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CLIMATE VARIABILITY AND CHANGE IMPACTS ON VEHICULAR FUEL CONSUMPTION AND EMISSIONS – A SYSTEMATIC OVERVIEW IN AFRICA

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ABSTRACT

Increasing energy demand has become a major issue of concern globally. Addressing the issue requires the sustainable development of the transportation sector of every nation. Sustainable transport system will meet basic and developmental needs while ensuring equity within and between generations. Fuel consumption and emissions are key issues of importance when considering the sustainability of road transportation. In order to actualize the SDGs, overarching factors impacting on transport vehicle fuel consumption and emissions should not be compromised. Weather being one of such factors is understudied especially in Africa based on the authors knowledge from literature. Consequently, the review accentuates on how weather parameters affect fuel consumption and emissions throwing more light on similar studies that have already been conducted to facilitate replicability in Africa. ‘Google scholar and Scopus’ were used to obtain relevant literature database from 2000-2022. In total, 111 articles were systematically reviewed, out of which 41 were from Europe, 38 from America, 23 from Asia and 7 from Africa. Among the weather parameters reviewed, temperature was the most pronounced with percentage share of 46 % followed by air pressure 16%, precipitation 15%, humidity 12%, wind 11%. All the weather factors strongly impacted on vehicular fuel consumption and its concomitant greenhouse gases emissions based on the results depicted by the review. Climate variability and change is detrimental to fuel consumption and emissions and should not be overemphasized when making road transport policies and decisions.

Keywords: climate change, fuel consumption, road transport, simulation tools, vehicular emissions.

INTRODUCTION

Fuel consumption is of major concern to passenger car users due to the volatile fuel prices and thus, information on their consumption rates will play substantive role in policy design and evaluation (Huo, He, Wang, & Yao, 2012; Predić, Madić, Roganović, Karabašević, & Stanujkić, 2018). Fuel consumption and emissions are strongly correlated - the concentration of carbon dioxide emitted is proportionate to the quantity of fuel consumed for a trip (Kopfer Schönberger, & Kopfer, 2014). It is a significant cost element in vehicle operation and represent about 50% of transport cost per production unit (Ivković Kaplanović, & Milovanović, 2017) hence, estimating vehicle fuel consumption serves as the basis for enhancing energy savings and cost as well as reducing negative environmental effects caused by fuel combustion (Predić et al., 2018). Minimizing fuel consumption is beneficial to emission reduction programs (Parajuli, 2005) and the introduction of fuel consumption rate regulations will curb vehicular greenhouse gas (GHG) emissions (Zhao, Liu, Lui, & Hao, 2019). In four of the biggest automobile markets - United States of America (USA); European Union (EU); China and Japan, governments have created and implemented fuel economy regulations to tackle fuel consumption in order to reduce greenhouse gases (Mbandi et al., 2019).

Estimation of vehicle fuel consumption in practice is complex due to the numerous variables that affect their outcome. Recently, machine learning approaches have been used to estimate the fuel consumption of vehicles. Artificial Neural Networks (ANN), Support Vector Machine (SVM), and Random Forests (RF) are powerful machine learning tools for regression analysis. Most proposed mathematical models consider diverse parameters from different categories like vehicle type, vehicle engine, roadway, weather, traffic and driver related factors. Artificial Neural Networks (ANNs) are mostly applied by researchers for modeling these interrelated variables during fuel consumption estimation. ANNs are computational models that are inspired by human brain functionalities. The model consists of simple processing elements called neurons that operate in parallel and capable of obtaining, keeping and using experiential knowledge that exceeds the possibilities of most conventional modelling methods (Predić et al., 2018; Perrotta, Parry, Neves, & Mesgarpour, 2018; Sun, Chen, Dubey, & Pugliese, 2021). It is able to capture relationships and model phenomena which are likely to be difficult or impossible to explain (Zhu, Gonder, Bjärkvik, Pourabdollah, & Lindenberg, 2019; Zhao et al., 2019). SVM is a biased classifier technique for machine learning with the capacity to regulate decision function. An extension of this technique is Support vector regression (SVR) which is commonly used as an alternative to traditional linear/non-linear regression models. Random Forest depends on decision tree concept normally used for classification. The outcome of this technique relies on the prediction of the decision trees, hence adding more trees can improve the model's accuracy (Mbandi et al., 2019; Predić et al., 2018; Perrotta et al., 2018; Katreddi, & Thiruvengadam, 2021).

Obtaining reliable data on real-world fuel consumption and emissions of on-road vehicles are very complicated. Vehicles do not record fuel consumption volume unlike vehicle kilometer per time which is read from odometers. This creates difficulties in obtaining on-road vehicular fuel consumption rates (Huo et al., 2012). According to Dror, Qin, & An (2019), on-board emissions measurements; tracing measurements; dynamometer and bench testing; tunnel tests and remote sensing are the five major methods normally used in calculating fuel consumption and CO_2 emission factors from passenger vehicles. The most pronounced methods in literature are: on-board emissions measurement, dynamometer testing and remote sensing. Dynamometer testing uses standardized driving cycles in a regulated environment to measure vehicles emissions. The driving cycle consists of a distinctive profile of stops, starts, steady-speed cruises, accelerations and decelerations and is typically distinguished by a total time-weighted average speed (Frey, Unal, Rouphail, & Colyar, 2003). Two different dynamometer types are normally employed to measure fuel consumption – chassis dynamometer and engine dynamometer. In chassis dynamometer testing, lots of variables can be held constant allowing high experimental repetition and control whilst engine dynamometer is applicable in regulations and does not account for transmission efficiency and air conditioning (Mills, 2019). Remote sensing approach utilizes absorption spectroscopy to evaluate exhaust pollutants of test vehicles by placing an optical instrument at an appropriate roadside (Borken-Kleefeld, 2014). They are capable of measuring emissions from large number of vehicles and are also cost effective making them more desirable relative to the other techniques (Cadle, Gorse, Bailey, & Lawson, 2003). The major drawback in this technique is that, it exclusively provides an immediate estimate of emissions at a particular site (Frey, Unal, Rouphail, & Colyar, 2002). Vehicles equipped with on-board instruments enable for data collection under real-world settings at any weather conditions and location that is traveled (Frey et al., 2003). This technique makes predictions about when exhaust emissions are likely to exceed norms using emission control parameters and engine monitoring rather than taking a direct measurement of them (Faah, 2008). On-board measurement is not widely utilized because is expensive and thus, focus on small number of vehicles (Frey et al., 2002). Inter alia, current smartphones have inbuilt sensors that are capable of measuring the position of vehicles, speed, acceleration and altitude. Kanarachos, Mathew, & Fitzpatrick (2019), successfully estimated vehicle instantaneous fuel consumption using smartphone measurements which was processed by the use of Recurrent Neural Networks (RNNs).

According to Lois et al. (Lois, Wang, Boggio-Marzet, & Monzon, 2019), fuel consumption/emission depends not solely on traffic, driving and road conditions but also on weather conditions. Weather conditions influence fuel consumption by impacting on driving patterns and the rolling and aerodynamic resistances (Predić et al., 2018). Evaluation of fuel consumption and GHG emissions under varying weather conditions is very crucial in quantifying energy cost and air pollution caused by road transport (Hien, & Kor, 2022) and also for enhancing efficient development of short, medium and long-term transportation planning policies (Mehrotra et al., 2011). Data on fuel consumption can serve as a blue print to modify government subsidies to attain energy efficiency goal in vehicles (Ehsani, Ahmadi, & Fadai, 2016). There are adequate data on road transport impact on climate change but minimal attention is given to the reverse case. Most of the studies conducted on climate and weather-related impacts on road transport focus on the physical impacts like road infrastructure (Gelete, & Gokcekus, 2018). From the authors experience and research, there is no review paper emphasizing on the area of ‘climate impacts on vehicular fuel consumption and emissions’ in Africa and previous reviews conducted in other continents have focused extensively on other related factors (excluding climate) affecting fuel consumption and emissions. Few available review papers have integrated climate factors; hence this review will accentuate exclusively on weather parameters impact on fuel consumption and emissions to broaden and augment knowledge and understanding in this area whilst concurrently serving as the premier review paper from Africa**.** The main objective is to review the impacts of weather factors on fuel consumption and emissions and the various approaches used to ascertain the impacts. The review is structured into four parts: Part 2 highlights the search methodology and literature database. Part 3 elucidates the approaches and findings of weather parameters (temperature, humidity, precipitation, wind and air pressure) effects on vehicle fuel consumption and emissions as well as various simulation models utilize in estimating vehicle fuel consumption and emissions. Conclusions and recommendations are provided in part 4.

METHODOLOGY

Search methodology

A systematic search for relevant literature database was conducted using online database (Scopus and google scholar). Boolean search using keywords and phrases were utilized to navigate via scientific search engines. Keywords and phrases used were *road transport systems*, *climate and road transport, climate modelling/simulations, fuel consumption modelling tools, emissions* *modeling/simulation tools, vehicle fuel consumptions, vehicular emissions, real-world vehicle fuel and emissions estimations, laboratory vehicle fuel and emissions estimations, fuel consumption measuring tools, vehicle emissions measuring tools, factors affecting fuel consumption, influence of weather factors on fuel consumption, weather impacts on vehicle emissions*. Related articles from regional, country and global level were included in the database to get a broader overview. The articles were systematically reviewed and the database was structured using pre-determined list in (table 1) to compile meta-data. The method considered all pertinent articles from 2000-2022. In total, 111 articles published between 2000-2022 were reviewed and added to the database. Figure 1 illustrates how the 111 articles were selected and figure 2 depicts the number of articles reviewed per publication year.

Table 1. List of meta-data for systematic review

Item	Definition
Title	Title of the document being reviewed
Objective	Study objective
Methodology	Approach used to attain the study objective
Weather parameters	Temperature, humidity, precipitation, wind and air pressure
Keys notes/summary	Study findings
Authors	Author (s) of the study
Continent/country	Continent / country of study
Journal type	Name of journal
Document type	Research article, review paper, conference proceedings etc.

Literature database

The methodology applied and findings of the selected 111 papers were taken into consideration. Key information on temperature, precipitation, humidity, wind and altitude (air pressure) effects on fuel consumption and emissions of gasoline and diesel vehicles; approaches employed for the evaluations and their gaps which identified areas for further studies were reported. Some obtained information on electric and hybrid vehicles and various modelling tools used for ascertaining fuel consumption and emissions were included in the database.

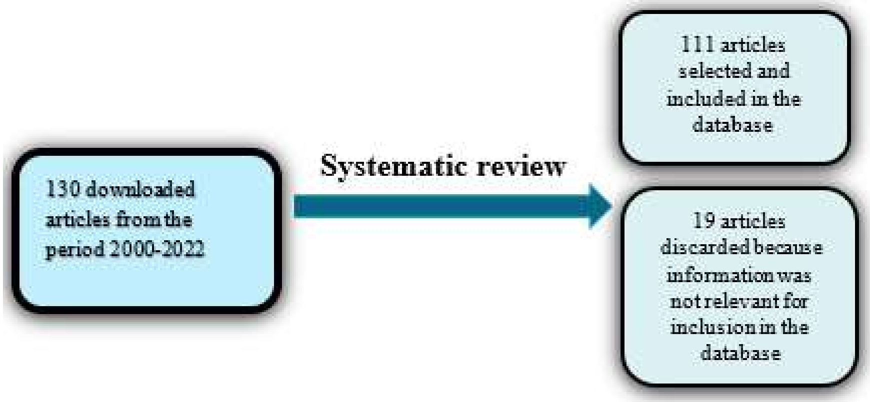

Figure 1. Flow chart depicting article selection process

RESULTS AND DISCUSSION

Database creation

The study location of most of these reviewed papers were in Europe and America. Out of the 111 papers that were reviewed; 41 were from Europe, 38 from America, 23 from Asia, 7 from Africa and 2 from Australia. Per country level, most of the papers selected were from USA (29), China (15), United Kingdom (6) and Canada (6). Full list of countries is in appendix figure a1. Temperature was the most pronounced factor in this review with a percentage share of 46% followed by air pressure/altitude 16%, precipitation 15%, humidity 12% and wind 11%. The number of reviewed weather variables (temperature, precipitation, air pressure, wind and humidity) per continent is provided in figure 3.

Articles retrieved were published in 49 journals with most of the publications from Transportation Research Part D: Transport and Environment (13), Energies (10) and Sustainability (5). Complete list of journals is shown in appendix table. a1. Majority of the retrieved published documents were research articles (84) whilst the remaining were conference proceedings (9), thesis (5), review papers (4), assessment reports (4), technical papers (4) and workshop paper (1).

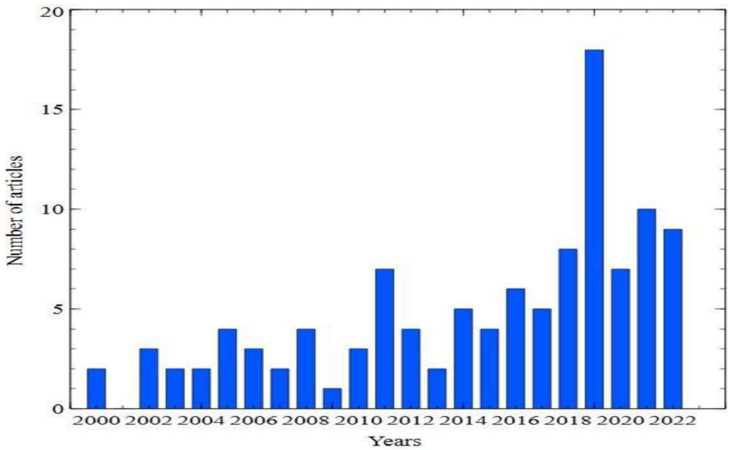

Figure 2. Number of articles reviewed per year

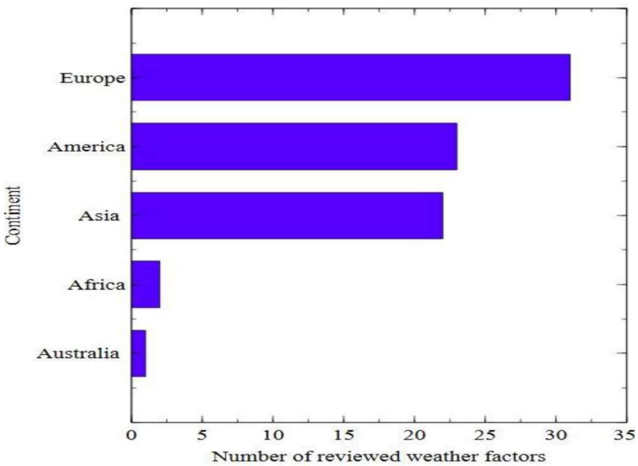

Figure 3. Weather variables reviewed per continent

Climate factors affecting vehicle fuel consumption and emissions

According to Zhou, Jin, & Wang (2016), the major factors influencing fuel consumption and emissions are weather/climate, vehicle type, road type, traffic, travel and driver related conditions. They described the travel factors as distance and trips made within a specific period; the vehicle factors as the speed and acceleration of the vehicle, engine type and driver factors as the driver's behavior and aggression determined by the acceleration and speed profiles. Faah (2008), also asserted vehicle technology, pavement conditions, weather and road conditions as parameters that affect fuel consumption and emissions. Amongst these factors, climate and weather conditions are given less attention globally. Handful researches have been conducted in this area with most of these few studies relying solely on expert opinions (Mansur, Mendelsohn, & Morrison, 2008). According to Gelete & Gokcekus (2018), road transport activities and climate change are distinctively connected – "one is the cause and the other is the effect and vice versa". Climate change has acute (through extreme events) and chronic (through gradual change) impacts on road transport. Aside its direct impact, climate change can indirectly affect road transportation by causing disruption in the electric power sector which is strongly interconnected with transport. Electric power is the main contributor to traffic signals and gasoline pumps operations and so on thus, interruption in these transport components ultimately leads to increased congestions, inadequate availability of fuel etc. Electricity also serves as a vital source of power for electric vehicles (EVs) (Markolf, Hoehne, Fraser, Chester, & Underwood, 2019). The number of EVs globally has increased from virtually zero to more than 16 million in 2021 with majority being battery EVs (Dioha, Lukuyu, Virgüez, & Caldeira, 2022). Electric vehicles are prominent in places like China (45%), Europe (24%) and USA (22%). In Africa, countries like South Africa had 5000 electric vehicles in use as of 2020, Mauritius had 17000 as of 2021 and Ghana imported 5,400 between 2017-2020 with majority being plug-in hybrid-electric vehicles (PHEV). Currently Mauritius is leading the African continent in terms of the importation of electric vehicles (Ayetor, Opoku, Sekyere, Agyei-Agyeman, & Deyegbe, 2022; Montmasson-Clair, Dane, & Moshikaro, 2020). With the increasing prevalence of electric vehicles, interconnection between transport and electricity will continually upsurge. Consequently, outages in electric power induced by climate change will augment vulnerability in the transport system (Markolf et al., 2019). Road transport systems are sensitive to the variations in weather factors hence, varying weather conditions will affect fuel efficiency because just a small change in weather parameters can have substantial impacts on fuel consumption (Wang et al., 2019; Jeon, 2019). Weather parameters - temperature, precipitation, humidity, wind, air pressure strongly affect fuel consumption and pollutant emissions in on-road vehicles (Choi, Beardsley, Brzezinski, Koupal, & Warila, 2010). These factors play independent roles in influencing fuel consumption and emissions (Wu et al., 2020). Intuitively, fuel efficiency is one of the channels that is both directly and indirectly affected by weather conditions (Jeon, 2019).

Temperature effects

Temperature affects drivers' behavior and causes changes in speed and acceleration of vehicles which alter fuel consumption and emissions (Ehsani et al., 2016). It also affects the car tires' resistance and necessitates usage of auxiliary loads like air conditions and fans in hot seasons and heater and seat heating components in cold seasons which ultimately increase fuel consumption and thus emissions (Nouri, & Morency, 2015). The utilization of heating, ventilation and air conditioning (HVAC) significantly affect vehicle efficiency (Yuksel, Tamayao, Hendrickson, Azevedo, & Michalek, 2016). They add extra loads to the engine causing it to consume more fuel during operation (Zöldy, & Zsombók, 2018). Weilenmann, Vasic, Stettler, & Novak (2005), studied the effects of air conditioning operation on fuel consumption and emissions of passenger vehicles. Findings revealed rise in emissions and fuel consumption when air condition (a/c) was on. According to the study of Nouri, & Morency (2015), temperature affected emissions in two states - cold start and hot running. They recorded high emissions with increasing low temperatures (-10, -20, -30, -40ºC) and high temperatures (0, 10, 20, 30ºC). They attributed their results to long warm-up of engines due to cold temperatures and use of air conditions at high temperatures (Nouri, & Morency, 2015). The study by Carlson, Wishart, & Stutenberg (2016), determined the impact of temperature on auxiliary loads and fuel consumption using on-road and laboratory measurement. On-road measurements were conducted by instrumenting vehicles with voltage and current detectors together with Controller Area Network (CAN) message tracking devices and On-board Data Acquisition (DAQ) equipment to record the voltage, current and CAN signals whilst the laboratory measurements were undertaken by the chassis dynamometer. High and low temperatures had greater impacts on auxiliary loads due to the use of air conditioners and heating systems in hot and cold temperatures respectively and hence, higher fuel consumption. Li, Li, Miwa, & Morikawa (2019), estimated driver's daily fuel consumption using CAN data obtained from private cars in Toyota city. The study defined the days with temperatures less than 10ºC as (cold days), higher than 25ºC as (hot days) and the remaining days as (comfortable). Fuel consumption increased significantly in the cold and hot days comparatively to the comfortable days due to the usage of air conditioners and heating devices during the hot and cold days respectively. Savostin-Kosiak et al. (2020), discovered high fuel consumption at high temperatures during their experimental analysis using Physical Emissions Rate Estimator (PERE) mathematical model to establish the relationship between ambient temperatures (-15ºC to 30ºC) and fuel consumption of diesel buses. They attributed the findings to two factors- fuel evaporation increase which affected the fuel combustion efficiency and air conditioning use during the hot temperatures. US Environmental Protection Agency (EPA) analysis on vehicles fuel economy depicted a reduction in the country's fuel economy by approximately 5-25% due to operating air conditioners during hot temperatures (Jeon, 2019). Choi, et al. (2010), estimated on-road vehicles emissions in conventional fuel vehicles utilizing Motor Vehicle Emission Simulator (MOVES) 2010 model. The model was run by keeping all other parameters constant except temperature. The percentage changes in emissions were calculated using 75 degrees as the base temperature. Emissions increased at temperatures below and above the base temperature. The effect of temperatures from start emissions resulted in increased emissions at temperatures below 75 degrees whilst the high emissions recorded at temperatures above 75 degrees were due to the operations of air conditions. The increase in emissions were more significant in gasoline vehicles compared to diesel vehicles. Giechaskiel, Komnos, & Fontaras (2021), evaluated the impacts of extreme ambient temperatures (ranging from -30 to 50ºC) on Euro 6d – Temp gasoline vehicle's carbon dioxide (CO_2) emissions. Energy consumption from the operation of air conditioning systems had significant impacts on the emissions after simulation using Carbon dioxide Model for Passenger And commercial vehicles Simulation (CO_2MPAS). With 23ºC as base temperature, there was 10% and 30% significant increases in CO_2 emissions at 35ºC and 45ºC respectively due to the use of air conditions. At low temperatures, there was (5 to 20%) rise in emissions at -25ºC primarily as a result of the maximum contributions of cold-start. Jeon (2019), used simple log-linear specification model to estimate weather impacts on gasoline fuel consumption. Results revealed an increase in gasoline consumption in hot days but statistically insignificant impact during cold days. The simulated climate change effects on fuel consumption depicted 4% increase in fuel consumption under "business-as-usual" Representative Concentration Pathways (RCPs) 8.5 scenario. The study findings of (Keramydas et al., 2018), revealed an increase in fuel consumption in summer months over winter due to the increase usage of a/c loads.

There is decrease in fuel economy at cold temperatures mainly as a result of engine and transmission friction and other technical factors (Jeon, 2019). According to a 2019 report by the US Energy Department, the fuel economy of gasoline vehicle at 20ºF is 15% lower than it would be at 77ºF. For hybrids and electric vehicles, the fuel economy can reduce at about 30% and 39% respectively considering the same temperatures. Low temperatures increase air density and aerodynamic resistance whilst high temperatures decrease aerodynamic resistance (Zacharof et al., 2016). Force of resistance depends on air density. Warm air has lesser density than cold air and hence, higher resistance in cold temperatures than hot temperatures. Resistance force at -10ºC is about 12% greater than 20ºC. The variations in air density between high and low temperatures account for relatively higher fuel consumption in cold temperatures compared to hot temperatures (Savostin-Kosiak et al., 2020). Rahimi-Gorji et al. (Rahimi-Gorji, Ghajar, Kakaee, & Domiri Ganji, 2017) also posited that the lower densities of high temperatures reduce fuel volumetric efficiency which in turn decrease fuel consumption. According to Lujan et al. (Lujan, Climent, Ruiz-Rosales, & Moratal 2019), fuel consumption and emissions are very critical under low temperatures as a result of combustion instabilities. Also, engine and catalyst require more time to warm up at lower temperatures resulting in increased rate of emissions (Suarez-Bertoa et al., 2017; Nouri, & Morency, 2015). Li et al. (2005), analyzed the impact of ambient temperature (-2ºC and 31ºC) on exhaust thermal emissions employing engine dynamometer test. They reported increase in fuel consumption at cold winter temperature (-2ºC) and attributed it to the rise in mechanical frictions, extra over-fueling and higher heat losses which occurred at the cold temperatures. The study by Payri et al. (Payri, Martin, Jose Arnau, & Artham, 2022) analyzed temperature (20ºC, -7ºC) impacts on energy balance during Worldwide harmonized Light vehicles test Cycles (WLTC) by experimental measurements and simulations. When ambient temperature was reduced from 20ºC to -7ºC, the brake performance decreased by 1% and fuel consumption increased by 4% due to higher friction caused by greater oil viscosity. Komnos et al. (Komnos, Tsiakmakis, Pavlovic, Ntziachristos, & Fontaras, 2022) reported higher fuel consumption at cold temperatures comparative to warm temperatures after simulating the impacts of real-world factors- ambient temperatures (-10 to 40ºC) on fuel consumption of European passenger car fleets using Passenger car fleet emissions simulator (PyCSIS) simulation tool. Ambient temperature has substantive effects on exhaust and evaporative emissions - cold start emissions surge due to the longer time vehicles' engines take to warm up at cold temperatures. A 1ºF increase in ambient temperature will cause a reduction of 1.3% in CO and 2.8% in HC emissions (Abo-Qudais, & Qdais, 2005). Bielaczyc, Szczotka, & Woodburn, (2011) reported significant extra carbon monoxide (CO) and hydrocarbon (HC) emissions over New European Driving Cycle (NEDC) at cold-start temperature (-7ºC) compared to temperature at 24ºC in spark ignition (SI) vehicles. Dardiotis, Martini, Marotta, & Manfredi (2013), determined fuel consumption and emission of gasoline and diesel vehicles over NEDC at 22ºC and -7ºC test temperatures. CO and HC emissions increased remarkably at the low temperature (-7ºC) comparative to 22ºC. Weilenman et al. (2009) examined the impact of temperatures (23, -7 and -20ºC) on cold-start emissions of diesel/ petrol cars using a developed cold start extra emissions (CSEE) model. Cold-start additional fuel consumption was (0.18, 0.13 and 0.039 liters/start) for temperatures (-20, -7 and 23ºC) respectively. CSEE of HC and CO at -20ºC were 35 and 15 times greater than at 23ºC. CSEE of gasoline cars were significantly higher than in diesel cars. Li et al. (Li, Andrews, & Savvidis, 2010) determined the effects of cold-start and ambient temperatures (7ºC, 10ºC, 21ºC, 26ºC, 30ºC) on real-world fuel consumption/ emissions using Maxim (MAX) 710 fuel flow measurement system and Fourier Transform Infrared (FTIR) spectrometer for fuel and emission measurement respectively. Fuel consumption was higher at lower ambient temperatures compared to high temperatures and hence, higher emissions of CO_2 and methane (CH_4) except nitrous oxide (N_2O) which was not affected by ambient temperatures because of absence of cold start peaks. Ammonia (NH_3) and nitrogen oxides (NOx) emissions from light-duty conventional vehicles were quantified using Portable Emissions Measurement System (PEMS) during real on-road driving under ambient temperatures (-7ºC and 23ºC). From their results, NOx and NH_3 emissions were greater when vehicles were examined at -7ºC and 23ºC respectively (Suarez-Bertoa et al., 2017). Lujan et al. (2019), after determining the effects of ambient temperatures (-7ºC and 20ºC) on pollutant emissions under WLTC and NEDC driving cycle reported increase in CO, HC and NO_x emissions at -7ºC temperature. Under the NEDC driving, -7ºC temperature led to 270%, 125% and 250% increase in (HC, CO and NOx) respectively with an observed 10% rise in fuel consumption. Joumard et al. (2006), reported decrease in exhaust emissions (CO, HC, NO_X and CO_2) with increasing temperature (10-20ºC) for petrol and diesel cars with maximum impacts on diesel cars during laboratory testing using chassis dynamometer.

Wu et al. (2020), employed Real-world Fuel Consumption Rate (RFCR) model data to determine light-duty vehicles' fuel consumption in different cities in China. They reported variations in temperature across different regions as the main cause of regional variability in fuel consumption in China. Lower temperature increased the period needed for internal combustion engine to attain its optimal state and thus high fuel consumption. Predić et al. (2018), used ANN model to determine the relationships between independent factors (city location, day time, week day) and passenger car fuel consumption during summer and winter periods. Findings showed that during summer periods, fuel consumption rose in the late afternoon hours mainly because of high rate of traffic delays and congestions but during the winter periods, fuel consumption was greater in the morning hours due to the longer period taken to pre-heat the engine as a result of low ambient temperatures. The study by Ehsani et al. (2016), used mechanistic model to ascertain vehicular fuel consumption. Temperature was categorized into cold region (T<67°F), warm region (T>87°F) and Federal Test Procedure (FTP) region (68°F<T<86°F) taken as the moderate temperature region. Cold and warm temperature regions caused 5.57% and 1.71% rise in fuel consumption respectively. Mbelle, Paune, Youmene, Tambere, & Talla, (2020), used Matrix laboratory (MATLAB)/ Simulink to simulate vehicular fuel consumption with respect to ambient temperatures (-15, 30, 45ºC). Every 15% drop in temperature resulted in 0.04 liters increase in fuel consumption. Yusuf and Inambao (2019), investigated the effects of changing ambient temperature on the cold start emissive behavior of gasoline direct injection (GDI) and port fuel injection (PFI) cars. Decreasing temperature from +30ºC to -7ºC resulted in a ten-fold rise in vehicle emissions. Fuel consumption also increased as temperatures dropped, and was more significant in PFI cars compared to GDI cars. In terms of emissions, GDI emitted more particulate matter compared to PFI cars.

Temperature has a significant impact on electric vehicles because it greatly affects battery capacity (Zacharof et al., 2016). Battery efficiency is significantly impacted by using 'heating, ventilation and air conditioning' (HVAC). Battery electric vehicles are estimated to expend 15% more energy in hot and cold areas in USA due to the use of HVAC (Yuksel et al., 2016). Lohse-Busch et al. (2013), determined the impact of ambient temperatures (20°F, 72°F and 95°F) on energy consumption of plug-in hybrid electric vehicle (PHEV) and battery electric vehicles (BEV). Energy consumption rise at 20°F in comparison with 72°F ranged from 2% to 100% whilst energy consumption increases at 95°F ranged from 2% to 70% due to additional energy needed to operate the air conditioning system to keep the cabin at 72°F. Aside the use of HVAC, cold temperatures have relatively strong impacts on battery energy performance compared to hot temperatures. Christenson, Loiselle, Karman, & Graham (2007), experimentally determined fuel consumption and emissions in gasoline-electric hybrid vehicle and a conventional gasoline vehicle under ambient temperatures (20ºC and -18ºC) using chassis dynamometer. The cold temperature (-18ºC) resulted in increased fuel consumption in all the test vehicles with greater impacts in the hybrid vehicle comparative to the conventional vehicle. Tulpule, Marano, & Rizzoni (2011), developed a vehicle model by using validated models of individual components to determine the correlation between PHEV energy performance and weather conditions. Increasing temperatures from -25 to 50ºC resulted in 23% reduction of air density which caused 5% and 10% decreased in vehicle energy demand in terms of urban and highway driving respectively. An experimental investigation using chassis dynamometer was carried out by (Alvarez, & Weilenmann, 2012) to determine the impact of ambient temperatures (23ºC, 8ºC and -7ºC) on the amount of fuel consumed and pollutants emitted by hybrid electric vehicles (HEV). The lower temperatures affected the operating efficiency of the hybrid system battery used in the hybrid electric vehicles' powertrain and thus, resulted in increased fuel consumption and cold start extra emissions. Zahabi et al. (Zahabi, Miranda-Moreno, Barla, & Vincent, 2014) employed Random-Effect Log-linear Regression Modeling (RELRM) method to determine the relationship between real world conditions and fuel economy. They discovered low temperatures (below 0ºC) during winter in Quebec cities in Canada to be detrimental to vehicle fuel economy. The fuel efficiency in wintertime dropped by 20% comparative to summertime. Increase in 10% average ambient temperature resulted in 0.3% reduction in fuel consumption rate of HEV. Laurikko and Pellikka (2010), also reported high fuel consumption in electric vehicles at low ambient temperatures under Nordic driving conditions. Jung and Li (2018), characterized emissions from PHEV under cold temperatures (-7ºC ~ -0ºC) during real world driving. High rate of NO_X emissions was recorded at the tested cold temperatures.

Table 2. Some key approaches for evaluating temperature effects on fuel consumption and emissions

Key method	Study objective	Gap	Reference
Simulation program was built using MATLAB software. Eight different road types and sets of ten car models were selected to run the simulation. Only parameters of (temperature, drag coefficient and coefficient of rolling resistances) were subjected to changes during each simulation. Simulation results were analyzed and interpreted using Microsoft Excel	Evaluate vehicle fuel consumption with respect to ambient temperature	Further studies to include other external factors	Mbelle et al., 2020.
Data on driving behavior factors and factors affecting fuel consumption of passenger vehicles in real world driving conditions were initially collected followed by exploratory and regression analysis. Simple descriptive techniques and graphics such as box plots etc. were generated under the exploratory analysis. Regression analysis was carried out by using (RELRM) method.	Determine the effects of winter season and low temperatures on fuel economy of hybrid and conventional gasoline vehicles	Further study should consider using disaggregate fuel consumption measures to validate the results and also regenerate data and analysis to measure flexibility of the findings in terms of data collection.	Zahabi et al., 2014.

On road and laboratory vehicle tests were done using PEMS and chassis dynamometer respectively. Vehicle simulations were performed with CO_2MPAS model to quantify the effects of temperature on emissions. Extreme operating conditions like (a/c fuel consumption at high temperatures and efficiency of low torque converter at low temperatures) were also simulated by the model.	Measured CO_2 emissions of a Euro 6d-temp gasoline direct injection (GDI) vehicle with a three-way catalyst and a gasoline particulate filter	Future improvement of the model to incorporate more new vehicle technologies and environmental parameters	Giechaskiel et al., 2021.

Humidity effects

Humidity affects the performance of vehicle tires and the driving style of drivers, hence causing frequent changes in speed and acceleration of vehicles (Ehsani et al., 2016). Increase in temperature is accompanied with decrease in humidity. Hence, at high temperature and consequent low humidity, there is vaporization of air which increase the engine pressure resulting in high fuel consumption. High humidity reduces flame speed making it unconducive for combustion (Soares, & Sodré, 2002). This is attributed to high moisture content during high humidity which tend to lower air density resulting in decrease engine combustion efficiency due to low oxygen content in the air. Relative humidity alongside temperature affects emission particles transformation processes. Low temperature and high humidity increase nuclei mode emission particles and cause the growth of already formed particles by increasing their condensation (Jamriska, Morawska, & Mergersen, 2008). Jamriska et al. (2008), reported increase in emission particle concentrations at low temperatures and high humidity when 'tree regression' was used to determine the relation between relative humidity/ temperature (RH/temp) and emission particle sizes. High humidity is known to result in low NOx emissions because it reduces the oxygen content in the air absorbed by the vehicle internal combustion engine (Yanowitz, McCormick, & Graboski, 2000; Zalakeviciute, López-Villada, & Rybarczyk, 2018). Lindhjem et al. (Lindhjem, Chan, Pollack, & Kite, 2004) determined the impacts of humidity on NOx emissions for both on- and off- road vehicles and engines and subsequent adjustment of emission estimates in eight-county Houston-Galveston nonattainment area (HGA). Counties closer to the coast as well as evenings and early mornings recorded low NOx emissions due to high humidity levels. Toback, Hearne, Kuritz, Marchese, & Hesketh (2004), also reported reduction in NOx emissions as relative humidity increased from 37 to 90% after simulating the idling emissions of school buses in an environmental chamber. Kihara, Tsukamoto, Matsumoto, Ishida, Kon, & Murase (2000), created and installed (on-board measurement system) in diesel vehicles to measure NOx emissions. Results revealed a decrease in mass emissions of NOx at high humidity supporting the findings specified in emission standards which states that NOx concentration should be modified using ambient humidity. Wimmer and Schnessl (2006), experimentally investigated the effects of specific humidity on engine efficiency and NOx emissions. They observed 60% decrease in NOx emissions with rise in specific humidity from (8 g/kg to 25 g/kg). This was attributed to increase in losses due to partial and actual combustion resulting from reduced burn rate. Reduction in burn rate which resulted in longer combustion duration retarded the ignition time and lowered engine efficiency which ultimately decreased fuel consumption.

Table 3. Approaches to estimate humidity effects on fuel consumption and emissions

Key method	Study aim	Gap	Reference
On-road data set was collected over a period of six months and subsequent statistical analyses comprising -(exploratory correlation analysis to locate pairwise linear relationships; factor analysis to evaluate multivariate effects and nonparametric regression tree techniques to examine interactions) were conducted	Analyze the impacts and interaction of temperature and relative humidity on emissions with particle sizes between 15 nm and 850 nm	More studies to be conducted for the sake of clarification	Jamriska et al., 2008.
Experimental research was conducted on a natural gas fueled research engine with one cylinder. A gas-scavenged pre-chamber approach was used for lean-burn operations.	Determine the effects of specific humidity on engine performance of a lean-burn natural gas engine	More studies to be conducted	Wimmer, & Schnessl, 2006.
On-board measurement system was developed using zirconia (ZrO_2) detectors in combination with other detectors and data recorders. Measurements were taken on a chassis dynamometer after the system was fitted in a diesel vehicle.	Measure real-time mass emission of NOx, fuel consumption using on-board system	Further research should include more external factors	Kihara et al., 2000.

Precipitation effects

Rain and snow alter the characteristics of road surface which impacts the grip and rolling resistance of vehicles. Snow and ice decrease the grip of tires and increase fuel consumption. Rain forms water layers that wheels of moving vehicles must overcome (Zacharof et al., 2016; Wu et al., 2020). Based on the research by Karlsson et al. (Karlsson, Carlson, & Dolk, 2012), water depths of 1, 2 and 4 mm resulted in 30%, 90% and 80% fuel consumption rise respectively. Lower rate in fuel consumption at 4 mm compared to 2 mm was attributed to reduced vehicle speed due to increase resistance of water. A USA study conducted by (Cummins, 2014) indicated an increase in fuel consumption with rain in heavy duty vehicles. Golbasi and Kina (2022), reported 15-25% variation in haul truck's fuel consumption depending on the precipitation effect. The highest fuel consumption was recorded in the month of April which had the maximum precipitation of 90 L/day whilst the lowest fuel consumption was in the month of July with the least precipitation of 80 L/day after simulation using discrete-event simulation (DES) model. Precipitation condition had more significant effects on the truck's rate of fuel consumption comparative to other studied variables (distance travelled and total payload). Shang, Zhang, & Shen (2021), used Comprehensive modal emission model (CMEM) to ascertain the impacts of rainy-weather conditions on on-road fuel consumption and emissions of taxis. Fuel consumption factor in rainy weather was 3.9 % to 6.7% lower than that of clear weather and 3.8% to 5.2% in terms of emissions for various road types (main roads, expressway, main and secondary road). The findings were attributed to less aggressiveness in drivers driving style during rainfall. Gong, Shang, Li, Zhang, He, & Ma (2021), also reported precipitation within the range of 1 mm and 8 mm to cause 4.9% decrease in fuel consumption in heavy-duty diesel trucks compared to a case of no rainfall. The reason is because of the attentiveness of drivers during light rains which cause driving process to be steady balancing the useful impacts between fuel consumption and precipitation. Heavy snowfall deteriorates road surface which in turn increase emissions and fuel consumption due to increase number of stops and traffic non-uniformity (Zakharov, Zakharov, Magaril, & Rada, 2018). Experiment conducted by Zakharov et al.

(2018), using Vissim traffic flow simulation model obtained 23% increase in average delay time, 17% reduction in average speed and 13.8% emissions (CO, NO_X, Volatile organic carbons (VOC)) increase under worse road conditions caused by heavy snowfall (snow with thickness more than 7 cm). According to Ferreira, de Almeida, & da Silva (2015), a relationship exists between traffic and severe precipitation events. Extreme precipitation events reduce vehicle's speed and thus, increase traffic delays (Pyatkova et al., 2019). Min (2015), discovered 1.3 km/h decrease in average speed for any additional centimeter of precipitation which in turn increase traffic volume and hence fuel consumption and emissions. Rain and snow recorded high traffic flow which led to increased fuel consumption when different weather parameters (clear, cloudy, overcast, foggy, aerial dust, light rain, shower and sleet) effects on fuel consumption were evaluated by (Yao, Zhao, Zhang, Chen, & Rong, 2020) using On-Board Diagnostics (OBD) for the real-world instantaneous fuel consumption and linear mixed model to establish the relationship between the parameters.

Table 4. Methodologies used by some selected articles to ascertain precipitation effects on vehicle fuel consumption and emissions

Key method	Study aim	Gap	Reference
Simulation modeling was applied and carried out by the use of Planung Transport Verkehr (PTV) Vissim program -timestep-based, microscopic model that treats driver-vehicle units as basic entities.	Sustainability of transport system with respect to the influence of amount and intensity of precipitation	Further studies should gear towards obtaining correcting coefficients for mathematical models of traffic parameters under adverse weather and climate conditions.	Zakharov et al., 2018
Analysis and summary description of collected 1153 naturalistic driving data from 34 heavy-duty diesel trucks. Binary logistic regression model was established to quantitatively explore the impact of key variables on fuel consumption.	Prediction of fuel consumption of heavy-duty diesel trucks	Future study should expand data collection in terms of quantity and type and model prediction accuracy should be improved by trying other data mining methods.	Gong et al., 2021
Driver's fuel consumption was directly collected by using on-board diagnostics (OBD) unit. Linear mixed model was constructed to determine the external conditions fixed-effects and the drivers' random effects.	Explore external factors affecting driving safety and fuel consumption	Further studies should include truck drivers and non-professional drivers as well as driver's age gender, income in combination with the already considered external factors	Yao et al., 2020

Wind effects

The influence of wind on fuel consumption is basically due to differences in direction between vehicle and wind strength thus, driving with wind minimizes fuel usage whilst driving against wind increases fuel consumption (Almér, 2015). Wind is affected by objects along the roadside and other vehicles that results in an uneven airflow and turbulence. It has a significant effect on vehicle aerodynamics- there is a linear correlation between aerodynamic resistance variations and emissions. The term "vehicle aerodynamics" describes the car's shape and design and projected frontal area. Increase in 30% aerodynamic resistance will cause 7% increase for NEDC. Crosswind (wind perpendicular to a moving vehicle) affects drag, lift and pitching of vehicles causing instability (Zacharof et al., 2016). Tailwind enhances vehicle movement and, therefore consume less energy but headwind requires more energy to resist against the wind (Ehsani et al., 2016). Zachiotis and Giakoumis (2021) asserted that the negative effects of headwinds far outweigh the advantages of tailwinds. The assertion was based on their study which used 'Monte Carlo Simulation' technique to examine how ambient wind affects light-duty car fuel consumption and emissions. They reported maximum increases of 28%, 22% and 13% in CO_2, nitric oxide (NO) and soot emissions respectively and 41% in specific energy consumption with strong headwinds. At tailwind environment, vehicle wind drag decreased which led to reduction in engine load and consequent fuel consumption/ emissions. Reduction in fuel consumption and emissions at tailwinds were not sufficient to balance the significant rise caused by the headwinds. Strong wind force causes greater air resistance leading to higher fuel consumption and emissions (Ehsani et al., 2016). Yang et al. (Yang, Gong, Xie, & Liu, 2022) reported increase in air resistance with increasing wind speed after using machine learning models to predict fuel consumption rate of light-duty gasoline vehicles under real-world conditions in China. Strong wind decreases vehicle speed due to poor visibility which increase traffic volume and affects fuel consumption and emissions. Wind speed influences the amount of air resistance encountered by the vehicle and this effect is more profound at higher speed (Khayyer Wollaeger, Onori, Marano, Özgüner, & Rizzoni, 2012). The study by Khayyer et al. (2012) reported the effect of wind speed on fuel consumption to be greater than temperature and air density after studying weather (wind, temperature and air density) impacts on PHEV fuel consumption using vehicle simulator developed in MATLAB/Simulink environment. According to the study of Min (2015), every 10 km/h rise in wind speed caused a 0.8 km/h decrease in average car speed. Wind speed of 12.5 mph and wind direction of -45 degree resulted in 8.5% reduction in the amount of vehicle fuel consumed as determined by the study of Lee, Fulper, McDonald, & Olechiw (2019), which used real world emission (RWE) vehicle model to estimate relationship between environmental factors and fuel consumption and emissions. They concluded that estimating wind direction is difficult because vehicle direction is changing constantly along the road. Increasing wind speed from (5 to 10 m/s) increased PHEV energy consumption by 21% and 16% in urban and highway driving respectively whilst change in wind direction caused large energy demand changes (56% for urban driving and 114% for highway driving) based on the findings of (Tulpule et al., 2011).

Table 5. Methods employed for assessing the effects of wind on vehicle emissions and fuel consumptions

Key method	Study objective	Gap	Reference
Simulation was done using vehicle model developed at (Center for Automotive Research) in Ohio State University. Model was developed using verified models of each individual components. Energy management algorithm was incorporated into the vehicle using 'Equivalent Consumption Minimization Strategy' (ECMS)- a strategy grounded on the idea that, a hybrid vehicle's battery energy usage should be recharged by burning the fuel	Estimate impacts of weather on the energy demand of PHEV vehicles	Further studies need to be conducted in this area	Tulpule et al., 2011.
Simulation was done by using vehicle simulator developed in MATLAB/ Simulink setting and impact variables were also assessed for diverse standard highway and urban driving cycles.	Determine the impacts of factors that influence energy consumption in PHEV vehicles	Further study should focus on other new vehicle technologies like solar vehicles etc.	Khayyer et al., 2012.

Sites were selected and primary data was collected, integrated and processed. Exploratory data analysis using correlation analysis and single variable analysis were conducted. Speed distribution and variation models were developed using multiple linear regression after which they were coupled with the engine emission models incorporated in MOVES emission estimation model.	Explore the relationship between weather and vehicular fuel consumption and emissions	Future research to consider model structures like time series cross section models and multilevel models. And also, monetary indicators like unit cost of fuels and various types of pollutants should be used to evaluate the impacts of vehicular emissions and energy consumptions	Min, 2015.

Altitude/ Air pressure effects

Altitude indirectly influences fuel consumption and emissions by causing changes in air pressure which is directly linked to vehicle fuel combustion. Variation in altitudes which implies different ambient pressures significantly affect fuel combustion and gas exchange processes (Bermúdez, Serrano, Piqueras, & Diesel, 2021). Air pressure directly affects tire pressure which tends to affect fuel consumption. The larger the tire pressure, the lower the fuel consumption and vice versa. A study by Yang et al. (2022), identified air pressure as the most significant climate factor impacting the consumption of fuel among other variables like temperature, wind, precipitation and sunlight after simulating real world fuel consumption using machine learning models. Increase in air pressure increases air density which augments intake charge of engines improving volumetric efficiency and thus higher fuel consumption (Rahimi-Gorji et al., 2017). According to Karnaukhov, Karnaukhova, Karnaukhov, & Ryndina (2022), combustion is a significant process to engine performance/ fuel consumption and increasing pressure surges combustion. Abdullah, Shahruddin, Mamat, Ihsan Mamat., & Zulkifli (2014), investigated engine efficiency, fuel economy and tailpipe emissions by varying in-let air pressure using air filter. They reported increase in engine efficiency and higher consumption of fuel, CO_2 and NOx emissions in the experiment void of air filter comparative to the one having air filter. This was due to efficient fuel combustion as air pressure increased without the use of the air filter. Soares and Sodré (2002), determined the effect of temperature, humidity and pressure on vehicle performance. Pressure was reported to be the most important parameter affecting vehicle efficiency. Theoretically, higher altitudes have lower air resistance resulting in lower air density and pressure (Wang et al., 2022). The lower air density and pressure cause changes in vehicle aerodynamics and decrease oxygen concentration leading to deterioration of engine combustion and thus, decrease in power output which ultimately lowers fuel consumption (Zervas, 2011; Hao et al., 2019; Wu et al., 2020). Hao et al. (2019), determined fuel consumption at different altitudes of 842, 1520, 2676 and 3030 m. Coast down test was used to ascertain the roadway load force of the test vehicle at the varying altitudes after which road resistance and the vehicle fuel consumption was measured using developed vehicle fuel economy model. Findings revealed an increase in fuel consumption/100 km with vehicle speed irrespective of altitude. The work of Zervas (2011), had similar findings when the effects of altitudes (70 m and 2200 m) on fuel consumption were studied over three controlled driving cycles (NEDC, FTP and the Highway driving cycle). He concluded that the effects of higher altitudes are not evident and fuel consumption is not always reduced. Experimental data from Al-Momani, & Badran (2007), revealed an increase in fuel consumption with increasing altitude. This was due to fluctuations in atmospheric pressure as altitude increased resulting in destabilization of the combustion process. Increasing altitudes also led to a decrease in vehicle performance due to reduction in vehicle's available horsepower. Payri et al. (2021), also reported 2.5% increase in fuel consumption by increasing altitude from 0 m to 1000 m in their study that focused on altitude impacts on energy balance during (WLTC). The results obtained were attributed to the change in pumping that decreased brake efficiency.

Wang et al. (2022), tested twenty-one light-duty vehicles over WLTC and real-driving emissions (RDE) at different altitudes between 26.7 and 2264.7 meters above sea level (masl). They reported strong linear correlation of CO_2 emissions in vehicle 2 (which was naturally aspirated) with altitude - every 1000 m rise in altitude resulted in 4.45%, 5.31% and 6.62% for low, high and extra-high speed respectively decrease in CO_2 emissions. Turbo-charged vehicles 1 and 3 had no linear correlation with altitudes and the rise in CO_2 emissions was as a result of the varying performance of the turbo-chargers at the different altitudes. For both tests (WLTC and RDE), there were no consistent patterns between the various altitudes and vehicle CO_2 emissions. This was attributed to the presence of more variables (driving patterns, road types etc.) during real test driving which might have impacted the emissions rather that the altitude growth and also the air-fuel variations at transient cycles and engine operation variations during the WTLC laboratory tests. The study by Fang, Lou, Hu, & Tan (2019), measured diesel cars cold-start emissions at various altitudes (0, 1000, 2000, 3000, 3750 and 4500 meters) with their concomitant pressure (kPa) 101.3, 90.1, 79.2, 70.1, 63.5 and 57.6 respectively. CO, CO_2 and NOx emissions decreased with rising altitude due to poor fuel combustion cause by less air taken into the cylinder at high altitudes. He et al. (2011), analyzed the variation of exhaust emissions of diesel engines at different altitudes (0, 1000, 2000 m) and reported increase in emissions (HC, CO and NOx) with rising altitudes. High HC and CO emissions were as a result of decrease in the in-take of air pressure and mass of oxygen with rising altitude which minimized air-fuel ratio and hence aggravated fuel combustion. Increase in combustion temperature due to ignition delay as a result of rising altitude led to more NOx emissions. Altitude effects on (HC and CO) emissions were higher than (NOx) emissions due to the distinct decrease in oxygen-fuel ratio influencing the HC and CO as compared to the slight increase in combustion temperature which influenced the NOx emissions.

Table 6. Key methodologies for determining the impacts of altitudes/air pressure on vehicle fuel consumption/ emissions

Key method	Study aim	Gap	Reference
Experimental research using engine test bench with altitude simulation system	Effects of altitude on particles number emission of diesel engines	Further study should measure simultaneously the magnitude of combustion temperatures and (NOx) emissions for the interest of high altitudes' NOx emission factor	He et al., 2011.
Experimental research was conducted on a direct-injection intercooled turbocharged diesel engine (with 14.25 compression ratio) by utilizing (combustion analysis/ emission measurement and plateau simulation systems).	Determined start-up emissions of heavy - duty low compression -ratio diesel engine at different altitudes	Future studies should focus on combustion, spray, chemical kinetics, emissions on the extreme environments	Fang et al., 2019.

Vehicles were first tested over WLTC and CO_2 data obtained from the WLTC test was employed for Moving Average Window (MAW) calculation. The resistance coefficients used for chassis dynamometer setting during lab testing were provided by the manufacturer. For RDE tests, PEMS was used to estimate emissions as vehicle was driven by a professional driver.	Evaluate altitudes impact on battery vehicle CO_2/pollutant emission	Real world testing introduced more variables (speed, driving patterns etc.) and the quantitative relationships between the variables and emissions are unclear, hence more further studies to analyze the impact of these variables and real driving emissions before assessing real driving emissions at different altitudes	Wang et al., 2022.

Table 7: Summary of key articles of the considered climatic variables

Reference	Purpose of study	Weather parameter(s) considered	Method/model	Gaps
Alvarez, & Weilenmann, 2012.	Determine fuel consumption rate and emissions in hybrid vehicles	Temperature	Chassis dynamometer testing	Further investigation on 'Initial State of Charge' (SOC) of hybrid system battery (HSB) to enhance detailed evaluation of temperature influence on HEVs
Wu et al., 2020.	Measure real-world fuel consumption of light duty vehicles	Temperature, humidity, altitude/air pressure	Big data retrieved from BearOil app to construct real-world fuel consumption rate (RFCR) model	Further research should gear towards the study of public green low-carbon driving behavior
Jeon, 2019.	· Investigates the relationship between weather and gasoline vehicle fuel consumption and · Simulate climate change impact on gasoline consumption	Minimum and maximum temperature, precipitation RCPs 4.5 and 8.5 for periods 2020–2039, 2040–2059, 2060–2079, 2080–2099.	Fixed-effect model NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset	Future research to consider technological improvements like solar and biofuels vehicle consumption
Choi, et al., 2010.	Examine the relationships between weather parameters and gasoline / diesel vehicles emissions	Temperature and humidity	MOVES2010 model	Future analysis should address impacts of additional parameters like fuel supply, road type distribution, ramp fraction, speed distribution, vehicle type
Ehsani et al., 2016.	Determine fuel consumption and fuel efficiency for different types of vehicles	Temperature, wind	Mechanical model	Future study should consider amount of humidity and sunroof impacts on the changes in wind power.

Yang et al., 2022.	Forecast the real-world fuel consumption rate of light-duty gasoline vehicles based on big data from BearOil app	Temperature, wind, air pressure, precipitation	Five regression models- linear regression, naïve Bayes regression, neural network regression, random forest regression, and LightGBM models	Further study to apply the Monte_Carlo function of the ForecastTB package for better comparison of models
Savostin - Kosiak et al., 2020.	Determine the effects of ambient temperature on city diesel bus fuel consumption	Temperature	Physical Emission Rate Estimator (PERE) mathematical model	Further study to estimate polynomial coefficients for city bus models
Hao et al., 2019.	Estimate fuel economy of light-duty vehicles in high altitude zones.	Altitude (air pressure)	Vehicle fuel economy model	Further research to elucidate the effects of higher altitudes on vehicle fuel consumption
Karlsson et al., 2012.	Estimate the effects of precipitation on road surface and vehicle fuel consumption	Precipitation (rain, snow and ice)	Virtual environment for test optimization (VETO) model	Further study - to determine if the impact of rain/ ice/ snow is primarily due to its impact on tire temperature or rolling resistance or both. - to ascertain actual water depths during dry spells, as well as the impact of rutting severity and topology
Shang et al., 2021.	Investigate the effects of road type and rainy-weather condition on fuel consumption and emission	Rain	CMEM model	Future study should include finer and detailed data in the database for the model to be more general and applicable.
Zachiotis, & Giakoumis, 2021.	Determine fuel consumption and emissions for light-duty cars operating in simulated ambient wind setting.	Wind	Monte Carlo simulation methodology	Study is an improvement to current homologation procedure which excludes ambient wind in road load calculation

Simulation models for vehicle fuel consumption and emission estimations

Fuel consumption and emission models are fundamental instruments used to assess the impacts of regional transportation and develop transportation technologies (Faris, Rakha, Kafafy, Idres, & Elmoselhy, 2011). Silva, Farias, Frey, & Rouphail (2006), used and evaluated the efficacy of different simulation models on the prediction of road infrastructure impact on vehicle fuel consumption/emissions. Based on the findings, they concluded that available models can effectively be utilized to predict fuel consumption and emissions. During modeling, the user defines the kind of vehicle, period of time, geographic regions, pollutants, kind of road and vehicle operating features to be modeled (Moradi, 2021). Different kinds of models – (white-box, grey-box and black box models) have been used by researchers globally. White-box models are comprehensive physical models developed by automobile or engine manufacturers. Grey-box models are combinations of non-complex physical models and data derived from experimental research. Typical example of this model is CMEM. Black-box models exclusively utilize information obtained from realistic driving tests. They are grouped into average and instantaneous fuel consumption models (Kanarachos et al., 2019). Models can also be categorized into macroscopic, microscopic and mesoscopic models based on their scale and purpose. The macroscopic estimate transport energy consumption and emissions over a wide area by the use of average aggregate network parameters. Examples are; Mobile Energy Emission Telematics System (MEET), Computer Program to compute Emissions from Road Transport (COPERT), Ecological Transport Information Tool (ECOTRANSIT), Emission Factor (EMFAC), Mobile source emissions factor (MOBILE), and MOVES. Microscopic models describe the energy consumption and emissions of vehicles by linking fuel consumption and emission rate to vehicle operating across a number of brief time steps. They compute data on a single vehicle's instantaneous energy consumption and emission using instant variables. Examples are; Instantaneous fuel consumption model (IFCM), Vehicle specific power (VSP), Virginia tech microscopic energy and emission model (VT-Micro), Comprehensive power-based fuel consumption model (CPFM), Passenger car and heavy-duty emissions model (PHEM) and CMEM. Microscopic models are useful at the micro scale but are not suitable for huge number of cars at the city scale due to the requirement of considerable estimations (Shang et al., 2021; Vallamsundar, & Lin, 2011).

Most fuel consumption models previously developed used speed as the only influencing parameter but currently developed models have included other parameters (Parajulii, 2005). Modeling of fuel consumption/ emissions are normally conducted by using physical and empirical based methods. The empirically based method is represented by MOVES developed by USA EPA to replace MOBILE in the estimation of vehicular fuel consumption whilst the physically based modal uses PERE to estimate second- by-second rate of fuel consumption by the use of vehicle specifications as well as second-by-second driving records as inputs (Wang, Fu, Zhou, & Li, 2008). MOVES utilizes VSP as an engine running status indicator (Lyu, Bao, Wang, & Matthews, 2020). VSP is the power of an engine per unit mass of vehicle exemplifying the demand of power on a vehicle operating under various conditions and speed. It is calculated using the instantaneous speed of vehicles and force an engine need to overpower to operate smoothly which includes (aerodynamic resistance, rolling resistance, engine inertia resistance, gradient force) (Min, 2015; Guensler et al., 2017). Key emission models include but not limited to MOBILE, MOVES, EMFAC, PHEM, CMEM, Corridor Flow (CORFLO), Verkeerssituatie (VERSIT), Emissions from Traffic (EMIT), Vehicle dynamics model, Vehicle transient emissions simulation software (VeTESS), Vehicle Energy Consumption Calculation Tool (VECTO), VT-microscopic model, Network Simulator (NetSim), Watson model, Virtual environment for test optimization (VETO) model, Advanced light-duty powertrain and hybrid analysis (ALPHA), Signalized Intersection Design and Research Aid (SIDRA) TRIP and COPERT.

MOBILE was created by US EPA. Inputs for this model were; age of the vehicle, ambient temperature, fuel variables and vehicles mode of operation. The model generally evaluated the following pollutants: HC, CO, NOx, NH_3, particulate matter (PM), sulfur dioxide (SO_2) and hazardous air pollutants (Faris et al., 2011). MOBILE estimated car emissions based on average speed and vehicle distance traveled, but overlooked the factors relating to the driver, traffic and roadway (Ahn, Rakha, Trani, & Van Aerde 2002). This model has now been replaced with MOVES which has more distinct features and functions (Vallamsundar, & Lin, 2011). PHEM computes road vehicles fuel consumption and emissions in 1Hz for a specific driving cycle using longitudinal dynamics of the vehicle and emission maps (Weller et al., 2019). COPERT was created by European

Environment Agency (EEA) and normally use in applications involving emission inventories and dispersion modeling (Faris et al., 2011). It is usually developed from several emissions tests conducted on new and old vehicles. It uses algorithms and emission factors to estimate emissions under conditions like speed, ambient temperature, vehicle technology etc. (Faah, 2008; Chen, Zhu, Gonder, Young, & Walkowicz, 2017). VETO is a simulation tool used to estimate fuel consumption and emission using roads, vehicles, weather characteristics and driving behavior as input parameters. It is a mechanistic model based on physical interactions and capable of accurately describing vehicles and given road segments (Karlsson et al., 2012). The European Commission created VECTO to measure their fuel usage and carbon emissions. The primary inputs for this model are: air resistance, tire rolling resistance, vehicle mass, axle/gearbox torque loss maps and engine maps. Fuel consumption is measured by interpolating from fuel usage map along with instant engine torque and speed (Zeng et al., 2021). CMEM model is access-coded program with specific humidity, vehicle characteristics and activity data as key inputs. The instantaneous engine load is calculated for a given driving cycle and used to evaluate the fuel consumption. Emissions are computed from fuel consumption and catalytic converter efficiency correlations (Silva et al., 2006). CMEM uses physical approach to break emissions processes into parts relating to physical phenomena that are connected to vehicle performances and emission productions (Cadle, et al., 2003). CMEM parameters depend on vehicle types instead of specific vehicle specifications (Donkers, Yang, & Viktorović, 2020). ALPHA is a modeling tool developed by USA EPA to estimate vehicle operations, fuel consumption and GHG emissions of light-duty gasoline and diesel vehicles as well as battery and hybrid electric vehicles. EMIT is a simple statistical model developed for estimating commercial vehicles' fuel consumption and emissions (Cadle, et al., 2003). SIDRA TRIP is a component of SIDRA software package. It is a power-based model that expresses the rate of instantaneous fuel consumption based on the required tractive power (Yeow, & Cheah, 2021).

CONCLUSIONS

This review stresses on climate variability and change impacts on vehicular fuel consumption and emissions. It depicts that most studies conducted on *weather parameters impact on fuel consumption and emissions* are from Europe, America and Asia. Temperature is revealed to be the most pronounced weather parameter compared to the other variables proving the assertion by (Zacharof et al., 2016) which posited that "temperature is the most studied weather parameter in relation to vehicle fuel consumption and emissions". The review unravels the massive impacts of weather parameters on vehicle fuel consumption and emissions and hence engenders the replication of such studies in Africa to ameliorate the transportation system and preclude any anticipated mishaps related to road transport in the continent. From the review the authors recommend that: Climate variability and change should be considered as threats to vehicle fuel consumption and emissions and hence, countries should adhere and comply rigorously to climate policies in order to reduce global climate change and its concomitant effects on automobiles; Climate variability and change impacts on vehicles should be incorporated in national transportation policies in Africa and accordingly addressed to curb their effects; There should be replication of numerous studies under this area in Africa to provide data that can be utilized in the formulation of optimal road transport policies and decisions.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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