [7]. Finally, the Stackelberg game theory, a type of non-cooperative game, in which a decision maker takes the lead or the favourable position, and the follower, plays the game after the leader. Stackelberg game model was proposed to study the influences of government's subsidy towards environmental-friendly products in a dual-channel supply chain. It was widely used to study the interactions among manufacturer, retailer, recycler and consumers [30].

4.2. EVs Environmental Impacts and Policy Implications

This review presents an in-depth content analysis of the selected articles. It is essential to highlight that the content analysis mainly is based on the objectives of the selected articles, their findings and suggestions and policy implications. It tries to deeply assess the works to enlighten possible research perspectives on the application of system dynamics approach in evaluating carbon emission reduction role of electric vehicles. Table 4 (in the appendix) presents information concerning relevant articles in the field, unveiling their topics, objectives, main findings and suggestions and policy implications. The articles' main research theme and focus mainly fall in to any of the following broad categories. Most of them have included in their analysis the impact of introducing electric vehicles on the environment and the economy [1, 3, 4, 5, 6, 8, 10, 12, 13, 22, 31]. All of them have directly or indirectly pinpoint a policy implication such as investment policy [2, 5, 9, 15, 16, 17 23, 31], incentive and subsidy policy [4, 20, 23, 25, 29], technology, innovation, substitution and adoption policy [5, 7, 11, 15, 23, 31] and factors determining adoption and diffusion of the technology [3, 11, 13, 14, 15, 16, 20, 25, 28], and indirect or counterbalancing effects of development of electric vehicles [18, 30].

4.2.1. Impact on carbon emission and fuel consumption

The studies under review encompass a wide range of scenarios, including economic growth, partial shifts in transport modes, improvements in fuel efficiency, upgrades to infrastructure, and various emission reduction targets. Notably, research conducted in both China and the United States validates the positive impact of electric vehicles (EVs) on reducing greenhouse gas emissions [1, 3, 5]. In China, one study specifically highlights the significant influence of widespread EV adoption on petroleum consumption and greenhouse gas emissions within the light-duty vehicle (LDV) fleet [4]. Furthermore, EVs are poised to make a substantial contribution to curbing oil dependency and CO2 emissions in OECD countries, China, and India by 2030, with even more significant reductions anticipated beyond that year. This analysis underscores the potential of EVs to reduce our reliance on non-renewable resources and mitigate CO2 emissions from road transportation, thereby advancing key energy and environmental objectives [14]. Additionally, the increased adoption of EVs translates into reduced air pollution and, consequently, reduced public health expenditure. These cost savings can be leveraged as incentives for individuals to purchase new EVs, creating a self-reinforcing cycle towards a greener transportation fleet.

In Qatar, a study explores the scenario in which battery electric vehicles dominate the market, revealing substantial reductions in fuel consumption and emissions, with an estimated decrease of over 8 million tons of CO2. It is essential to note, however, that while emissions decrease, the transition from gasoline vehicles to electric ones leads to an increase in electricity consumption [7]. Moreover, in the United States, battery electric vehicles are emerging as a more sustainable option across various impact categories. While the benefits, such as contributions to employment and GDP, as well as the potential for CO2 emission reduction, become more pronounced toward 2050, other sustainability indicators, including vehicle ownership costs and the human health impacts of BEVs, surpass those of other vehicle types in the 2010s and 2020s [12].

Africa's only relevant study [13] takes a unique approach by utilizing system dynamics to evaluate the impact of electric buses, cars, and trucks on carbon emissions in South Africa. The results indicate an optimistic 12.33% decrease in carbon emissions within the transport sector and a 4.32% increase in the electricity sector, following a world reference scenario. However, when considering South Africa's specific economic structure and running GDP scenarios, the reduction in carbon emissions within the transport sector diminishes to 1.77%, accompanied by a 0.64% increase in the electricity sector. The study underscores that while the penetration of electric cars yields the most substantial carbon emission reductions, practical considerations, such as price parity and affordability across income groups, must be factored in to determine the feasibility of achieving these volume targets [13].

On a different note, a study in the United States emphasizes that EVs, by themselves, cannot solely achieve the most ambitious greenhouse gas (GHG) emission reduction targets. This challenge persists even as the energy source mix transitions away from coal and towards natural gas. Since traditional internal combustion engine vehicles will continue to dominate the light-duty vehicle fleet for several decades, efficiency improvements in conventional vehicles offer the most significant potential for GHG emissions reduction during this period [3]. Additionally, another study [5] highlights the substantial potential of promoting EVs in reducing transport GHG emissions in China. However, the intensity of this influence remains uncertain, contingent upon the penetration rate of EVs, the decarbonization of the power sector, and the efficiency improvements in EVs and internal combustion engine vehicles [5].

On the other hand, some studies caution against overlooking the potential negative effects of the widespread adoption of electric vehicles in the transportation sector. For instance, Ref [5] suggests that increased EV adoption leads to higher electricity demand, potentially resulting in increased GHG emissions from the energy sector. This phenomenon has been dubbed the "crowding-out effect" in a Chinese article, which suggests that carbon tax policies and new energy vehicle promotion policies may offset their positive emissions-reduction effects [10]. A global study adds another layer to this discussion, indicating that a 1% increase in green energy production depletes rare-earth-elements (REEs) reserves by 0.18% and raises GHG emissions during the exploitation phase by 0.90%. The cumulative effect of using permanent magnets in various applications resulted in a staggering 32 billion tons of CO2-equivalent GHG emissions globally between 2010 and 2020 [6].

Furthermore, a study conducted in Europe delves into the availability of mineral resources and their impact on electric vehicle recycling. It predicts that cobalt reserves, crucial for lithium-ion batteries, are likely to deplete. Surprisingly, recycling plays a substantial role in reducing the demand for materials in the production of lithium-ion batteries [18]. Another study [30] evaluates recycling subsidy policies in China, highlighting their influence on recycling effectiveness and economic benefits. It demonstrates that both recycling subsidies and technological advancements can enhance overall recycling rates and profitability. Specifically, subsidies incentivize manufacturers, while technological improvements engage retailers and third-party recyclers in the recycling of spent EV batteries. The system's growth can be sustained, even with the gradual withdrawal of recycling subsidies, as long as technology continues to advance [30].

4.2.2. Subsidies and Incentives Shaping the Future of EVs

In the realm of electric vehicles (EVs), various studies have examined the impact of subsidies and incentives on both EV adoption and emissions reduction. A study conducted in China explored the effects of acquisition subsidies and research and development (R&D) subsidies on EV demand and CO2 emissions reduction. While acquisition subsidies were found to stimulate short-term EV sales, they came at a higher cost. In contrast, R&D subsidies proved more effective in promoting long-term EV penetration, especially when implemented through dynamic schemes [4].

Ref. [25] delved into the application of System Dynamics (SD) methodology to analyze electric car incentive scenarios in the Netherlands and Norway. This study explored the implications of three incentive stimuli: continuing subsidies for EVs, taxing cars based on tailpipe emissions, and penalizing manufacturers based on the average tailpipe emissions of sold cars. Findings underscored the necessity of regulations on emission targets for manufacturers to facilitate the transition away from fossil fuel-based vehicles. Strong incentives were identified as crucial for achieving significant sales shares of zero emission vehicles [25].

Additionally, a study [29] conducted simulations to assess the impact of reducing or eliminating public subsidies for electric car purchases in the European Union. The findings highlighted that retaining these subsidies led to a higher electric car market share. Specifically, a medium-term purchase subsidy program offering €3000 for plug-in hybrid electric cars and €4000 for battery electric cars between 2020 and 2024 resulted in the fastest uptake of electric cars.

In Shanghai, reference [23] simulated the introduction of time-sharing electric vehicles under varying levels of government subsidies. Surprisingly, the study found that higher subsidies did not necessarily yield better results. In fact, private internal combustion engine vehicle users were most inclined to switch to time-sharing electric vehicles when subsidies were lower. This counterintuitive outcome emphasizes the importance of conducting thorough ex-ante assessments and comprehensive planning during industry development processes.

Moreover, reference [20] analyzed the impact of specific renewable energy incentives on electric vehicle deployments in the transportation system and investment in electricity generation capacity. The simulated results indicated that increasing wind capacity incentives accelerated the electrification of the transportation system, and the incentives for electrifying the transportation system influenced wind capacity positively. On the another issues, a study in China suggested that policies should focus on incentives for off-peak and time-division charging of EVs, which could further reduce the greenhouse gas emissions associated with electricity generation [5].

Shifting focus to policy effectiveness, in China, carbon tax policies for motor vehicles were examined, but their effectiveness was found to weaken over time. On the other hand, the promotion of new energy vehicles had mixed effects, while science and technology policies were more effective in reducing vehicle pollution and carbon emissions. However, a combination of policies might lead to a "crowding-out effect" [10]. Meanwhile, South African research emphasized that achieving emission reduction targets required considering factors beyond volume, including price parity and affordability across income deciles [13].

In the United States, incentives were introduced to expand electric vehicle fleets and renewable electricity generation. Simulation results revealed the positive impact of wind capacity incentives on electrification and the sensitivity of electric vehicle adoption to gas prices [20]. Besides, policy sensitivity analysis indicated that the best-case scenarios for government targets involved manufacturers' emission targets of zero emissions by 2030, along with the continuation of current incentives or emission taxes on car owners [25].

Ref [14] argued that effective policy instruments play important roles in facilitating the vehicle electrification process, in view of the need to foster the demand for EVs at the crucial stage of EV market penetration. Thus, the introduction of adequate fiscal incentives, favoring cleaner technology that generates fewer negative externalities, may represent a valuable "carrot-and-stick" policy instrument [14].

Ref [16] suggested that governments must explore options such as purchase subsidies to promote EVs. The model identified a 25% reduction in the purchase price as required, along with additional policy actions like discounts in the cost of electricity and carbon taxes to achieve EV adoption targets. Ref [19] also emphasized that, at the early stage of EV development, the government needs to provide a variety of subsidies or tax exceptions to promote popularization and improve consumer awareness of EVs. Furthermore, it recommended considering charging prices and developing a reasonable price mechanism to guide an orderly charging pattern, without compromising the advantages of EVs in cost and environmental aspects [19]. Additionally, attracting private vehicle users to the electric-sharing mode requires careful consideration of government subsidies, which should be kept at a comparatively low level [23].

In a study in China, an increase in the cost of motor vehicle trips through appropriate carbon tax policies was suggested. This approach encourages low-carbon trips by private cars and trucks. However, the implementation of carbon tax rates should be adjusted in a timely manner according to economic development [10]. Ref [25], drawing on the policy sensitivity analysis, the best-case scenarios for government targets are the policy simulations that include at least (i) manufacturers' emission targets of zero emissions by 2030, and either (ii) the continuation of current incentives or (iii) emission taxes on car owners [25].

As a summary, across these studies, a recurring theme emerged: governments must explore various options, such as purchase subsidies and discounts on electricity costs, to promote EV adoption. However, it was noted that high purchase subsidies alone were not a long-term solution, and the sustainability of EV market growth relied on market mechanisms rather than perpetual subsidies [9]. While the current evolution of battery prices is favorable, electric car purchase subsidies remain an effective policy measure to support electro-mobility in the coming years. In contrast, very high purchase subsidies alone did not lead to long-term EV market success. Subsidies could only promote the availability of EV technologies in the short term, and market growth beyond the initial deployment phase needs to be sustained by market mechanisms other than subsidies. Due to technology competition dynamics, offering EV purchase subsidies before all technologies are available could lead to technology lock-in and inhibit the long-term maturity of less developed technologies [9].

To conclude, these findings collectively underline the multifaceted nature of policy considerations in shaping the future of electric vehicles, from subsidies to incentives and beyond, as governments worldwide grapple with the challenge of transitioning to sustainable transportation systems.

4.2.3. Embarking on Transport Modalities

Ref [17] shifts the focus to the advantages of transit metropolis construction, emphasizing the pivotal role played by new energy sources and low-emission vehicles in the quest to curtail vehicle-related emissions. The study's projections indicate a substantial 70% reduction in nitrogen oxide emissions, a transformation with profound positive implications for urban environments [17]. In a complementary perspective, Ref [23] accentuates the importance of transitioning private vehicle users toward shared mobility modes as a strategic approach to achieving emission reduction targets [23].

Furthermore, Ref [11] employs a system dynamics model to propose a set of mitigation measures aimed at diminishing fossil fuel consumption and CO2 emissions stemming from road transport in Lebanon. These measures encompass elevating the market share of fuel-efficient and hybrid electric vehicles and enhancing the utilization of bus services. When executed in concert, these strategies paint a promising picture of substantial emissions reductions anticipated by 2040 [11].

Ref [16] simulated the adoption of alternative transportation options (E85, EVs, CNG) in India until 2050, projecting they could comprise 34% of private vehicles but lead to 668.75 million tons of CO2 emissions. Meeting government targets for EVs and ethanol blending requires substantial investments in cost and infrastructure. Policy options and technology milestones were explored, but ambitious government goals face challenges, including high EV prices and limited charging infrastructure [16].

4.2.4. Promotion of Electric Vehicle Awareness

Awareness and knowledge of the electric vehicles vitality and benefit is also an important policy instrument to go for in an effort to publicize the technology in the market and win the interest of the users themselves [10, 14, 15, 19, 21, 24, 31]. In fact, due to the high familiarity of customers with conventional powertrains, market introduction of alternative powertrains will become very difficult as competition is high [21]. Ref [10] stated that promotion of new energy vehicles such as electric vehicles is vital to penetrate the market, but should be made in a way to avoid negative effects such as large amount of energy consumption. It has stressed that efforts should be made to strengthen the publicity of energy conservation, emission reduction, and green travel; raise residents' awareness of environmental protection; and then make travellers take the initiative to choose green travel [10]. It also promotion of new energy vehicles such as EVs should be appropriate to avoid negative effects such as large amount of energy consumption, while giving the priority of promoting them in the fields of public transportation and trucks [10].

A study in the Netherlands recommended that market segmentation may serve to better understand how transition policies and strategies can target different classes of consumers. Accordingly, a more effective policy can be designed by considering EV development in each group. For instance, in the early stages of e-mobility, the main potential purchasers appear to be the young and middle-aged people with higher incomes in low-density cities. Accordingly, marketing and promotion activities should concentrate on this market segment, rather than the entire potential market [15]. Government subsidies and tax exceptions at the early stages of EV development were recommended to promote popularization [19]. Also, collaboration between industries was advised to accelerate technology improvements across vehicle ranges. The development of joint compliance strategies in order to penetrate the market and get consumers' willingness and decision to use EV. The automotive industry should not focus on improving conventional powertrain technology for selected vehicles or "prestige projects". Instead, technology improvements have to be consequently implemented across the whole range of vehicles offered. This way, customers have to choose efficient technologies, and compliance becomes independent of customers' purchasing behaviour. Just as in the context of emission reduction of conventional powertrains, automobile manufacturers should implement new technologies across the whole range of vehicles offered. A higher number of potential purchasers will be addressed, since the decision of customers is taken for a specific powertrain without vehicle size being a limiting factor [21].

However, the adoption of electric vehicles (EVs) faces challenges, for instance in India, where a sensitivity analysis identified purchase price and charging infrastructure as major hurdles [16]. Ref [29] utilized a system dynamics approach to analyze consumer and manufacturer resistance to EV adoption, considering factors like infrastructure, range anxiety, cost differences, and government policies [29]. Transitioning to low carbon vehicles in Japan revealed that infrastructure development had a minor impact on battery electric vehicle (BEV) penetration, with battery cost being a crucial factor [8]. Ref [18] assessed mineral resource availability for electric vehicle recycling in Europe, emphasizing the benefits of recycling for lithium-ion batteries [18].

4.2.5. Infrastructure, Technology, and Energy Generation

The studies discuss various aspects of infrastructure, technology, and energy generation in the context of electric vehicle (EV) adoption and greenhouse gas (GHG) emissions reduction Infrastructure, technology requirements, investment, and energy generation played key roles in electric vehicle projects. Studies emphasized investments in EV-related infrastructure and technology [2, 3, 8, 9, 10, 16, 17, 19, 21, 24], including scientific research [5].

Ref [2] used system dynamics for planning EV projects with solar energy generation, optimizing installation times and sizes of EV charging stations combined with solar PV. Ref [8] discussed the impact of infrastructure development on BEV growth, highlighting the importance of battery cost. In terms of the life cycle GHG emissions, staged implementation of infrastructure development is necessary to promote BEVs, and to mitigate the life cycle GHG emissions [8] Strengthening the support towards infrastructure construction such as charging facilities, and working towards improving the EV charging efficiency are recommended. Also, strengthen key technologies such as EV battery systems and improve EV performance and charging convenience will attract more consumers to choose EVs [19].

Infrastructure and policy correlation was explored, suggesting that strong plug-in electric vehicle (PiEV) policy could inhibit hydrogen fuel cell vehicle maturity [9]. Ref [5] emphasized increasing investments in EV scientific research and guiding enterprises and research institutions to develop key technologies. Ref [31] explored the synergies of the following four emerging technologies both qualitatively and quantitatively: wireless charging technology; shared mobility services technology; autonomous driving technology; and battery electric vehicle technology. Compared to a plug-in charging BEV system, a wireless charging and shared autonomous battery electric vehicles system pays back the additional GHG emission burdens of wireless charging infrastructure deployment within 5 years if the wireless charging utility factor is above 19%.

Besides, clean energy generation and carbon capture were identified as significant determinants of carbon emissions in the transport sector [1, 3, 10, 19]. Improving fuel efficiency, reducing exhaust emissions, and focusing on new energy vehicle technologies were recommended to achieve pollution and carbon reduction goals [10]. Vehicle stock turnover with cohort modelling is an important technique that can be used to estimate vehicle fleet inertia, vehicle growth, resulting emissions as well as impact of various policies on the transport sector in the future. Results reveal a significant reduction in the emissions and fuel consumption by the introduction of more fuel-efficient, alternate fuel vehicles into the vehicle stock. However, the inertia of the current stock creates resistance to the rapid transformation towards greener transport systems. Additional policy interventions are needed to speed up the transformation of the vehicle stock to more efficient vehicle types. Such intervention may include incentives to purchase BEV or FCEVs at discounted rates by returning the gasoline or diesel cars [7].

Moreover, investment in improving the internal combustion engine might be the cheapest, lowest risk avenue towards reducing GHG emissions. However, barring unexpected leaps in technological performance, policy and technology investment will have to both be leveraged to meeting the most ambitious GHG reduction targets in 2050 [3].

On another considerations, some of the generation technologies were neglected in the electricity market such as photovoltaic panels, nuclear power plants, hydroelectric power plants, and pumped storage power plants, which could have a considerable effect on price and load profile [20]. Battery production technology improvements are crucial for achieving emission reduction targets from EVs [16]. Ref [20] has pointed the importance of investment on expansion of transmission lines and distribution systems. It also highlighted finally the relevance of examining the effect of development in the technology of PEVs, batteries, charging stations, and the maturity of their technology on the whole system [20].

An international oil price rise affects vehicle penetration like a carbon tax while the more significant the infrastructure development the greater the associated capital and operating costs [8]. Strengthening support for infrastructure construction and key technologies like EV battery systems were suggested to attract more EV users [19]. Ref [10] suggested that investment is vital in improving fuel efficiency and reducing exhaust emissions can help to achieve vehicle pollution reduction and carbon reduction. Ref [10] also advised increasing capital and talent investment in vehicle production, fuel quality, and exhaust gas purification [10].

4.2.6. Policy Mix, Integration, and Regulation

The importance of adopting a mix of policies, integrating them effectively, and implementing regulations was highlighted to promote electric vehicle technology and achieve emission reduction targets [10, 11, 21, 24, 26, 27]. Collaboration between GHG and zero emission vehicle (ZEV) regulations was emphasized, suggesting that technology improvements should be implemented across the entire vehicle range in order to avoid civil penalties [21]. Mitigation policies and carbon pricing and/or carbon taxation would need to be pursued together if stringent stabilization targets are to be met at lower costs [26]. Government interventions tailored to consumer and manufacturer behavior were deemed important [4]. Thus, emission reduction policies should be integrated with promotion and publicity efforts towards energy conservation, emission reduction, and green travel, raise residents' awareness of environmental protection; and then make travellers take the initiative to choose green travel [24].

On the other hand, regulation on emission limits, adoption of a certain charging technology and electric vehicles are recommended by some of the studies such as [11, 21, 26, 27]. Having long term emission target regulations in place is necessary for technology transition. The most ambitious long term targets benefit PHEV and BEV when subsidies are also in place. And, higher regulatory emission targets appear to reduce sensitivity to charge point provision [9]. Also, ref [21] stated that the feedback structure between the GHG and ZEV regulatory requirements should be considered. To this end, a joint strategy has to be developed allowing compliance with both requirements simultaneously [21]. In the Netherlands and Norway, for instance, strong incentives resulted in large sales shares of zero emission vehicles so that it is suggested that regulations on emission targets incentives for manufacturers are necessary for a transition away from new sales of fossil fuel-based vehicles [25].

Finally, ref [26] find that a mix of efficient regulation and revenue recycling is required to support the low-cost achievement of the targets and that the more stringent targets can only be achieved at low costs by stronger regulation forcing an early penetration of key technologies, e.g. all-electric vehicle, and thereby allowing for substantial economies of scale and reductions in unit costs. Direct climate policy support supplements the effects of the increases in carbon prices, so that the accelerated adoption of new technologies leads to lower unit costs [26]. Ref [27] also suggested that binding national measures such as conventional car bans applicable from a pre-defined future date may be increasingly necessary.

Some studies also advocated long-term emission target regulations and incentives for manufacturers to transition away from fossil fuel-based vehicles [25]. Finally, on collaboration, a study in the US revealed that the US transportation sector, alone, cannot reduce the rapidly increasing atmospheric temperature and the negative impacts of the global climate change, even though the entire fleet is replaced with BEVs. Reducing the atmospheric climate change requires much more ambitious targets and international collaborative efforts [12].

5. Conclusions and Implications

In this study, the application of system dynamics models to the decarbonization of road transport through electric vehicles was systematically reviewed. Particular attention was placed on the models' structure and their components, sub-models and the respective functions, determining factors and variables, dynamic factors, their environmental impacts and policy implications along with the objectives that are meant to be achieved in each study. Much effort has been exerted to assess the studies so as to enlighten possible research perspectives on the application of system dynamics approach in evaluating environmental role of electric vehicles, and the respective policy implications. In terms of model's presentation, majority of the papers have presented all the three basic components of the SD model: causal loop diagram, stock-flow diagram and equations of the SD model, including the simulation periods, software applied and validation steps.

In addition, many of the articles have used a variety of sub-models and sub-methods. Among the sub-models developed are: energy-economic sub-model and carbon-emission sub-model; energy supply sub-model, fuel production sub-model, electricity grid sub-model, and vehicle sub-model; transportation sub-model, environmental sub-model, economic sub-model, and social sub-model. The Powertrain Technology Transition Market Agent Model (PTTMAM); Transport, Energy, Economics, Environment (TE3); and the Energy-Environment-Economy Model at Global level (E3MG) are among the important sub-models employed to support the analysis of the system dynamics models. Also, life cycle assessment (LCA) method, life cycle sustainability assessment (LCSA), the greenhouse gases, regulated emissions, and energy use in transportation (GREET) model along with the IPCC's method of calculating the carbon emissions in transportation are applied in a few of the articles.

The first conclusion of this literature review is related to the limited boundaries of the models to represent the system. Overall, system dynamics models were found for the electric vehicles decarbonization roles, with varying levels of details, where skewed attention is given mostly to policy variables that are enabling to the success of the market penetration and decarbonization effort. The attention given to the estimations of the emission reduction quantities by the electric vehicles only are limited and none of them has addressed clearly how and when a given level of emissions reduction could be achieved, except the final simulation or scenario time. As clearly discussed in the introductory part of the paper, road transport has a systemic nature, whereby changes in one element affect other elements of this system over time. A partial or isolated view limits a final evaluation of the most effective measures or policy actions. The coordination of different policy measures is expected to be a fundamental challenge for the penetration of EVs and decarbonization efforts of the road transport system in the coming years. Methods need to be developed to study the interaction of different policy measures.

The second conclusion taken from the literature review analysis is the lack of transparency in some studies concerning the system dynamics software that has been used in the analysis. Although most authors provide their simulation periods along with the simulation results, they did not clearly present the background of pathways or the delay assumptions for each decision to achieve the results in those defined terms. The dynamic component of the reviewed system dynamics models in a few papers is often not clear, which is observable through the absence of model equations, system dynamics diagrams, and even model descriptions and assumptions. For this reason, the SD community should focus on describing the time component of their models, either through actual data or assumptions, to deepen discussions regarding the problem, including the model's equations representing the time-oriented stock and flow variables.

Thirdly, there is also clear absence of transparency in a few studies whether or not the study has empirically has tested and validated the system dynamic model. Understanding should also be established that an important step in any SD model's development, i.e., validation, should be clearly conducted before making any policy implications or recommendations. Without making sure the model is valid and works on the ground, it is irrational to make policy implications that have no practical relevance. In fact, there are many challenges on the ground in testing and validation phases of the model development. In practice, it is very difficult and demands a huge effort to get fully all the data required for the validation process. Estimating quantitatively the factors or relationships between agents, such as market acceptance of the new vehicle technologies, and policy variables is expected to be another potential challenge. It may be acceptable to make certain feasible assumption this stage since no model is perfect and established without assumptions. We should at least present the causal link or the associated time delay in the model process.

On another hand, most of them have included in their analysis the impact of introducing electric vehicles on the environment, especially in emission reduction. All the papers have directly or indirectly pinpoint one or more of the policy implications such as investment policy, incentive and subsidy policy, technology, innovation, substitution and adoption policy and factors determining adoption and diffusion of the technology, and indirect or counterbalancing effects of development of electric vehicles. The scenarios applied in the reviewed studies were diversified across economic growth, transport modes partially, fuel-efficiency, infrastructure, and emission reduction targets.

The fourth conclusion we can make here is that the introduction of electric vehicles decreases the emission of greenhouse gases in different parts of the world, though the introduction and penetration process possess significant technological, structural, fiscal, and market challenges to attain the required levels of emission reduction in the transport sector. Electric vehicle substitution, clean energy generation, and its utilization are the main factors of carbon emission reduction. With the presupposition that electric vehicles can reduce carbon emission, various forms of incentives (such as purchase subsidies) are suggested in order to boost demand and adoption for electric vehicles and thus attain the emission reduction targets. The introduction of adequate fiscal incentives, favoring cleaner technology that generates less negative externalities, may represent a valuable "carrot-and-stick" policy instrument.

Fifthly, we conclude from the review that it is vital to adopt, not a single and isolated policy, rather a mix of various policy instruments in order to effectively introduce the electric vehicle technology and achieve the greenhouse gas emission targets in different parts of the world. It is also vital to put regulatory requirements on the technology and emission reduction targets. Besides, the dynamics and time responses of market penetration of electric vehicle technologies can be identified by analyzing organizational adoption behaviors, considering the competition that arises from the already familiarized and adopted traditional vehicle technologies and how it would impact the dynamism of adoption of the electric vehicle and related technology.

As a summary, in the pursuit of decarbonizing the road transport sector, electric vehicles (EVs) play a pivotal role. This document explores policy implications and recommendations related to investment, subsidies, marketing, and regulation for promoting EV adoption and achieving carbon emissions reduction targets. The transition to electric vehicles is critical for reducing carbon emissions in the road transport sector. This document outlines key policy considerations to facilitate this transition. The transition to EVs is closely linked to the adoption of carbon capture technologies and clean energy generation and storage.

Improving internal combustion engine efficiency is a cost-effective way to reduce greenhouse gas emissions. Enhanced investment in EV-related infrastructure, including charging facilities, is essential to support EV adoption. Improving EV charging efficiency and battery technology can attract more consumers to choose EVs. Government purchase subsidies and incentives significantly influence EV adoption when strategically implemented. The effectiveness of various subsidy and tax strategies on the EV market varies in the short and long term. Effective marketing and promotion are essential to raise awareness and generate interest in EVs. Tailoring marketing efforts to different consumer segments can optimize EV adoption.

A mix of policy instruments is necessary to address the complexities of transitioning to EVs effectively. Regulatory requirements, including emissions limits and technology standards, play a crucial role in driving EV development. These findings and insights provide a comprehensive overview of the policy considerations related to EV adoption and carbon emissions reduction in the road transport sector. Policymakers, researchers, and industry stakeholders can use this information to inform their decisions and actions in promoting greener transportation solutions. In conclusion, a comprehensive approach encompassing investment, incentives, marketing, and regulation is vital for accelerating the adoption of electric vehicles and achieving carbon emissions reduction targets.

The study suggests that future researches should consider a holistic model with all possible factors, variables and actors related to electric vehicle's role in the road transport decarbonization process and the respective time lag outcomes so as to develop a more realistic, valid and plausible system dynamics model in the field. It also proposes the rebound effect of transport efficiency on logistics costs and prices, goods and services prices and, subsequently, on demand for travel and transportation. The role of electric vehicles in the carbon emission reduction effort in Africa is not explored and can be a potential research agenda. It also recommends that it would be feasible to explore the role of electric vehicles in reducing emissions at mode of transportation level, such as private, public, or taxi.

Finally, it is important to note that the current search results is subject to improvements, as there may be studies not included here, either because they are not in Google scholar database at the time of the search or because they do not contain the keywords used in our search. Given these potential gaps, this paper is believed to be useful in serving as reference or threshold for researchers in using the system dynamics approach in the analysis of road transport decarbonization strategies through the development of electric vehicles.

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Appendix:

Title, objectives, sub-models, main findings and suggestions of the 31 articles selected for the SLR

File No.	Title of Article	Main Objective	Sub-Models and/or Sub-Methods***	Main Finding	Main Suggestions or Policy Implications
1	System dynamics model of Beijing urban public transport carbon emissions based on carbon neutrality target	Studying the carbon emissions of public transport in Beijing, mainly bus, taxi, and rail transit from fuel consumption and electricity.	Energy-economic model; carbon-emission sub-model; symbolic regression method	Electric vehicle substitution and carbon capture, clean energy generation, utilization and storage are the main factors of carbon emission reduction.	It can provide essential information for policy-makers to advance Beijing's future low-carbon development in public transport. The electric vehicle substitution, clean energy generation and carbon capture, utilization and storage provide a new perspective to research carbon emissions in the transport sector.
2	Planning and optimizing electric-vehicle charging infrastructure through System Dynamics	Developing a framework for planning and analyzing EV projects with solar energy generation.	Evolution optimization method	The staging plan optimizes the sizes and times of installing EVCSs combined with solar PV keeping the EV-PV project at maximum economic and environmental targets.	The proposed framework can find the optimum staging plan for EV and PV infrastructure based on the policy choices. The optimum policy can affect the optimum power infrastructure limit to maximize the economic benefit by the solar tariff.
3	The Future Adoption and Benefit of Electric Vehicles: A Parametric Assessment	Analyzing the set of market, technology, policy, and economic characteristics that could drive adoption of electric vehicles and/or lead to notable reductions in fleet greenhouse gas emissions.	Energy supply; Fuel production; vehiclel; and Electricity grid sub-model; and Monte Carlo simulation	While electric vehicle (EV) adoption can reduce petroleum consumption and greenhouse gas (GHG) emissions from light-duty vehicles (LDVs), it cannot achieve the most aggressive GHG reduction targets, even with a shift in electricity sources from coal to natural gas.	Investment in improving the internal combustion engine might be the cheapest, lowest risk avenue towards reducing GHG emissions.
4	Designing government subsidy schemes to promote the	Examining the effects of different subsidy schemes on the development of the EV	Consumer Discret Choice Model	Both acquisition and R&D subsidies promote EV adoption and reduce CO2 emissions. Acquisition subsidies drive short-term sales but cost more. R&D	Relying solely on government subsidies to meet long-term EV industry targets is not feasible. Instead, targeted government

	electric vehicle industry: A system dynamics model perspective	industry and on environmental protection.		subsidies are cost-effective for long-term EV penetration and emissions reduction.	interventions addressing key factors influencing consumers and manufacturers are needed.
5	Transport oil product consumption and GHG emission reduction potential in China: An electric vehicle-based scenario analysis	Analyzing the effects of the introduction of EVs in China.	CTEGER; ECMs; ADL; Cointegration; WTW	Promoting EVs in China has the potential to significantly reduce transport GHG emissions, but the extent of this impact depends on EV penetration, power sector decarbonization, and vehicle technology improvements.	Policies should incentivize off-peak EV charging to reduce GHG emissions from electricity. Increasing investments in EV research and involving enterprises and research institutions in key technology development is crucial.
6	Global environmental cost of using rare earth elements in green energy technologies	Analyzing environmental impact of using rare earth elements in green energy technologies globally.	LCA & GMM; GREET model.	An increase by 1% of green energy production causes a depletion of REEs reserves by 0.18% and increases GHG emissions in the exploitation phase by 0.90%. Our results demonstrate that between 2010 and 2020, the use of permanent magnets has resulted cumulatively in 32 billion tonnes CO2-equivalent of GHG emissions globally.	We need innovative methods for decarbonization. This underscores the importance of adopting strategies to enhance the reuse and recycling of REEs, reduce dematerialization, promote substitution, and advance elimination technologies. These steps will aid the development of sustainable strategies for green energy technology and decarbonization.
7	Modeling and understanding the impacts of efficiency measures on fleet fuel consumption in vehicle importing countries: A case study of Qatar	Examining how vehicular composition and turnover rate affects the energy consumption patterns of a country that imports all of its vehicles and is both oil- and gas-rich.	GREET; Vehicle Cohort Modeling	In an extreme scenario with battery electric vehicles prevailing, they notably cut emissions, reducing over 8 million tons of CO2. However, the fuel consumption savings are not as substantial because gasoline vehicles are replaced by electric ones, leading to an increase of over 8 TWh in electricity consumption.	Fuel-efficient vehicles reduce emissions and fuel consumption, but the existing vehicle stock's inertia slows the transition to greener systems. Policy incentives, like discounts for electric or fuel cell vehicle purchases in exchange for returning traditional cars, are needed for faster change.

8	Impact of low emissions vehicles on reducing greenhouse gas emissions in Japan	Examining transitioning to low carbon vehicles such as battery electric vehicles (BEVs), hydrogen fuel cell vehicles (FCVs), and natural gas vehicles (NGVs) for curbing GHG emissions in Japan	MNLM	Infrastructure development has a minor impact on the penetration of BEVs with BEVs growing more slowly with a higher carbon tax. Battery cost is an important factor for BEV growth. BEVs start to grow faster after the battery cost reaches its lowest level 2029.	Staged implementation of infrastructure development and a higher carbon tax is necessary to promote BEVs, FCVs and NGVs and to mitigate the life cycle GHG emissions.
9	An exploratory policy analysis of electric vehicle sales competition and sensitivity to infrastructure in Europe	Bringing about further understanding for policymakers regarding the interaction between e-mobility and related infrastructure.	PTTMAM	Robust plug-in electric vehicle (PiEV) policies may hinder the development of hydrogen fuel cell vehicles. While infrastructure is vital for PiEVs, it may have a weaker impact on uptake in the early market until PiEVs reach a share of around 5%.	The results of our study can help policymakers to find the right balance and timing of measures targeting the transition towards low carbon alternative vehicles Reffer to Ref [9] for further policy insights.
10	Modeling and simulation analysis of vehicle pollution and carbon reduction management model based on system dynamics	Establishing a management model of vehicle PRCR, and exploring the emission reduction effects and other benefits of different policies.	IPCC's carbon emission calculation method	1. Carbon tax policies lose effectiveness over time, and new energy vehicle promotion has limited impact. 2. Science and technology policies lead to significant pollution and carbon reduction by 2030. 3. Multiple policies don't always yield more CO2 reduction; a "crowding out effect" can occur.	1. Invest in vehicle production, fuel quality, and exhaust gas purification to reduce pollution and carbon emissions. Improve fuel efficiency and reduce exhaust emissions. 2. Encourage low-carbon transportation by raising the cost of motor vehicle trips for private cars and trucks. Promote energy-saving, emission reduction, and green travel awareness among residents to encourage eco-friendly choices.
11	Future Trends and Mitigation Options for Energy Consumption and Greenhouse Gas Emissions in a Developing Country of the Middle East	Proposing mitigation measures based on Lebanon's commitments for reducing fossil fuel use and CO2 emissions from road transport by increasing the share of fuel-efficient and hybrid	ForFITS model	Increasing fuel-efficient vehicle market share to 35% by 2040 stabilizes emissions. Adding hybrid vehicles at 10% saves 11%. Boosting bus travel share to 45% reverses impacts. Combining all measures results in a 63% reduction by 2040.	For a sustainable national transportation system, we need a strategy that integrates measures and policies for long-term functionality and sustainability.

	Region: a Case Study of Lebanon's Road Transport Sector	electric vehicles and increasing the utilization of the existing bus service			
12	Integration of system dynamics approach toward deepening and broadening the life cycle sustainability assessment framework: a case for electric vehicles	Developing a more deepened and broadened approach from a system perspective in order to provide an in-depth sustainability impact assessment of alternative vehicle technologies	LCSA; Transportatio n; Environmenta l; Economic; & Social sub model; DICE model.	BEVs excel in sustainability in many categories. Benefits like job creation, GDP growth, and CO2 reduction increase by 2050. However, BEVs have higher ownership costs and health impacts in the 2010s and 2020s. Manufacturing impact rises as vehicle performance improves over time.	To improve future sustainability assessments (LCSA), we need to account for the intricate relationships among sustainability indicators. Addressing climate change demands ambitious global goals and cooperation. The choice of vehicle types has a limited effect on public well-being, which depends on income, education, and life expectancy.
13	Using a System Dynamics Modelling Process to Determine the Impact of eCar, eBus and eTruck Market Penetration on Carbon Emissions in South Africa	Providing an overview of the system dynamics method applied for understanding the impact of electric-bus, -car, and -truck market penetration on carbon emissions in South Africa, through the development of the electric mobility simulator.	NA	The results indicate that the World Reference scenario is the most optimistic, with a 12.33% decrease in carbon emissions in the transport sector and an increase of 4.32% in the electricity sector. But, if the economic structure that is specific to South Africa is to be considered and the GDP scenario is run, then there would only be a 1.77% decrease of carbon emissions in the transport sector and an increase of 0.64% in the electricity sector	Although the eCar market penetration produces the highest reduction in carbon emissions, the volumes that are required are large and other factors, such as price parity and affordability in the various income deciles, would have to be considered in determining whether this volume is achievable.
14	EV Market Development Pathways: An Application of System Dynamics for Policy Simulation	Exploring several possible EV market development pathways and their corresponding impacts on oil demand and CO2 emissions in key countries.	NA	EVs will reduce oil demand and CO2 emissions in selected countries by 2030 and continue to do so afterward. They'll lower reliance on non-renewable resources and cut road CO2 emissions, helping achieve energy and environmental goals.	Offering fiscal incentives for cleaner technologies can be a powerful policy tool. Calculating emission savings across countries can provide valuable insights into global road transport mitigation efforts.
15	Toward the Dynamic Modeling of Transition	Developing a theory-guided and entity-based simulation model to	NA	The results highlight how innovation policies affect the EV market through subsidies and resource allocation. This	The model is adaptable for various e-mobility challenges by modifying entities. Market segmentation helps

	Problems: The Case of Electric Mobility	better understand, among others, electric vehicle (EV) adoption processes as a specific yet core element driving business innovation.		simulation approach deepens our understanding of e-mobility transition challenges.	tailor transition policies for different consumer groups. Initially, younger, wealthier individuals in less crowded areas are the primary e-mobility consumers, so marketing should target them.
16	System dynamics-based assessment of novel transport options adoption in India	Studying the adoption of the novel options (ethanol blended fuel (E85) vehicles, electric vehicles (EV), and compressed natural gas (CNG) vehicles) for private transport needs in India	MNLM; ARX	By 2050, E85, EVs, and CNG vehicles may make up 34% of private vehicles, emitting 668.75 million tonnes of CO2. Meeting EV and ethanol blending goals requires cost and infrastructure upgrades. High EV prices and limited charging infrastructure hinder greater adoption.	The government should consider purchase subsidies for EVs, aiming for a 25% price reduction. To meet EV adoption goals, other actions like discounted electricity and carbon taxes are necessary. Improving battery production technology is crucial for reducing greenhouse gas emissions.
17	System Dynamics Analysis of the Relationship between Transit Metropolis Construction and Sustainable Development of Urban Transport: Nanchang, China	Analyzing systematically the benefits of transit metropolis construction	NA	By developing new energy vehicles and low-emission vehicles, vehicle emissions will drop from 0.05 tons/year to 0.04 tons/year, and overall nitrogen oxide emissions will fall by 70%, which is significant for urban environments.	The research results provide theoretical support for the significance of transit metropolis construction, and promote the sustainable development of urban transportation.
18	Availability of Mineral Resources and Impact for Electric Vehicle Recycling in Europe	Assessing availability of mineral resources and impact for electric vehicle recycling in Europe.	SRI Matrix	They find that for lithium ion battery needs, only cobalt is likely to see its reserves depleted. Other materials such as nickel, manganese, copper, graphite and iron are at risk of depletion due to developments unrelated to electro-mobility. In all cases, we show that recycling significantly reduces the consumption of materials for lithium-ion batteries	Contrary to public perception, lithium won't run out even with widespread EV use. However, supply risks like geographic concentration and geopolitics require a multi-criteria criticality assessment.

19	Scale Evolution of Electric Vehicles: A System Dynamics Approach	Simulating and forecasting the scale of the Electric Vehicles (EVs)	Delphi Method; LWGM	In the early stage of EV development, because of the low level of technology and imperfect infrastructure construction, the evolution of EVs will be restricted. Government policy will be the main factor which can be used to promote the development of EVs.	In the early stages of EV development, governments should offer subsidies, tax incentives, and infrastructure support to promote awareness. Enhance EV battery systems, performance, and charging convenience to attract more consumers.
20	On the Role of Renewable Energy Policies and Electric Vehicle Deployment Incentives for a Greener Sector Coupling	Analyzing the impact of the specific renewable energy incentives on both deployment of electric vehicles in the transportation system and investment in capacity generation in the electricity market.	NPV; Logit Model	Increasing the wind capacity incentives accelerated the electrification of the transportation system and increasing the incentives for electrification of transportation system influences wind capacity positively. Moreover, the sensitivity of the electric vehicle adoption to gas price is more than the sensitivity of the wind capacity penetration to gas price.	Future research can explore the impact of PEV, battery, and charging technology advancements on the overall system. Investigating the influence of renewable energy and EV adoption on the ESS market is also important. Additionally, analyzing pricing and charging strategies at DC stations should be considered. Finally, incorporating transmission and distribution system expansion will enhance models for policymakers.
21	Impact assessment in the automotive industry: mandatory market introduction of alternative powertrain technologies	Examining fundamental automobile manufacturer strategies for compliance.	NA	Results show that meeting requirements necessitates an early introduction of alternative powertrains in many vehicle segments. In order to comply with GHG regulatory requirements, reduction of GHG emissions is necessary for almost every conventional powertrain that is supplied to the market.	Automakers must adopt joint strategies to meet GHG and ZEV regulations. Swiftly introducing alternative powertrains across their lineup is vital to avoid penalties. Hybrid solutions are recommended for the short and medium term due to battery tech limitations. Pursuing GHG and ZEV compliance together is crucial; they should not be separate endeavors.
22	Addressing the Sustainability Issue in Smart Cities: A Comprehensive Model for	Evaluating environmental, social, and economic impacts exerted by the diffusion of electric vehicles (EVs)	LCA	An increase in the number of EVs results in less air pollution and, therefore, minor public health expenditure. System Dynamics, in particular, allows singling out causal relationships among variables,	Cost savings can incentivize EV purchases, creating a greener fleet in a self-reinforcing cycle. Further research is needed to analyze pollutant emissions and costs using

	Evaluating the Impacts of Electric Vehicle Diffusion			thus anticipating possible effects of planned policy actions	updated data and a broader pollutant range for model development.
23	Assessment of the Development of Time-Sharing Electric Vehicles in Shanghai and Subsidy Implications: A System Dynamics Approach	Simulate the effect of introducing time-sharing electric vehicles in changing the user quantities in transportation tools, including public and private sectors, under different levels of government subsidies, thus providing policy implications and ex-ante assessment for the subsidies	NA	It is not the greater the subsidy, the better the effect. It is actually under low subsidy that private internal combustion engine vehicle (ICV) users are most attracted to the TSEVs compared to the medium and high ones. The gap between the simulation results and common sense reminds us that ex-ante assessment and overall planning in the process of industry development are necessary	Results gave us some subsidy implications that for the specific purpose of attracting private vehicle users to the sharing mode, the government subsidies should be carefully considered and kept at a comparatively low level. In future work, focus will be laid on the portrayal of the actual user choice through questionnaires to obtain the joint probability distribution of cost–convenience, and make the study more practical and applicable to the city.
25	Analysis and testing of electric car incentive scenarios in the Netherlands and Norway	Analyzing and testing electric car incentive scenarios in the Netherlands and Norway.	PTTMAM; Theil's Inequality Method; Loop Knock-out Method	Regulation on emission targets for manufacturers are necessary for a transition away from new sales of fossil fuel-based vehicles. Only strong incentives resulted in large sales shares of zero emission vehicles in the Netherlands and Norway.	The best scenarios for governments' 2030 targets involve three policies: zero-emission vehicle (ZEV) manufacturer targets, existing incentives, and emission taxes on car owners. However, even with these policies, achieving a 50% ZEV sales share by 2030 is uncertain, according to the analysis. Including all three policies makes it more likely, while dropping any of them reduces the likelihood of reaching the target.
26	Modeling Low Climate Stabilization with E3MG: Towards a 'New Economics' Approach to Simulating Energy-	Assessing the implications of a low - stabilization target of 400ppm CO2 equivalent by 2100, assuming both fiscal instruments and regulation	E3MG	If governments adopt more stringent climate targets for rapid and early decarbonization, such actions are likely to induce more investment and increased technological change in favor of low-carbon alternatives. Contrary to the conventional view on the economics of	Efficient regulation and revenue recycling are needed for cost-effective target achievement. Stringent goals require strong regulation to push early adoption of key technologies like all-electric vehicles, reducing costs. To meet

	Environment-Economy System Dynamics			climate change, a transition towards a low-carbon society as modeled with E3MG leads to macroeconomic benefits, especially in conditions of unemployment, with GDP slightly above a reference scenario, depending on use of tax or auction revenues. In addition, more stringent action can lead to higher benefits	strict targets economically, complementary mitigation policies alongside carbon pricing or taxation are essential. Climate policy support enhances technology adoption, reducing unit costs and reinforcing price signals.
27	Simulating the battery price and the car-mix in key electro-mobility markets via model coupling	Exploring future battery electric and plug-in hybrid electric powertrain deployment in key electro mobility markets.	PTTMAM; TE3	The reliance on conventional cars in these scenarios leads to the situation that GHG emissions and air pollution are not curbed as desired by policy makers. Conventional car technology continues to dominate the car-mix. And, battery price remains a crucial explanatory variable for annual electric car sales in simulation exercises.	(i) sub national measures need to be further analysed; (ii) binding national measures such as conventional car bans applicable from a pre-defined future date may be increasingly necessary; (iii) non-motorized modes, public transport and zero tailpipe emission technologies may still have a greater role to play.
28	Electric Vehicle Adoption in India: A Study Based on System Dynamic Approach	Understanding policy resistant behavior of consumers and automotive manufacturers towards EV adoption through system dynamics approach.	NA	EV adoption is related to various variables like infrastructure, battery charging stations, range anxiety, the cost difference between EVs and ICEVs, environmental awareness and government policies. The underlying effects of various interlinked variables that effect the EV adoption is identified and represented using CLD. System dynamics approach is very helpful in understanding policy resistance behavior of people towards any new initiative.	The model can be used to understand and forecast the determinants of EV adoption in the near future. This paper gives the insight into the topic through system dynamics modelling. The system dynamics model gives more practical approach in solving the real life situations by analyzing cause and effect relationships.
29	The Effect of Reducing Electric Car Purchase Incentives in the European Union	Exploring the potential effect of reducing or removing electric car purchase public subsidies in the	PTTMAM	The electric car market share is higher when the subsidies remain in place. In the medium-run, a purchase subsidy scheme granting €3000 for plug-in hybrid electric cars and €4000 for battery electric	Though the current evolution of the battery price is favorable, electric car purchase subsidies remain an effective policy measure to support electro-mobility in the next years.

		European Union		cars over the period 2020–2024 yields the fastest electric car market uptake of all the scenarios considered	
30	Electric Vehicle Battery Recycling: System Dynamics Game Based Analysis for the Influencing Factors	Evaluating several recycling subsidy policies being considered and tested in China for their influences on recycling effect and economic benefits.	Game Theory	Both recycling subsidy and advancement in technology could improve total recycling rate and profit. The former can improve recycling rate of manufacturer while the latter can raise the interest of retailer and third-party recycler in spent EV battery recycling. Even with gradual withdrawal of recycling subsidy, the system could still maintain steady growth as long as the technology advances to a higher level.	The results could provide support to manufacturer in managing the multi-channel recycling system and the government agencies in optimizing the recycling policy. The hybrid method, game theory combined with system dynamics, can improve the limitations of these two methods and can be applied to other complex systems with game traits.
31	Wireless charging and shared autonomous battery electric vehicles (W+SABEV): synergies that accelerate sustainable mobility and greenhouse gas emission reduction	Evaluating and demonstrating the synergies of the following four emerging technologies both qualitatively and quantitatively: wireless charging technology; shared mobility services technology; autonomous driving technology; and battery electric vehicle (BEV) technology.	LCA	Compared to a plug-in charging BEV system, a W+SABEV system pays back the additional GHG emission burdens of wireless charging infrastructure deployment within 5 years if the wireless charging utility factor (ratio of en route charging time vs. trip time) is above 19%.	Shared mobility and eco-driving are key drivers to reduction of GHG payback time due to the benefits of fleet size reduction and fuel efficiency improvement brought by each technology respectively.

(Source: Own Summary from SLR Articles, 2023)