PLOS CLIMATE

RESEARCH ARTICLE

The enablers, opportunities and challenges of electric vehicle adoption in Qatar: A systematic review of the literature and assessment of progress toward transportation transformation targets

Abdulla Al-Shaiba[1], Alexandra Wilson[2], Logan Cochrane[1]*

1 College of Public Policy, Hamad Bin Khalifa University, Doha, Qatar, **2** School of International Development and Global Studies, University of Ottawa, Ottawa, Ontario, Canada

* lcochrane@hbku.edu.qa

Citation: Al-Shaiba A, Wilson A, Cochrane L (2023) The enablers, opportunities and challenges of electric vehicle adoption in Qatar: A systematic review of the literature and assessment of progress toward transportation transformation targets. PLOS Clim 2(9): e0000271. https://doi.org/10.1371/journal.pclm.0000271

Editor: William Usher, KTH Royal Institute of Technology: Kungliga Tekniska Hogskolan, SWEDEN

Received: May 16, 2023

Accepted: July 24, 2023

Published: September 5, 2023

Data Availability Statement: All data used for the analysis in this paper are shown in this paper and/or referenced.

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

Abstract

Governments around the world are working to reduce greenhouse gas emissions, and the transportation system is focal to the transition toward more renewable energy sources. The State of Qatar has transitioned buses in its public transportation system to be fully electric and has set a 2030 target for 10% of all new sales of vehicles to be electric vehicles (EVs). Although constrained by data limitations, this paper synthesizes and assesses the evidence and makes recommendations to support the transportation transition. OBJECTIVE: This paper assesses the available evidence on EV transitions in Qatar, identifying enablers and barriers through the use of a systematic literature review and data obtained from government sources within Qatar. METHODS: The systematic literature review was conducted in March of 2023 using two academic databases (Scopus and Web of Science). Only English language peer-reviewed articles, books, and conference proceedings pertaining to Qatar and EVs or EV charging stations were included. No resources were identified on an Arabic language database. RESULTS: The systematic review process identified 26 relevant publications, which is synthesized and critically assessed into the following thematic clusters: (a) assessments related to the electrical grid and diversifying the energy mix, (b) the planning and distribution of charging stations, and (c) knowledge, attitudes, and behaviors as it relates to the socio-cultural dimensions of EV adoption. DISCUSSION: The authors conclude that to meet the 2030 target, the State of Qatar must improve data collection for monitoring, rapidly expand charging station infrastructure, enable private sector engagement, and raise awareness regarding EVs to change consumer perception and choices. They explore the specific policy interventions that these domains require for the country to meet its transportation transition objectives. OTHER: This review received no funding, and the authors have no registration name or number to declare.

Introduction

In response to the challenges of climate change and in seeking to fulfil the commitments governments have made to reduce their greenhouse gas (GHG) emissions, domestic transportation systems are rapidly transitioning from hydrocarbon-based fuel vehicles to electric vehicles (EVs). This push has come as the result of the transportation sector being responsible for approximately 25% of CO_2 emissions globally and the commitment of over 160 nations to the Paris Agreement in 2015 aimed to keep global temperatures from surpassing 2˚C [1, 2]. Individual nations have had to commit to their own plans to decarbonize, via the Nationally Determined Contributions (NDCs). With regard to EVs and transportation system transformation, governments have set a wide range of time-bound targets with incentives and disincentives put in place to enable the desired change (e.g., subsidies, tax breaks, tariffs, bans, phase-out plans, percentage sales targets) [3, 4]. Although the concept of EVs is not new, it was not until 2010 when major vehicle manufacturers began making EVs accessible. The transition was then supported, variably by country, with the provision of government supports alongside technological and infrastructural advances. According to the International Council on Clean Transportation [5], starting from tens of thousands of EV sales in 2011, the world reached 1 million EV sales in 2016, which increased substantially, to nearly 7 million, in 2021. The vast majority of these 2021 sales (98%) were light duty vehicles (LDVs); with EVs reaching the highest share of new sales to date in that year (8.3%) [5]. For the State of Qatar, the focus of this study, the aim is that by 2030, 10% of all new car sales will be EVs, rising from a 2020 goal of 4% [6–8]. As a result, the objective of this article is to assesses the initiatives and progress thus far in creating the enabling environment for this target to be met, and what will be required in the years leading up to 2030 to ensure the country is on track to meet, and ideally exceed, its aim.

Since then, there have been notable successes in transportation transformation within Qatar, aligned with sustainability goals that the country set ahead of hosting of the FIFA 2022 World Cup. For example, a metro system was developed to connect the city and stadiums, and the bus feeder system leading to the metro was fully transitioned to electric buses. However, several challenges have been raised regarding the broader EV transition in the country, ranging from insufficient EV charging stations (EVCS) infrastructure and heat-related battery challenges to consumer attitudes. InvestQatar has outlined enablers that can overcome barriers and facilitate the EV sales objective, namely: (a) government support via regulation, research and development, and the establishment of facilities for investors; (b) 15,000 public EVCS in place by 2030; (c) national enablers (e.g., Qatar Foundation, Hamad International Airport, Lusail City); (d) private sector partnerships with major EV manufacturing companies; and (e) an attractive investment ecosystem [9].

Before delving into our up-to-date analysis for the State of Qatar, the following section presents the methodology, which employs a systematic literature review approach (searching two academic platforms: Scopus and Web of Science). The results of the systematic literature review are synthesized and critically reviewed, using the available evidence. Upon the foundation of that evidence base, this paper reviews the current trends and future pathways for the EV transition in Qatar, followed by concluding remarks. The results suggest that to meet the 2030 target, the State of Qatar must improve data collection for monitoring, rapidly expand EVCS infrastructure, enable private sector engagement, and raise awareness regarding EVs to change consumer perception and choices. The discussion section of this paper elaborates on these recommendations and offers options for specific policy interventions for the country to meet its transportation transition objectives.

Methodology

This research relies upon data obtained from government sources within Qatar, such as the Planning and Statistics Authority (PSA), the Ministry of Environment and Climate Change (MOECC), and the Ministry of Commerce and Industry (MOCI). The data collection took place from March to May 2023 and is reflective of the data available at that time. The second source of data for this article was obtained using a systematic literature review approach, searching for relevant publications on two academic databases (Scopus and Web of Science). The specific search criteria, as well as the inclusion and exclusion criteria that were applied are outlined in Table 1. The use of both databases within this study was critical as they index different materials, and the literature specific to the State of Qatar is relatively limited. These searches were conducted in March of 2023 using the search strings outlined in Table 2.

The number and type of results retrieved by the search strings varied by database. All results from these search strings were downloaded as PDFs to be screened and assessed for eligibility by one of the authors, with duplicates and false positives being manually removed (see Fig 1). While it was intended to have a more inclusive approach, the addition of the Web of Science database yielded only one additional publication [10]. As a result, the additional database, in this instance, did not add much literature to the systematic review process. This, however, seems to be an exception; utilizing more than one database for systematic literature reviews is a good practice. After completing the screening processes outlined in Table 1, 25 studies were identified as unique and relevant to the study. These include: [1–4, 6, 10–28]. All these papers were then read, analyzed, and coded based on theme to arrive at the conclusions outlined in the following section of this paper.

The limitations to this study are three-fold. The first is linguistic. Only English language sources were searched for and analyzed. This is a hinderance given that the official language of Qatar is Arabic and some sources on Qatar's transition towards electrification may therefore be published in Arabic language journals without English translation. However, previous studies conducted with parallel searches in Arabic have identified few additional academic

Table 1. Literature review inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Publication Type	Peer-reviewed articles, books, conference proceedings	Social media, blog posts, government documents, NGO reports, briefs, patents, news articles, etc.
Location	Qatar	Everywhere else
Time	Any	None
Language	English	All others
Key Terms	Qatar, Elective Vehicles, Electric Vehicle Charging Stations, Electric Cars	False positives

https://doi.org/10.1371/journal.pclm.0000271.t001

Table 2. Web of Science and Scopus search strings.

Database	Search String
Web of Science*	TS (Qatar AND "Electric Vehicles") OR TS (Qatar AND "EV charging stations") OR TS (Qatar AND "electric vehicle charging stations") OR TS (Qatar AND "electric cars")
Scopus	TITLE-ABS-KEY (Qatar AND "Electric Vehicles") OR TITLE-ABS-KEY (Qatar AND "EV charging stations") OR TITLE-ABS-KEY (Qatar AND "electric vehicle charging stations") OR TITLE-ABS-KEY (Qatar AND "electric cars")

*TS on Web of Science is inclusive of the title, abstract, author keywords, and keywords plus.

https://doi.org/10.1371/journal.pclm.0000271.t002

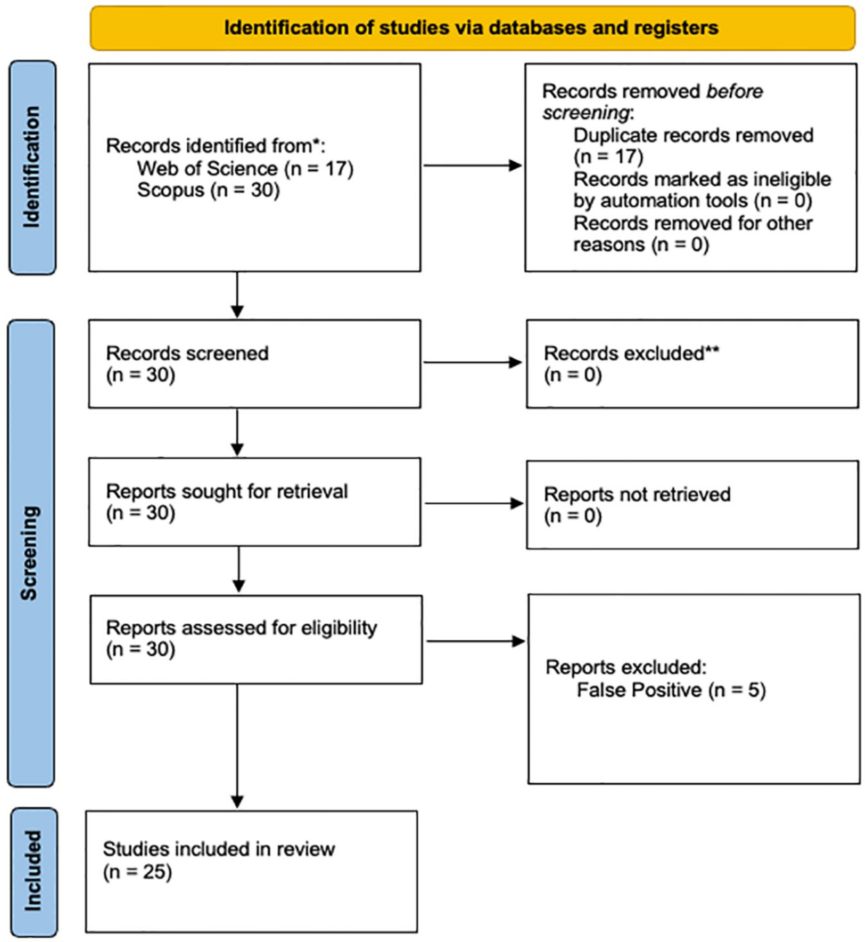

Fig 1. Prisma flow diagram.

https://doi.org/10.1371/journal.pclm.0000271.g001

publications. Furthermore, the Arabic Citation Index, created in 2020 within Web of Science, shows no results for the keywords noted in Table 2 and none for the broader search term of "sustainability" AND Qatar. This suggests that this study has not missed academic literature in Arabic. However, there may be important publications in Arabic by governments or non-governmental organizations. These, however, would not have been included in the systematic literature review search parameters. Relatedly, the second limitation is that only peer-reviewed articles, books, and conference proceedings were included within the structured literature review. As a result, all government publications, journalistic reporting, and social media discussion on the topic were excluded from the systematic literature review. The decision to focus on peer reviewed literature was because non-peer reviewed sources presented inconsistent or incorrect information regarding EVs in Qatar. The focus on academic literature narrowed the scope but ensured a higher degree of rigor and quality in the reviewed content. The third limitation of the study is selection bias, which might emerge during the qualitative screen process for inclusion and exclusion. In this study, this bias potential is minimal since only five studies were deemed to be false positives: (a) a cover profile of academics, (b) an article discussing an upcoming automotive show in Qatar, (c) a discussion on rising oil prices in 2010, (d) a design for an electric car, and (e) an article on converting internal combustion vehicles (ICVs) to compressed natural gas hybrids. Future research may be able to address some of these limitations and complement this study by completing a systematic review of the literature using the same terms but with Arabic language databases or by expanding the scope of the study to also include government publications and journalistic articles by using Google Scholar or other databases that include a broader set of publication types.

Results of a systematic, detailed literature review

This study reviews and synthesizes the available evidence for the State of Qatar, and then assesses the 2030 EV target. Before delving into the results of the systematic literature review, this context briefly situates the EV transition, as EV adoption rates vary from country to country (Fig 2). While some countries have experienced rapid adoption and transportation transformation (e.g., EU27 countries), sales in Qatar remain low. Other countries that have hydrocarbon resources are also relatively slow to transition, such as Kyrgyzstan [29] and Nigeria [30], where adoption appears low but assessment is constrained by data availability. The United Arab Emirates, with a similarly small population and resource-reliant economy based in the Gulf region, has seen EV adoption rise slowly (~1% as of 2023), while the government expands EVCS infrastructure and prepares for wider adoption in the future [31]. Singapore, on the other hand, increased EV car sales (new car registrations) from 0.2% in 2020 to 12% in 2022 [32, 33], which was achieved through a combination of government incentives, a rapid expansion of public charging points, and support for home charging installations. As discussed below, Qatar's electrical grid has been primarily powered by natural gas, making the climate and/or carbon case for transition of comparatively lower priority in comparison to other options. This has begun to change, as new renewable inputs for the electrical grid are introduced in the country. Additionally, the EV transition has the potential to improve air quality, which is a serious challenge [34] with significant health consequences [35]. In what follows, the available evidence on EV transitions in Qatar is synthesized and assessed, recognizing that this is an under-researched country with limited available evidence but one that requires tailored, evidenced-informed, recommendations.

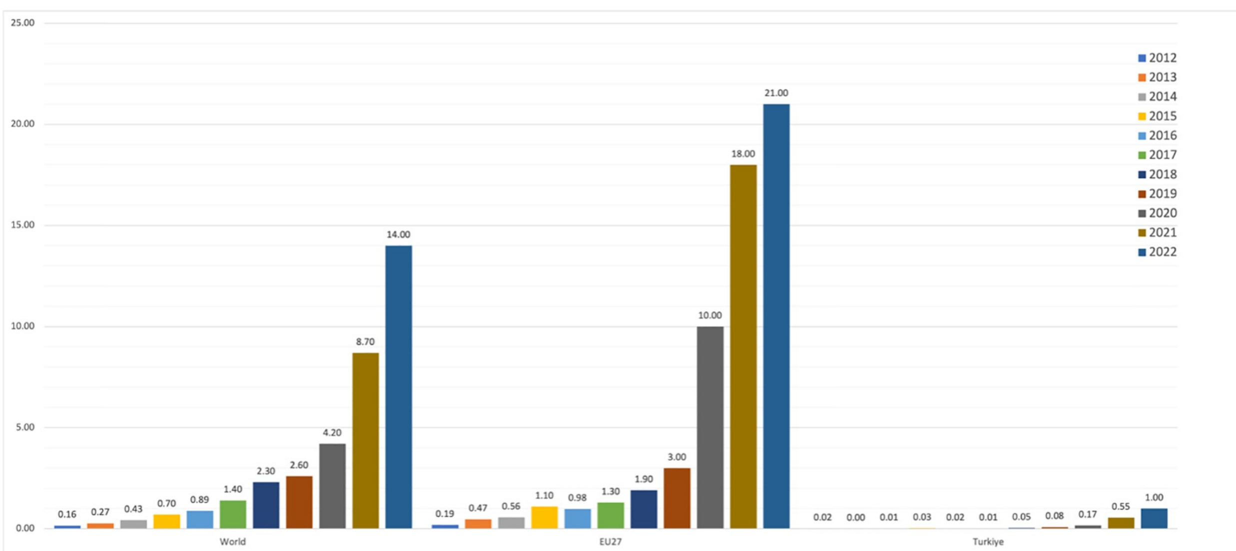

Fig 2. Market share of EV sales [36].

https://doi.org/10.1371/journal.pclm.0000271.g002

Historical context for electrification within Qatar

The State of Qatar has rapidly developed since gaining independence in 1971, and particularly since the development of natural gas reserves in the 1990s [10]. In July of 2008, the State of Qatar published its 2030 National Vision (QNV 2030). The QNV 2030 aimed to advance the country's social and economic growth while also improving the environment [23]. Energy consumption per capita is high [26], and until recently, electricity was produced via natural gas, and while compared to gasoline was a cleaner option, was still reliant upon hydrocarbons. Since the publication of these papers, the country inaugurated the first major solar power plant, which produces 10% of peak energy, and another 10% is expected to come online in the coming year or two [37, 38]. With renewable energy contributions to the electrical grid, there are additional incentives for the government to encourage the transportation transformation to EVs as part of its NDC to reduce GHG emissions.

In May of 2017, the State launched its 'Green Car Initiative' which aimed to increase private vehicle EV penetration to 10% by 2030 in the hopes of reducing national emissions and improving air quality [17]. This is significant given that 85% of the vehicles on the road are private and single occupancy, and over 1.5 million of the country's fleet are ICVs [27]. The remaining 15% of vehicles on the road belong to public transit, a system that is underutilized due to factors relating to convenience, comfort, and custom [27]. Although not identified within the literature from the systematic review process, other research has noted that the cost of driving ICVs is additionally very low due to oil subsidization by the State disincentivizing the use of not only the use of public transit but the switch to EVs [39]. The challenges to the adoption of EVs within the State of Qatar, however, go beyond subsidies. Issues pertaining to range anxiety due to lack of EVCS infrastructure and reduced battery capacity in hot arid climates are also prevalent and factor into the country's low EV adoption rates. In the following section, the major challenges and solutions that were identified in the systematic literature review will be outlined. Knowledge gaps will also be identified to help direct where increased research focus should be placed given that not all challenges or solutions pertaining to the situation in Qatar that were identified within the literature were thoroughly researched.

Challenges and solutions to the adoption of EVs in Qatar

The systematic review process identified 26 relevant publications, which were synthesized and critically assessed, grouped into three thematic clusters: (a) assessments related to the electrical grid and diversifying the energy mix, (b) the planning and distribution of EVCSs, and (c) knowledge, attitudes, and behaviors as it relates to the socio-cultural dimensions of EV adoption. Within these clusters, the focus is on two main components in the analysis. Firstly, there is an inquiry as to what the emerging evidence is, what challenges are being identified, and what potential solutions are being proposed. Secondly, where relevant, reflections are made with regard to how these studies contribute to the objectives of this study.

Demands on the electrical grid. One challenge of a rapid transition to EVs in that the transportation sector places significantly more demands on the electrical grid. If the system is not prepared for distribution and demand, implementation might have negative impacts, including overloaded systems. Of the articles covered in the systematic review of the literature, two papers focused on the load that would be applied during charging events for EVs and the problems that this might pose on the grid system [14, 26]. One paper [14] discusses the impact that EVCS have on the grids, offering specific technical recommendations to handle demands as per Qatar Energy & Water Company standards [14]. The main concern of the authors in this paper is the heightened harmonic distortion caused by increased energy demand as charging stations increase the peak current of the electrical grid. Such harmonic distortion can create higher operating temperatures and lead to more frequent equipment failure. To address this potential issue, the authors recommend connecting high capacity EVCS to dedicated feeder stations, while smaller capacity charging stations are capable of being integrated into the existing power grid [14]. Conversely, the second paper [26] discusses the issue of the potential power strain caused by plug-in electric vehicles (PEVs), looking to answer the question of whether Qatar's power grid can meet the demands required of a 10% PEV penetration rate. Based on normal operations, where peak energy demand occurs in the afternoon and where EV charging takes place at night, the research finds there is plenty of capacity available for both summer and winter months. However, under a worst-case-scenario where all vehicle charging takes place at 2 p.m., the aggregate PEV load exceeds the generation limit and increases the peak demand by 19.2%. However, the article notes that this is only when considering the current grid operations as of 2019 and does not factor in any power generation from the new 800 MW PV solar farm. If this source of electricity is taken into consideration, peak electricity generation will be misaligned with peak electricity demand and therefore to best make use of this energy surplus they recommend charging vehicles between 5 am and 11 am. This would reduce the peak demand induced by EVs, flatten the demand curve, and reduce the requirements of natural gas generators as an auxiliary power source. The author further investigated the energy cost of transitioning Qatar's consumer vehicle fleet to all electric. When considering the 2019 power generation peak capacity of 8.5 GW, the daily spare capacity would be 0.035 TWh during peak consumption events, which would allow PEV penetration of up to 85% if energy usage was optimized. This suggested optimization would be in the form of smart charging algorithms designed to equalize power consumption throughout the day. The simulations did not, however, model different vehicle segments. It also did not consider driving habits and parking statistics. As a result, the energy demand of PEVs could increase or decrease depending on these factors (e.g. synced daily driving habits spurred by commuting may lead to high demand in the morning while spaced out driving and parking may better spread the load, larger vehicles may require more energy during a charging event). To address these gaps, the researcher recommends experimental studies of surveys. Four different strategies for solving the aforementioned issue were found within the literature. These were (a) development of off-grid charging systems to avoid increased strain on the current grid [16–20], (b) diversification of energy production systems to include photovoltaic power generation with the existing grid [10], (c) development of smart charging schedules to temporally spread out the load to be more manageable throughout the day [21], and (d) modeling the spatial arrangement of charging networks to better distribute the load during charging events [4, 11, 12, 28].

The above-noted study [26] mentioned the addition of solar energy inputs to the electrical grid (using 500 MW as an example). Although it is yet to be reported in the academic literature, in 2022, an 800 MW solar power project came online in Qatar, which will cover 10% of peak energy demand in the country [37]. In addition to this, the government has announced that two additional solar power projects will be launched within two years, adding another 880 MW, which will surpass 20% of peak energy demand provided by solar energy [38]. Before the launch of the first major project, researchers had been calling for the development of Qatar's solar capacity (2). In addition to centralized, large-scale solar power projects, five papers discussed the solution of off-grid EVCS [16–20]. All papers conclude that an off-grid EVCS should include two to three main power sources–solar (PV), wind turbines, and optionally bio-generators–along with some form of energy storage system either in the form of batteries or in the form of chemical storage [16–20]. Four of these papers focus on developing an EVCS that can support 50 vehicles per day [16–20]. This system would require 250 kW of wind turbine produced energy, 450–468 kW of CPV/T, and 10–100 kW of biodiesel [16–20] (see

Table 3 for paper by paper breakdown). Additionally, to support charging throughout the night and during unfavorable climactic conditions, some form of energy storage system is recommended. This was frequently a mix of lithium-ion batteries (304–595 kWh) along with electrolysis and storage of hydrogen and natural gas which could be consumed at a later time [16–20]. Two of these four papers explored the cost of one of these systems which placed a system within the range of $2.38 million and $2.92 million with the cost of electricity being between 0.284 and 0.329 $/kWh [19, 20]. A fifth paper explored the development of a EVCS to support 80 vehicles per day [18]. They recommend for the CPV/T of 1,728 kWh/day. They also recommended 250 kW of wind and 654 kWh lithium-ion battery [18]. The assumption of the daily charging demand of each EV in all studies was 35 kWh/day [16–20]. All studies also assumed that 1,500 m2 of space would be required for the EVCS [16–20]. The [19] paper also conducted a life cycle cost analysis, which determined the upkeep cost of each system component over the course of its lifetime.

On the other hand, only one paper discussed the solution of diversifying Qatar's existing energy production systems to include photovoltaic (PV), concentrated photovoltaic (CPV), and wind turbine power generation in order to maximize the benefits received from electrifying the consumer vehicle fleet [10]. Due to Qatar's geography, solar and wind energy have been identified as the most feasible RES, although the authors also discuss the potential to produce energy by converting waste to natural gas [10]. Two cases of hybrid RES are explored. The first is comprised of wind (1900 MW), CPV (3,180 MW), and a solar thermal storage unit (60 GWh), which would produce 16.89 TWh of energy, 34.9% of total electricity production (TEP) and would result in a CO_2 emission reduction of 31% compared to current power generation [10]. The second scenario involves PV (3,003 MW) and wind (3,392 MW), which would yield 15.42 TWh annually, 31.8% of TEP and a 17.5 MT reduction in CO_2 emissions [10]. This paper also mentions several challenges and limitations to RES development in Qatar, the first being related to the energy storage associated with CSP [10]. While a thermal storage system can double the utilization of CSP, the supply only lasts for a period of 6 to 9

Table 3. A comparison of proposed off-grid EVCS.

		Al Wahedi & Bicer, 2020a [17]	Al Wahedi & Bicer, 2020b [18]	Al Wahedi & Bicer, 2020c [16]	Al Wahedi & Bicer, 2021 [19]	Al Wahedi & Bicer, 2022 [20]
Number of Cars Per Day		50	80	50	50	50
Daily Total Energy Demand (kWh)		1,750	2,800	1,750	1,750	1,750
Wind Energy	Capacity (kW)	250	250	250	250	50
	Daily Output (kWh)	1,350	556	1,350	1,350	1,066–1,125
Solar Energy	Capacity (kW)	468 (CPV/T)	N/A (CPV/T)	N/A (PV)	450 (CPV)	450 (CPV/T)
	Daily Output (kWh)	1520 (CPV/T)	1,172.8	1,200	N/A	1,016
Daily Auxiliary Power Production		10 kW (bio-diesel generator)	33 kW (biomass steam engine)	N/A	100kW (bio-diesel generator)	15 kW (bio-diesel generator)
Li-ion Battery Storage	Daily Output (kWh)	595	654	650	324	304–324
Chemical Energy	Chemical Storage Capacity	200 kW (hydrogen & ammonia production)	Dependent on excess solar energy (hydrogen & ammonia production)	(hydrogen & ammonia storage incorporated)	50 kg H2 storage tank	200 kg H2 storage tank,
	Daily Fuel Cell Energy Production (kWh)	200	422(H2), 122 (NH3)	200 (H2, NH3)	N/A (H2, NH3)	249 (NH3) 324–328 (H2)
Total Cost		N/A	N/A	N/A	$2.378 M (0.284 $/kWh)	$2.53 M to $2.92 M (0.285 to 0.329 $/kWh)

https://doi.org/10.1371/journal.pclm.0000271.t003

hours, at best [10]. The authors mention that a pump hydro storage system has greater capacity but requires a geographically suitable location [10]. An alternative for long-term storage is liquid fuel (ex. hydrogen) [10]. However, cost and low State-level motivation as a result of energy security remain a challenge [10]. Thus, while a near 100% renewable energy scenario is possible the biggest challenge is energy storage [10]. The authors mention that to achieve the State of Qatar's target of 20% renewable energy by 2030, no matter which methods are employed, it will cost on average about USD $7 billion over a 10 year period, as of 2021 [10]. The authors suggest that to reach the 2030 targets there needs to be favorable market and political conditions such as low interest loans and research grants [10].

Only one paper discussed the solution of smart charging schedules to temporally spread out the load to be more manageable throughout the day [21]. Using an optimization approach that aims to identify the least cost options, the model was tested on a cluster of six-buildings at Qatar University and was able to strategically reduce the operation cost by 21.04%. They did so by thermally mapping each building to determine strategic locations to deploy HVAC as required as well as to redirect cool air from lower occupancy areas to ones of higher occupancy. They also modelled the management of a flexible load system involving both the buildings aggregate flexible loads as well as EV loads to avoid peak price spikes and huge demand charges. By managing both the time of use of electricity as well as the location of cooling within buildings, the latter being a major electrical demand in the country, operations can distribute demand and increase overall energy efficiency.

Spatial distribution of EVCS. As alluded to in the above-mentioned studies, the distribution of EVCS has an impact not only on accessibility and uptake of EVs, but also on electrical demand. Four articles discussed the solution of modeling the spatial arrangement of charging networks to better distribute the load during EV charging [4, 11, 12, 28]. In order to determine the optimal locations for EVCSs, Zafar et al [4] tracked the driving habits of 7 vehicles (6 ICV, one BEV) to understand driving habits and energy consumption in Qatar. Regardless of work-week or weekend scenarios, charging at home was deemed to be the most convenient, which implies that capacity in the private sector needs to be sufficient to meet the demand of EVCS at homes. As the driving habits of both vehicle types (ICV and BEV) involved extended periods of parking, the authors suggest that a level 2 charger would be sufficient, although they also recommend investigating the installation of fast chargers at shopping malls as these parking events are much shorter [4]. The intensity and/or frequency of driving patterns impacts how dense the EVCS network needs to be, and thus Zafar et al also assessed the daily driving distances of drivers and found that nearly 80% of all ICV daily trips are less than 100 km and only 3% of trips are higher than 200 km [4]. These averages, however, were much lower for the EV, which they posit was likely due to range anxiety [4]. The daily trip is about 19 km and 80% of the trips are less than 26 km even though the vehicle in question has an advertised range of 299 km [4]. Due to these low mileage trips the researchers inferred that the owner used a separate petrol car to complete other longer trips [4], however the short trips are also due to the concentrated nature of the State of Qatar, with the vast majority of population and economic activity occurring around the capital city. The authors were also able to compare the fuel efficiency of an ICV and determined a decline of 24% due to AC usage [4]. This range reduction is likely higher for EVs although it should be investigated further to better understand [4]. The results of this study suggest that EVCS distribution could be optimized at locations where people are parked for longer durations, at homes (which would require charger installation) and at public locations (e.g., malls) and work places (where EVCSs could be installed by the government and private sector). These two approaches require different types of capacities (individual home installation and public providers), both of which may require support in the initial stages of EV expansion.

Abdullah et al [11] developed a framework for determining the best locations for chargers, using a case study of Qatar University. To successfully determine the best spot for charger placement the author recommends following these steps: (1) "define the project goals and objectives," (2) "define the potential sites (alternatives) and associated attributes," (3) "identify which criterion is more important than another with the help of experts and decision-makers," (4) "solve for the EV placement," and (5) "sensitivity analysis" [11]. The authors also recommend revaluating the best spots for EV placement following each installation as the attributes will change. A second paper by Abdullah et al [12] also focused on the implementation of EVCS at Qatar University, it forecasts the average number of EVs on campus, recommend the optimum number of chargers each year, solar power plant sizes, and required policy. To do this, the model applies a system dynamic approach initially developed by Forest and colleagues at MIT in the 1950s where variables are classified as either as either belong to reinforcing (positive feedback) look or balancing (negative feedback) loops. The specific case study is informative for the State of Qatar, however additional studies are needed that examine EVCSs at a broader scale. Finally, Sultana et al. [28] used a particle swarm optimization algorithm to determine where on an IEEE-37 bus system EVCS can be placed with minimal energy loss. They determined the best location is bus 19. Additionally, adding a solar PV system to the grid can reduce the cost of lost energy by 29% and actual power loss by 70%.

Life cycle assessments. The other major subset of articles in the systematic review were life cycle sustainability assessments of various vehicle types (ICV, HEV, PHEV, BEV) and models (SUV versus sedan) [1, 3, 13, 24, 25]. All the papers concluded that EVs are better in all environmental impact categories asides from water withdrawal and water consumption [1, 3, 13, 24, 25]. However, this is only due to Qatar's reliance on natural gas as the primary source of electricity generation. If Qatar were to transition towards solar water withdrawal and consumption that factor would be reduced and/or be negligible. The studies also concluded that economic benefits, which are very closely tied at the moment to fossil fuel production, result in ICVs being favored within this category as only the current economic landscape of Qatar is taken into account, not any future diversification that would occur due to electrification [1, 3, 13, 24, 25]. The same can be said for the social indicators considered, which includes total tax, employment compensation, employment, and human health impacts [1, 3, 13, 24, 25]. As the first three indicators are directly tied to fossil fuel production, the reduction in fossil fuel consumption associated with EV uptake will have a direct negative effect on these categories. The articles again do not mention or take into account any future opportunities electrification would create, a limitation of the studies. Human health impacts, however, were positively correlated with the adoption of EVs as they reduce emissions [1, 3, 13, 24, 25]. As a result, in the short term the main recommendations were that a mix of HEVs and BEVs be used while Qatar's electricity is generated by natural gas [1, 3, 13, 24, 25]. As this changes in the long term from natural gas to solar, however, a complete conversion to BEVs is optimal [1, 3, 13, 24, 25]. An important caveat to these findings, however, is that these studies results were likely found prior to Qatar's large solar projects being connected to the grid. The assumption that natural gas would continue to provide 99% of the power to Qatar's grid was one that was considered long-term but, Qatar is now quickly moving away from natural gas as a power source for their grid. 10% of the electrical grid is now powered by solar and this number is expected to increase to 20% in the next two years.

Al Mamun et al. [15] discuss the benefits and drawbacks of electric, hybrid, or conventional ICV taxis as well as the public acceptance of electric buses which will not be focused on as it is outside the scope of this study. In regards to taxis, Al Mamun et al. [15] states that after 10 years of use or 150,000 km, HEVs become cheaper than both ICVs and BEVs. It was also found that HEVs can reduce emissions by 37.85% compared to ICVs no matter the electricity generation scenario of the country. As a result, HEV taxis have several advantages over the use of ICVs as taxis, namely fuel efficiency, decreased costs, reduced emissions, as well as extended range having to be fueled less frequently due to regenerative breaking. The authors also highlight that this switch to HEV taxis can occur in the short-term given that taxis on average only last 3–6 years before needing to be replace at which time they could be replaced by HEVs.

Knowledge, attitudes, and behaviors. The dimensions of EVs, EVCS, and load capacity of the electricity grid have been largely technical assessments. However, the transportation transformation in Qatar also requires shifts in knowledge, attitudes, and behaviors. Only two articles [6, 23] discusses the social side of EV adoption. Al-Buenain et al [6] interviewed consumers and found that the majority preferred ICVs for their commute. Furthermore, it was found that these same consumers would require convincing to purchase an EV despite believing EVs could compete with ICVs. Current government incentives were also not sufficient to encourage adoption. Khandakar et al [23], on the other hand, conducted a survey and categorizes respondents into two groups, non-technical and technical. They defined technical respondents as those who worked in part of the EV industry either directly or indirectly while non-technical respondents did not [23]. The study ultimately found that compared to non-technical audiences, technical respondents were more aware of climate change, more willing to work toward a solution, and were more willing to buy EVs despite the higher purchasing cost and lower range, and instead being more swayed by the long-term savings of EVs through reduced maintenance and charging costs. Additionally, technical respondents were more persuaded by possible government incentives such as free charging, subsidized replacement parts, and purchasing bonuses. Overall, non-technical respondents had more neutral responses, likely due to a lack of understanding of climate change as well as the potential of EVs as a solution. Therefore, in order to increase uptake the researchers recommend enhancing public awareness through the development of a mobile app which disseminates information regarding EVs and their benefits, give information on nearby EVCS and allow users to reserve spots to increase convenience [23]. The authors also recommend the implementation of government incentives such as those outlined above along with allowing EV users to feed any unused power back into the grid for profit [23]. Finally, they also mention that having sufficient EVCS is pertinent in achieving greater adoption by the general public [23].

Discussion: Current trends and future pathways

To complement the literature, updated data is contributed (where available) in three domains: private EV trends, public transportation EV transition, and EVCS trends. The data is presented and the analysis reflects on these trends to inform the derived implications and recommendations.

Personal vehicles

The adoption of EVs in Qatar is relatively slow compared to the fast-paced increase witnessed in some countries and in comparison to electric buses (discussed below). The increase in charging facilities and incentives like free charging [40], are examples of enablers that can support the expansion of EV adoption. Calculating the exact number of EVs on the road in Qatar is challenging, as no data is publicly available that specifies this. With no direct data available as to number of EVs in Qatar, numbers need to be estimated from various sources. Given that the PSA estimates that there are 4,500 new private vehicles per month and that an estimated 0.5%-1% of these are EVs, this would mean that there are 276–540 new private EVs on the road per year [41]. The 0.5% to 1% figure is a high estimate, based on comparator countries that are at a similar stage of EV development [41].

As noted in the literature, one of the barriers to adoption and consumer confidence is relatively sparse charging infrastructure, an expansion of which is required to increase consumer confidence in EVs [4]. The current public charging infrastructure in Qatar is provided by Kahramaa (Qatar General Electricity & Water Corporation) and is made up of 100 current EVCS as of 2022, with plans to add an additional 150 in 2023, with a final goal of 600–1000 EVCS by 2025. The number of current EVCS appears to be an under-estimate, however, as Kahramaa awarded a contract in 2022 to install 100 EVCS [42], and recently announced that all Woqod fuel stations (of which there are over 100) would offer EV charging [43, 44].

Public transportation

Hosting the FIFA World Cup 2022, and making strong sustainability commitments for the events [45], enabled the State of Qatar to make significant transformations to sectors. This objective was aligned with national strategies, specifically the QNV 2030 [46], wherein the government aimed to electrify all public buses and school buses by 2030 [47]. Amongst these commitments, the transportation system, and in particular the public transportation system, was transformed. This was not a stand-alone or event-specific trend, as the country has created two sustainable cities, Msheireb and Lusail, both of which have public transport rail systems and EVCS infrastructure [27]. Nonetheless, the decade leading up to the FIFA 2022 World Cup event allowed for large-scale investments in infarstucture to align with the sustainability aims outlined in the QNV 2030.

The quantity of electric buses needed for FIFA 2022 demanded a robust and flexible charging infrastructure for clear and uninterrupted transport during the event. In preparation for the FIFA World Cup, the public transport company of the State of Qatar, *Mowasalat*, placed large orders for EVCS and a variety of buses to meet different needs. The types of electric buses that were under operation during the event (see Table 4) transitioned into the public system after the event (this is noted to highlight the important catalyst that the FIFA World Cup 2022 had in this transformation). Each bus, based on the type of operation, requires a different charging strategy. For example, frequent stopping buses use opportunity chargers, others use overnight chargers or fast plugin chargers based on operational requirements. The total estimated charging capacity is estimated to be up to 125MW [48]. The charging infrastructure is spread geographically across bus routes and with clusters of chargers in various depots and charging hubs. The depots include state Lusail Bus depot, Middle East's first solar powered depot with around 11,000 PV Solar panels and generating 4MW of power daily [49].

The chargers and buses are all equipped with state-of-the-art management and monitoring systems. Charging Management Systems include: Real-time overview of the charging process, power level, and general vehicle information; Depots' parking status; Charger status with alert monitoring; Remote resets; Smart charging; Overview of all charging sessions; and detailed charge sessions overview. In addition, vehicle health monitoring system included in all the e-buses include: Real-time overview of the buses and their status, location, speed, SOC, and

Table 4. Electric buses and infrastructure [50].

Type of Bus	Event	Public Transport	Emergency	Total
Type of buses	741	90	45	**876**
Type of Charger	Single Gun 150kW	Double Gun 150kW	Pantograph 300kW	DC Mobile 24 kW
Type of buses	52	527	85	24
Type of Infrastructure	Depots	Bus Stations	Charging Hubs	
Type of buses	4	8	3	

https://doi.org/10.1371/journal.pclm.0000271.t004

mileage; Fleet health monitoring; Smart diagnostics; Energy consumption reports; and Driving behavior reports.

Introducing new technology was not the only requirement, new standards needed to be reviewed, adopted and introduced (for example, charging infrastructure adopted European standards as these were viewed as the most widely compatible for chargers). The State of Qatar has also set aims for electric bus assembly within the country [51] and manufacture charging infrastructure [52], which will reduce costs and enhance domestic capacity. The transformation of this public transport infrastructure, assets and standards will have a legacy long after FIFA World Cup 2022.

Implications for transportation transformation

The State of Qatar has demonstrated that when decisions are made, large-scale infrastructural projects can be implemented on a rapid timeframe. The complete electrification of the public bus system and the development of a public metro system are two examples of this. Available evidence does not indicate that the temperature or humidity concerns will be serious impediments, nor have they been in other jurisdictions with high temperatures (e.g., Arizona, UAE) or high levels of humidity (e.g., Malaysia, Singapore) [53–56]. To date, the expansion of EVCS has not been as rapid as needed to increase consumer confidence in the reliability and accessibility of charging stations. At the same time, however, EVs are in limited supply on the market. As one example, on one of the most popular car sales websites Qatar Sale (as of 6 May 2023), there are only 76 EVs available on the market (13 of which are marked sold) [57]. As a result, there are both supply and demand constraints that have limited the expansion of EV adoption. To address this, there will need to be (a) promotion and awareness raising, (b) data collection and monitoring, (c) government interventions via incentives and procurement, and (d) government support to expand EVCS infrastructure. These general recommendations align with recommendations in other early-transition contexts (e.g., [29]), each of these recommendations require country contextualization to be suitable and effective.

With regard to awareness raising, the government will need to take a more active role in promoting EVs, including indirect promotion via increasing knowledge about related issues (e.g., air quality and climate change). Available evidence suggested more informed consumers are more likely to purchase EVs, and during this early stage of transition the government may need to take an active role in creating the enabling environment, improving demand and supply conditions [6, 23]. One example of the lack of government leadership is the absence of accurate and informative data tracking the progress of EV penetration into the vehicle market or the positive environmental trends associated with increased EV adoption. EV penetration can only be monitored if data is available, which may include the PSA collecting data on vehicle types, and recording data on EV imports, sales, and sellers. In addition to monitoring import and sales data, EV energy consumption needs to be monitored to assess impacts on the electrical grid and the distributional impacts that will have as EV uptake increases over time.

The case of the electrification of all public buses shows that when decisions are within the sphere of control of the government, transformations can occur rapidly. Similar decisions could be made regarding government vehicle procurements and/or in government institutions, such as the public transportation provider, as it also has taxis. Converting government-procured personal vehicles such as these to EV could play a major role in reaching the 10% EV sales target by 2030 and could be mandated into procurement contracts. This would have a knock-on effect in society, as EVs would be more common on in the transportation network and EVCS would necessarily need to expand to meet the need. As EV adoption increases, the electrical demand needs to be taken into consideration, with the available evidence suggesting two modalities would be most suitable to current grid loads: (1) incentives for charging while at work / at workplaces (5 am to 11 am), and (2) incentives for charging overnight at home, the latter aligns with when the evidence suggests consumers find most convenient. Incentives might be, for example, reduced energy tariffs during the evening to encourage overnight charging (this might even be conditional upon owning an EV in the early stages of EV transition). Conversely, explorations are needed to create disincentives for afternoon charging as this is when peak demand occurs. Based on this study, two areas stand out as under-researched and/or as opportunities for investment in research and development. The first is investing in energy storage systems, specifically suited to demands of EV expansion and the opportunities available in Qatar, specifically storing solar powered systems for charging outside of daylight hours. The second is investing in research on the social dimensions of knowledge, attitudes, and behaviors, as there are context specific socio-cultural barriers that need to be better understood and addressed to enable widespread EV adoption.

Conclusion

With the catalysts of major events, such as the FIFA World Cup 2022, alongside government initiatives to support the expanded use of EVs (included as part of QNV 2030), the transportation system has begun a transformation. A public metro system supported by a fully electric public system was an important, government-led, transition step. For vehicles, the country aims to have 10% of all new vehicles sales being electric, by 2030. The aim is realistic, however supporting infrastructure has (2019 to 2022) slower than anticipated. However, 2023 signals a potential shift, with major announcements for EVCS expansions, and the government has demonstrated that it can undertake major infrastructural projects rapidly. This article reviewed existing literature and available data to highlight potential challenges, explore enablers, and assess current trends. The lack of data presented a challenge for the latter of these tasks, and it is part of the key recommendations moving forward; the need to develop monitoring systems to allow for continuous evaluation and adjustment of transportation system up to, and beyond, 2030. In the systematic review of the literature, this paper found that three themes were most prominently discussed: (1) the alterations needed to Qatar's electrical grid in order to meet the demand of EVs as well as the need to incorporate greater RES to realize the full environmental benefits of electrification, (2) where EVCS should be placed within the State of Qatar to encourage EV adoption by the general public, and (3) the socio-cultural impacts of EV adoption. Based on this, greater research is needed within the Qatari context on (1) battery storage systems and (2) socio-cultural hindrances to adoption by the general public. These could be areas for national research funding agencies (e.g., Qatar National Research Fund) to highlight for research calls. The transportation transition is expected to occur in stages, with government-led initiatives in infrastructure, private sector supply and demand incentives, and public awareness campaigns for changing attitudes and behaviors. As demand increases, energy grid demands will shift, and policy incentives will be needed to distribute demands (geospatially and temporally). The continued expansion of renewable energy into the electrical grid will foster greater incentives for the transition (e.g., shifting from hydrocarbon sourced energy to renewables). Hydrocarbon-based economies have unique politico-economic settings that require tailored transition designs toward low carbon economies, with sector-specific analyses supporting these efforts. This article demonstrates that the State of Qatar can, and has begun, the transition toward a lower carbon transportation system and sets the pathway for meetings its 2030 objectives.

Supporting information

S1 Checklist. PRISMA 2020 for abstracts checklist.
(DOCX)

S2 Checklist. PRISMA 2020 checklist.
(DOCX)

Author Contributions

Conceptualization: Abdulla Al-Shaiba, Logan Cochrane.

Data curation: Abdulla Al-Shaiba, Alexandra Wilson.

Formal analysis: Abdulla Al-Shaiba, Alexandra Wilson, Logan Cochrane.

Investigation: Alexandra Wilson, Logan Cochrane.

Methodology: Abdulla Al-Shaiba, Alexandra Wilson, Logan Cochrane.

Validation: Abdulla Al-Shaiba, Logan Cochrane.

Writing – original draft: Abdulla Al-Shaiba, Alexandra Wilson, Logan Cochrane.

Writing – review & editing: Abdulla Al-Shaiba, Alexandra Wilson, Logan Cochrane.

References

1. Onat N, Aboushaqrah NNM, Kucukvar M, Tarlochan F, Magid Hamouda A. From sustainability assessment to sustainability management for policy development: The case for electric vehicles. Energy Convers Manag. 2020; 216: 112937. https://doi.org/10.1016/j.enconman.2020.112937
2. Babonneau F, Benlahrech M, Haurie A. Transition to zero-net emissions for Qatar: A policy based on Hydrogen and CO2 capture & storage development. Energy Policy. 2022; 170: 113256. https://doi.org/10.1016/j.enpol.2022.113256
3. Onat N. How to compare sustainability impacts of alternative fuel Vehicles? Transp Res Part Transp Environ. 2022; 102: 103129. https://doi.org/10.1016/j.trd.2021.103129
4. Zafar U, Bayram IS, Bayhan S, Jovanovic R. Analysis of GPS-based High Resolution Vehicle Mobility Data towards the Electrification of Transportation in Qatar. IECON 2022–48th Annual Conference of the IEEE Industrial Electronics Society. Brussels, Belgium: IEEE; 2022. pp. 1–6.
5. Cui H, Hall D. Annual update on the global transition to electric vehicles: 2021. The International Council on Clean Transportation; 2022 Jun. https://theicct.org/publication/global-ev-update-2021-jun22/
6. Al-Buenain A, Al-Muhannadi S, Falamarzi M, Kutty AA, Kucukvar M, Onat NC. The Adoption of Electric Vehicles in Qatar Can Contribute to Net Carbon Emission Reduction but Requires Strong Government Incentives. Vehicles. 2021; 3: 618–635. https://doi.org/10.3390/vehicles3030037
7. International Trade Administration. Qatar Electric Vehicles Challenges and Opportunities. In: International Trade Administration U.S. Department of Commerce [Internet]. 29 Oct 2021 [cited 2 May 2023]. https://www.trade.gov/market-intelligence/qatar-electric-vehicles-challenges-and-opportunities
8. Investment Promotion Agency Qatar. Electric Vehicles. Investment Promotion Agency Qatar; 2022 Sep. https://www.invest.qa/storage/2144/63fafb03c4fa5_EV_Industry_Sector_Study.pdf
9. InvestQatar. What is driving Qatar's EV growth? 7 Dec 2022 [cited 2 May 2023]. https://www.invest.qa/en/media-and-events/news-and-articles/what-is-driving-qatars-ev-growth
10. Okonkwo EC, Wole-Osho I, Bamisile O, Abid M, Al-Ansari T. Grid integration of renewable energy in Qatar: Potentials and limitations. Energy. 2021; 235: 121310. https://doi.org/10.1016/j.energy.2021.121310
11. Abdullah HM, Gastli A, Ben-Brahim L, Mohammed SO. Integrated Multi-Criteria Model for Long-Term Placement of Electric Vehicle Chargers. IEEE Access. 2022; 10: 123452–123473. https://doi.org/10.1109/ACCESS.2022.3224796
12. Abdullah HM, Gastli A, Ben-Brahim L, Mohammed SO. Planning and Optimizing Electric-Vehicle Charging Infrastructure Through System Dynamics. IEEE Access. 2022; 10: 17495–17514. https://doi.org/10.1109/ACCESS.2022.3149944

13. Aboushaqrah NNM, Onat NC, Kucukvar M, Jabbar R. Life Cycle Sustainability Assessment of Sport Utility Vehicles: The Case for Qatar. In: Sierpiński G, editor. Smart and Green Solutions for Transport Systems. Cham: Springer International Publishing; 2020. pp. 279–287.
14. Ahmed A, Iqbal A, Khan I, Al-Wahedi A, Mehrjerdi H, Rahman S. Impact of EV charging Station Penetration on Harmonic Distortion Level in Utility Distribution Network: A Case Study of Qatar. 2021 IEEE Texas Power and Energy Conference (TPEC). College Station, TX, USA: IEEE; 2021. pp. 1–6.
15. Al Mamun A, Abouzeid A, Al-Yafei H, Hussain S, Ahmad AM, Aseel S, et al. Sustainable Transportation in Qatar. 2021 IEEE 8th International Conference on Industrial Engineering and Applications (ICIEA). Chengdu, China: IEEE; 2021. pp. 583–588.
16. Al Wahedi A, Bicer Y. Development and Thermodynamic Analysis of a 100% Renewable Energy Driven Electrical Vehicle Charging Station with Sustainable Energy Storage. In: Uyar TS, editor. Accelerating the Transition to a 100% Renewable Energy Era. Cham: Springer International Publishing; 2020. pp. 207–232. https://doi.org/10.1007/978-3-030-40738-4_10
17. Al Wahedi A, Bicer Y. A Case Study in Qatar for Optimal Energy Management of an Autonomous Electric Vehicle Fast Charging Station with Multiple Renewable Energy and Storage Systems. Energies. 2020; 13: 5095. https://doi.org/10.3390/en13195095
18. Al Wahedi A, Bicer Y. Development of an off-grid electrical vehicle charging station hybridized with renewables including battery cooling system and multiple energy storage units. Energy Rep. 2020; 6: 2006–2021. https://doi.org/10.1016/j.egyr.2020.07.022
19. Al Wahedi A, Bicer Y. Techno-economic assessment of a renewable energy-based electric vehicle fast-charging station in Qatar. Computer Aided Chemical Engineering. Elsevier; 2021. pp. 1629–1634.
20. Al Wahedi A, Bicer Y. Techno-economic optimization of novel stand-alone renewables-based electric vehicle charging stations in Qatar. Energy. 2022; 243: 123008. https://doi.org/10.1016/j.energy.2021.123008
21. Angizeh F, Ghofrani A, Zaidan E, Jafari MA. Adaptable scheduling of smart building communities with thermal mapping and demand flexibility. Appl Energy. 2022; 310: 118445. https://doi.org/10.1016/j.apenergy.2021.118445
22. Kamal A, Al-Ghamdi SG, Koç M. Modeling and understanding the impacts of efficiency measures on fleet fuel consumption in vehicle importing countries: A case study of Qatar. J Clean Prod. 2020; 259: 120619. https://doi.org/10.1016/j.jclepro.2020.120619
23. Khandakar A, Rizqullah A, Ashraf Abdou Berbar A, Rafi Ahmed M, Iqbal A, Chowdhury MEH, et al. A Case Study to Identify the Hindrances to Widespread Adoption of Electric Vehicles in Qatar. Energies. 2020; 13: 3994. https://doi.org/10.3390/en13153994
24. Onat N, Aboushaqrah NNM, Kucukvar M. Supply Chain Linked Sustainability Assessment of Electric Vehicles: the Case for Qatar. 2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA). Tokyo, Japan: IEEE; 2019. pp. 780–785.
25. Onat N, Kucukvar M, Aboushaqrah NNM, Jabbar R. How sustainable is electric mobility? A comprehensive sustainability assessment approach for the case of Qatar. Appl Energy. 2019; 250: 461–477. https://doi.org/10.1016/j.apenergy.2019.05.076
26. Safak Bayram I. A Stochastic Simulation Model to Assess the Impacts of Electric Vehicle Charging on Power Generation: A Case Study for Qatar. 2019 IEEE Transportation Electrification Conference and Expo (ITEC). Detroit, MI, USA: IEEE; 2019. pp. 1–5.
27. Shaaban K, Adalbi MA. Smart City Transportation System in Developing Countries: The Case of Lusail City, Qatar. In: Stanton N, editor. Advances in Human Aspects of Transportation. Cham: Springer International Publishing; 2021. pp. 445–452.
28. Sultana U, Mujahid A, Jilani HA, Perveen U. Cost Minimization in Radial Distribution System Integrated with Commercial Electric Vehicle Charging Station. IEEC 2022. MDPI; 2022. p. 15.
29. Kondev B, Dixon J, Zhou Z, Sabyrbekov R, Sultanaliev K, Hirmer SA. Putting the foot down: Accelerating EV uptake in Kyrgyzstan. Transp Policy. 2023; 131: 87–96. https://doi.org/10.1016/j.tranpol.2022.12.007
30. Dioha MO, Duan L, Ruggles TH, Bellocchi S, Caldeira K. Exploring the role of electric vehicles in Africa's energy transition: A Nigerian case study. iScience. 2022; 25: 103926. https://doi.org/10.1016/j.isci.2022.103926 PMID: 35243266
31. Benny J. Electric vehicles make up more than 1% of UAE car market, energy minister says. In: The National [Internet]. 29 May 2023 [cited 4 Jul 2023]. https://www.thenationalnews.com/business/energy/2023/05/29/electric-vehicles-make-up-more-than-1-of-uae-car-market-energy-minister-says/
32. Singapore EV Landscape. EV Reporter; 2022 pp. 1–28. https://evreporter.com/wp-content/uploads/2022/10/Singapore-EV-Landscape_2022_EVreporter.pdf

33. Kok X. Singapore push for all-EV future faces a love of crazy, rich combustion. Reuters. 23 Mar 2023. https://www.reuters.com/business/autos-transportation/singapore-push-all-ev-future-faces-love-crazy-rich-combustion-2023-03-23/. Accessed 4 Jul 2023.

34. Mahmoud N, Al-Shahwani D, Al-Thani H, Isaifan RJ. Risk Assessment of the Impact of Heavy Metals in Urban Traffic Dust on Human Health. Atmosphere. 2023; 14: 1049. https://doi.org/10.3390/atmos14061049

35. Burjaq R, Omar N, Hammoudeh S, Janahi I. Asthma Management in Qatar: Environmental Challenges and Recommendations. J Environ Sci Public Health. 2020; 4: 431–441.

36. Global EV Data Explorer–Data Tools. In: IEA [Internet]. [cited 12 Jul 2023]. https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer

37. Al Kharsaah, a pioneering solar power plant in Qatar. In: TotalEnergies [Internet]. 8 May 2023 [cited 8 May 2023]. https://totalenergies.com/projects/renewables-electricity/al-kharsaah-pioneering-solar-power-plant-qatar

38. Ataullah S. Qatar to build two more 880MW solar power plants. The Peninsula. 8 Apr 2023. https://thepeninsulaqatar.com/article/08/04/2023/qatar-to-build-two-more-880mw-solar-power-plants. Accessed 8 May 2023.

39. Moghbelli H, Niasar AH. Conversion of Gasoline Vehicles to CNG Hybrid Vehicles (CNG-Electric Vehicles). Res J Appl Sci Eng Technol. 2013; 6: 2332–2338. https://doi.org/10.19026/rjaset.6.3704

40. Ataullah S. Green initiative: Qatar plans five percent electric cars by 2022. The Peninsula. 17 Sep 2019. https://thepeninsulaqatar.com/article/17/09/2019/Green-initiative-Qatar-plans-five-percent-electric-cars-by-2022. Accessed 16 Apr 2023.

41. Farmer R, Gupta R, Lath V, Manuel N. Capturing growth in Asia's emerging EV ecosystem. In: McKinsey [Internet]. 30 Jun 2022 [cited 16 Apr 2023]. https://www.mckinsey.com/featured-insights/future-of-asia/capturing-growth-in-asias-emerging-ev-ecosystem

42. The Peninsula. ECM wins Kahramaa contract to supply and install 100 EV chargers. 15 Jun 2022. https://thepeninsulaqatar.com/article/15/06/2022/ecm-wins-kahramaa-contract-to-supply-and-install-100-ev-chargers. Accessed 8 May 2023.

43. Ataullah S. Kahramaa to install EV charging units at all Woqod fuel stations. The Peninsula. 15 Jan 2023. https://thepeninsulaqatar.com/article/15/01/2023/kahramaa-to-install-ev-charging-units-at-all-woqod-fuel-stations. Accessed 8 May 2023.

44. Service Stations. In: WOQOD [Internet]. [cited 8 May 2023]. https://www.woqod.com/EN/Fuel_Retail/Pages/Stations-Map.aspx

45. Cochrane L, Al-Hababi R, editors. Sustainable Qatar: Social, Political and Environmental Perspectives. Singapore: Springer Nature; 2023.

46. Qatar National Vision 2030. State of Qatar; 2008 Jul. https://www.gco.gov.qa/en/about-qatar/national-vision2030/

47. Hukoomi. MOTC: Public Transport Buses and Government School Buses to Be Electric by 2030. In: Hukoomi [Internet]. [cited 16 Apr 2023]. https://hukoomi.gov.qa/en/news/motc-public-transport-buses-and-government-school-buses-to-be-electric-by-2030

48. ABB. ABB to charge Qatar's largest electric bus infrastructure project. In: ABB [Internet]. 1 Jul 2021 [cited 16 Apr 2023]. https://new.abb.com/news/detail/80100/abb-to-charge-qatars-largest-electric-bus-infrastructure-project

49. Intelligent Transport. Middle East's first solar-powered bus depot launched in Lusail, Qatar. Intelligent Transport. 28 Oct 2022. https://www.intelligenttransport.com/transport-news/140822/middle-easts-solar-powered-bus-depot-lusail-qatar/. Accessed 16 Apr 2023.

50. Ministry of Transport. The Public Bus Infrastructure Program. In: Ministry of Transport [Internet]. 11 Dec 2022 [cited 16 Apr 2023]. https://mot.gov.qa/en/ThePublicBusInfrastructureProgram

51. Qatar Free Zones. Framework agreement signed to manufacture E-Buses in Qatar Free Zones. In: Qatar Free Zones [Internet]. 30 Nov 2020 [cited 16 Apr 2023]. https://qfz.gov.qa/framework-agreement-signed-to-manufacture-e-buses-in-qatar-free-zones/

52. Ashghal. 'Ashghal' in coordination with Free Zones and ABB ink MoU to establish factory for electric chargers for vehicles. In: Ashghal [Internet]. 25 Sep 2021 [cited 16 Apr 2023]. https://www.ashghal.gov.qa/en/MediaHub/News/Pages/%E2%80%98Ashghal%E2%80%99-in-coordination-with-Free-Zones-and-ABB-ink-MoU-to-establish-factory-for-electric-chargers-for-vehicles.aspx#.ZDwdVOzMK3I

53. Asadi S, Nilashi M, Iranmanesh M, Ghobakhloo M, Samad S, Alghamdi A, et al. Drivers and barriers of electric vehicle usage in Malaysia: A DEMATEL approach. Resour Conserv Recycl. 2022; 177: 105965. https://doi.org/10.1016/j.resconrec.2021.105965

54. Hamzah MI, Tanwir NS, Wahab SN, Rashid MHA. Consumer perceptions of hybrid electric vehicle adoption and the green automotive market: the Malaysian evidence. Environ Dev Sustain. 2022; 24: 1827–1851. https://doi.org/10.1007/s10668-021-01510-0

55. AlHammadi A, Al-Saif N, Al-Sumaiti AS, Marzband M, Alsumaiti T, Heydarian-Forushani E. Techno-Economic Analysis of Hybrid Renewable Energy Systems Designed for Electric Vehicle Charging: A Case Study from the United Arab Emirates. Energies. 2022; 15: 6621. https://doi.org/10.3390/en15186621

56. Asna M, Shareef H, Achikkulath P, Mokhlis H, Errouissi R, Wahyudie A. Analysis of an Optimal Planning Model for Electric Vehicle Fast-Charging Stations in Al Ain City, United Arab Emirates. IEEE Access. 2021; 9: 73678–73694. https://doi.org/10.1109/ACCESS.2021.3081020

57. Cars For Sale. In: QatarSale [Internet]. [cited 6 May 2023]. https://qatarsale.com/en/products/cars_for_sale