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Driving Towards Sustainability: Unveiling the Complexities of Electric Vehicle Range Optimization Across Diverse Terrain and Weather Conditions

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Abstract *- Electric vehicles (EVs) are a promising solution for reducing fossil fuel dependency and mitigating environmental concerns. However, their range is significantly influenced by weather conditions, temperature variations, and pavement types. This study uses empirical data analysis with the Tata Nexon EV to examine these external factors. Our findings indicate that EVs achieve optimal range on flat, smooth roads during high summer temperatures. In contrast, rough, uneven, wet, and hilly terrains lead to increased battery consumption and reduced range. Extreme conditions, such as driving on hilly roads during cold and rainy seasons, further exacerbate range limitations. These results provide critical insights for policymakers, engineers, and urban planners, emphasizing the need for EV-friendly infrastructure, such as smoother roads and strategically placed charging stations. Additionally, the study offers valuable guidance for improving EV design and performance, ultimately contributing to more sustainable and efficient transportation solutions*.

Keywords- Electric Vehicle (EV), Range anxiety, Range extension, Road conditions, Temperature

1. INTRODUCTION

The transport industry is a significant source of carbon emissions, which are still increasing alarmingly. The emissions from India's fleet of passenger cars substantially contribute to the country's declining air quality [1][2]. According to an IEA 2020 report, the transport industry is responsible for almost one-fourth of all global CO_2 emissions, and by 2035, it is expected to expand by about 50%. China, the United States, the European Union, India, the Russian Federation, and Japan are the biggest emitters of CO_2, according to a comparison of CO_2 emissions from various nations [3][4]. India wants to eliminate all carbon emissions by the year 2070, which is a highly challenging goal to achieve, given that the year is already 2023 [5].

With EVs becoming the primary substitute for petrol and diesel cars and trucks today, especially in the non-heavy duty vehicle segments (two-, three- and four-wheelers, as well as light and medium trucks), it is possible to make the switch to clean electricity, which is essential for the environment [6]. Another reason for EV adoption in India can be the rise in fuel prices every year [7]. When compared to ICE, EVs possess many advantages, including the foremost and undeniable one, i.e., zero carbon emissions. In addition, the noise in EVs is negligible; therefore, EVs are very helpful in the reduction of both air and noise pollution [8]. Even though the ownership cost of an EV is very high due to the battery pack, the running cost of it is very low as compared to ICE vehicles. The higher efficiency of an EV because of its electric power train is another advantage when compared to an ICE vehicle. The estimated efficiency of an electric power train is around 90%, which is around 45% higher than an ICE vehicle [9].

Fig. 1 shows the year-wise fuel price and the hike accordingly in EV sales, and it is clear that with the rise in fuel price, EV sales have desperately increased [10]. Despite these many remarkable advantages, EVs do have some downsides, which prevent potential buyers from investing in them. Along with the high cost, the non-availability or very limited availability of charging stations and the long charging durations of up to 10 hours act as a barrier to the adoption of an EV in current Indian scenarios [11]. One of the major blockades in the adoption of an EV is the limited range it provides on a single charge. This range is decided by the remaining charge percentage of the battery pack [12]. Some EVs can cover up to 450 km on a single charge, while the vehicle equipped with the combustion engine can cover much higher distances depending upon the capacity of the fuel tank. According to some research, EV users claim that the "battery range" and "battery charging" of an EV are the two most significant reasons for their dissatisfaction [13]. The EV users face the problem of range anxiety: What if the battery gets discharged and there is no charging station nearby, or what if the battery gets drained before reaching the destination and the vehicle just stalls on the road [14]? Even though the estimated range can be seen on the display of the EV, it is true that the situation that arises on the road cannot be predicted [15]. Therefore, in order to reduce the range anxiety problem, it is necessary to investigate and analyse the factors that influence the range of EVs. The information regarding where the energy of the EV's battery is most consumed can play a crucial role in pre-defining the range of the vehicle and

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hence can be helpful in deciding the measures that need to be taken to increase the range of an EV to avoid range anxiety [16][17].

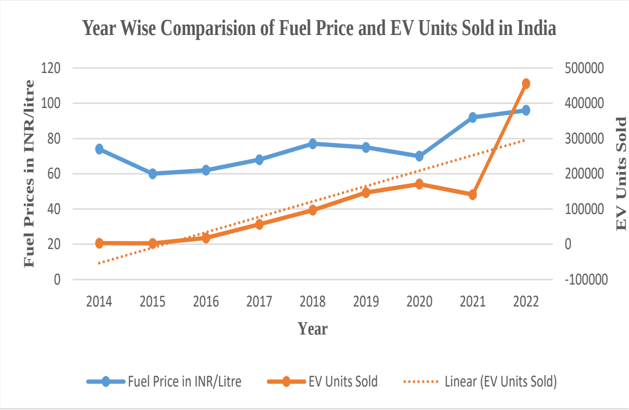

Fig. 1. Year-wise fuel price and EV sales in India

The most significant factor that can be analysed in the energy consumption study of EVs is the ambient temperature [18]. The battery life is impacted by temperature, which reduces the potential range of the EV [19]. According to some research, the ambient temperature has a similar impact on energy usage for ICE and EV vehicles since increased air density during colder weather increases rolling resistance and air drag [20][21]. The batteries are heated up at low temperatures and cooled down at high temperatures. In order to determine the causes of the effects of temperature on batteries, the research would be feasible to test out energy consumption at various temperatures [22]. Traffic circumstances and driving style are two other factors that determine how much energy an EV uses, as they have an impact on acceleration and speed and ultimately reduce range [23]. The weather conditions, i.e., windy, rainy, or humid, also affect the driving range differently on different types of roads. The opposite wind directions act as a resistance for the EV drive cycle. Also, the inclination can act as a supporter or barrier in driving the EV. The EV will run well on a smooth road, and the battery consumption will be normal for this road, but if the road is wet or muddy, there will be more consumption of battery energy to drive the vehicle and, as a result, lower range of EV [24][25].

This research examines EV energy use across various road and environmental scenarios. Unlike previous studies focusing solely on temperature or pavement, we assess their combined effects along with seasonal variations. This addresses gaps in understanding battery consumption. Our findings provide practical insights for accurately predicting EV range and identifying energy-saving strategies, which are vital for users, manufacturers, and policymakers due to implications for energy efficiency, environmental impact, and cost-effectiveness.

This work is organized into four sections in addition to this introduction. The forces operating on EVs and their modelling will be presented in the section that comes next. A case study on the Tata Nexon EV and the particular parameters used for the work is included in Section 3. Section 4 covers the execution, data analysis, the results, and discussion. Section 5 concludes by summarizing the major findings and directions for future research.

2. DYNAMICS OF EV

According to Newton's first law of motion, a number of forces act together to move a vehicle in a particular direction. These forces may aid up and support the vehicle's movement, while others may act as a resistance in the motion. In the case of EVs, the weight and shape of the vehicle, the speed, the grade of the road, the electric motor and battery, and even the type, as well as the radius of tires, can regulate the force on that EV [26]. The Fig. 2. represents all the forces that act on a vehicle. Further, the forces acting on the vehicle are explained as follows-

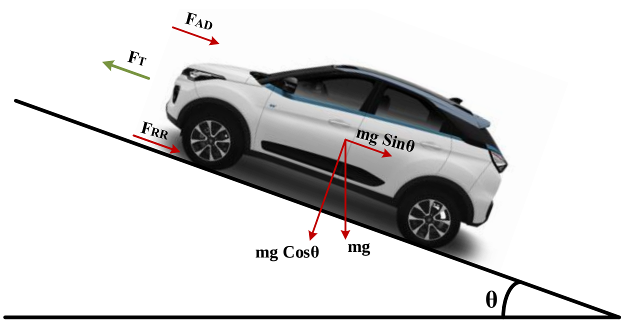

Fig. 2. Forces acting on vehicle

2.1 *Aerodynamic Drag Force*

The opposition caused by the speed of wind in the motion of a vehicle is referred to as drag force. This aerodynamic drag force is higher at the high velocity of the vehicle and is insignificant at the lower speeds. Also, this force is affected by the shape of the vehicle and the direction of flow of air. The drag force can be defined with the help of the following equation-

$$F_{AD} = 0.5 * \rho * C_D * A * (V_{vehicle} \pm V_{air})^2 \quad (1)$$

Where F_{AD} is the aerodynamic drag or air resistance force in Newton [N], ρ is the density of air in Kg/m^3, C_D is the aerodynamic drag coefficient, A is the frontal area of the vehicle in m^2, $V_{vehicle}$ is the forward velocity of a vehicle in Km/h or m/s, V_{air} is the velocity of wind in Km/h or m/s. The sign ± in which (+) demonstrates a headwind, the wind velocity is opposing the vehicle's speed; And (-) demonstrates a tailwind, the wind velocity is in the same direction as the vehicle's speed.

2.2 *Rolling Resistance Force*

The force that opposes a wheel's motion as it travels over a surface is known as the rolling resistance force [25]. The friction between the wheel and the surface is the main reason for this issue. The material of the wheel and the surface affect the coefficient of rolling resistance, which is a dimensionless quantity. The rolling resistance force can be defined by the equation below.

$$F_{RR} = \mu_{RR} * m * g * Cos\theta \quad (2)$$

Where F_{RR} is the rolling resistance or wheel resistance force in [N], μ_{RR} is the coefficient of rolling resistance, m denotes the total mass of the vehicle in Kg, g is the gravitational constant with a value of 9.8 m/s^2, θ is the angle of inclination with the road surface.

2.3 Gradient Resistance Force

The force that opposes a vehicle's upward motion is known as the gradient resistance force. It results from the vehicle's gravitational force acting in the opposite direction to the direction of speed. The gradient force is as shown below-

$$F_G = \pm m * g * Sin\theta \qquad (3)$$

Where F_G is the gradient resistance force in N, m is the total mass of the vehicle in Kg, g is the gravitational constant with a value of 9.8 m/s^2, *and* θ is the angle of inclination with the road surface. The sign (+) is used when the vehicle is going up or ascending the hill, and (-) is used when the vehicle is descending on the hill. The force of gradient resistance plays a significant role in how well a vehicle performs on hills. The car will struggle to move uphill as the gradient resistance force increases [27].

2.4 Inertia Force

This force comes into the picture when the velocity of the vehicle changes with time, and extra force is required along with the previous force. This force is determined as per the Newton's second law of motion.

$$F_I = m * a \qquad (4)$$

Here F_I is the inertia force and m and a are the mass of the vehicle and acceleration of the vehicle respectively.

2.5 Traction Force

The total resulting force that is responsible for the forward or backward motion of the vehicle is called Traction Force. This traction force is the sum of all the forces discussed above. The drive train transmits this force to the road from the tires, which produce it.

$$F_T = F_{AD} + F_{RR} + F_G + F_I \qquad (5)$$

Here, F_T is the traction force.

3. CASE STUDY

The "Range" of an EV can be defined as the distance that an EV can travel on a single charge of its battery. This range is measured in kilometres (km). This range is directly related to the charged percentage of the battery and is consequently limited. This limited range makes the user worry that the battery will drain while driving and the EV might stagnate on the road [28]. This fear of running out of battery before reaching the destination is called "Range Anxiety," which is a major barrier for potential EV buyers. To overcome this problem of range anxiety, it is required to work on the factors that alter the range of the vehicle.

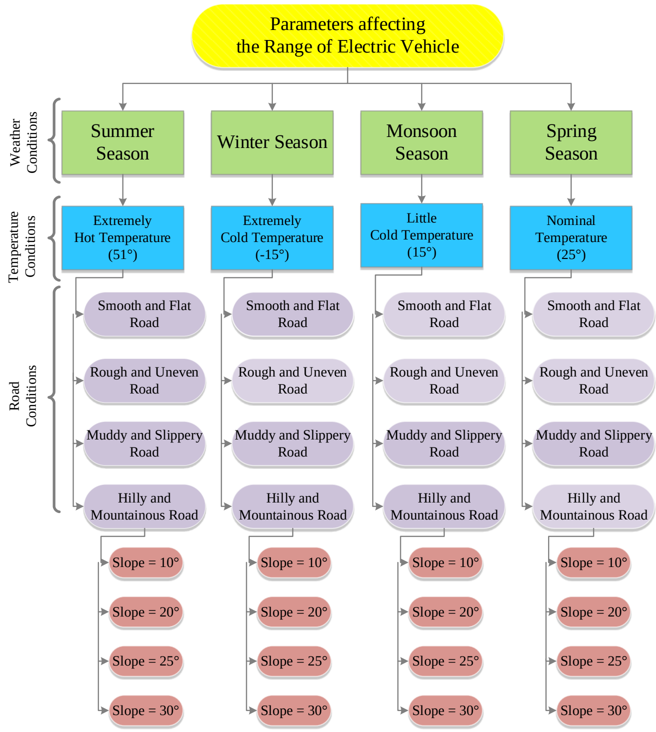

Fig. 3. Parameters affecting the range of an EV

Table 1. Vehicle specifications.

Battery (KWh)	30.2
Range (Km/Full Charge)	312
Vehicle curb weight (Kg)	1400
Passenger weight (Kg)	60
No. of passenger	5
Luggage weight (Kg)	100
Vehicle total weight (Kg)	1400+(60*5) +100= 1800
Frontal area (m^2)	2.9084

In this paper, the effects of seasonal changes, temperature variations, and different road conditions on EV forces are analysed. Seasonal temperatures—51°C in summer, -5°C in winter, 15°C in monsoon, and 30°C in spring—directly impact vehicle forces, influencing the range, as shown in Fig 3. These temperatures are further correlated with various road conditions. Road conditions caused by poor construction, heavy traffic, rains, aging, and digging increase EV battery consumption and reduce range. This study classifies roads into: 1) Flat and smooth, 2) Rough and uneven, 3) Wet and slippery, and 4) Hilly and mountainous with slopes of 10°, 20°, 25°, and 30°. The Tata Nexon EV is used for analysis, with specifications detailed in Table 1.

4. RESULTS AND DISCUSSION

The factors responsible for aerodynamic force are air density, aerodynamic drag coefficient, vehicle velocity, opposing air velocity, and frontal area of the vehicle. The values for air density are taken for different seasonal or temperature variations. The aerodynamic drag coefficient is taken for the Tata Nexon EV, and running velocities are taken for different road conditions. The opposing air velocity is neglected in the case of spring and summer seasons, which have temperatures of 25° and 51°, respectively. The effect on the force for various pavements, along with different temperature variations on aerodynamic drag force, is elaborated in Table 2.

Table 2. Determination of aerodynamic drag force for various pavements in different weather conditions.

Season/ Temperature	Air density	Drag coefficient	Vehicle velocity	Opposing air velocity	Frontal area	F_{AD} (N)
Smooth and Flat Road						
Nominal temperature (25°C)	1.184	0.18	22.22	0	2.9084	153.02
Extremely high temperature (51°C)	1.089	0.18	22.22	0	2.9084	140.74
Rainy season (15°C)	1.225	0.18	22.22	2.4	2.9084	194.36
Extremely cold temperature (-15°C)	1.367	0.18	22.22	2.4	2.9084	216.89
Rough and Uneven Road						
Season/ Temperature	Air density	Drag coefficient	Vehicle velocity	Opposing air velocity	Frontal area	F_{AD} (N)
Nominal temperature (25°C)	1.184	0.18	20.22	0	2.9084	126.71
Extremely high temperature (51°C)	1.089	0.18	20.22	0	2.9084	116.54
Rainy season (15°C)	1.225	0.18	20.22	2.4	2.9084	164.07
Extremely cold temperature (-15° C)	1.367	0.18	20.22	2.4	2.9084	183.08
Muddy and Slippery Road						
Season/ Temperature	Air density	Drag coefficient	Vehicle velocity	Opposing air velocity	Frontal area	F_{AD} (N)
Nominal temperature (25°C)	1.184	0.18	15.27	0	2.9084	72.26
Extremely high temperature (51°C)	1.089	0.18	15.27	0	2.9084	66.47
Rainy season (15°C)	1.225	0.18	15.27	2.4	2.9084	100.12
Extremely cold temperature (-15°C)	1.367	0.18	15.27	2.4	2.9084	111.72
Hilly and Mountainous Road						
Season/ Temperature	Air density	Drag coefficient	Vehicle velocity	Opposing air velocity	Frontal area	F_{AD} (N)
Nominal temperature (25°C)	1.184	0.18	14.22	0	2.9084	62.67
Extremely high temperature (51°C)	1.089	0.18	14.22	0	2.9084	57.64
Rainy season (15°C)	1.225	0.18	14.22	2.4	2.9084	88.57
Extremely cold temperature (-15° C)	1.367	0.18	14.22	2.4	2.9084	98.84

To represent driving conditions on various roads, different forward velocities were chosen: 22.22 m/s for smooth roads, 20.22 m/s for uneven roads, 15.27 m/s for wet conditions, and 14.22 m/s for mountainous roads. Fig. 4 shows that aerodynamic drag is lowest on smooth roads during summer and spring but peaks in winter across all pavements, leading to the highest energy consumption and reduced EV range. Mountainous roads are the least suitable for EVs due to the increased force required to drive uphill, exacerbated by low temperatures.

The rolling resistance force for various pavements, along with different seasonal or temperature variations, is exhibited in Table 3. It is clear that the most important factor here for resistance force calculation is the type of pavement, as the rolling resistance coefficient depends upon the road type.

Fig. 5 shows rolling resistance for smooth, uneven, and muddy roads across temperatures and seasons. Smooth roads in summer have the least resistance and highest EV range, while muddy, slippery, or uneven roads during the rainy season have the highest resistance, leading to more battery use and reduced range. Fig. 6 shows that rolling resistance is highest on hilly roads with slopes of 10°, 20°, 25°, and 30° during the rainy season, while the lowest force and highest range occur on hilly roads in summer.

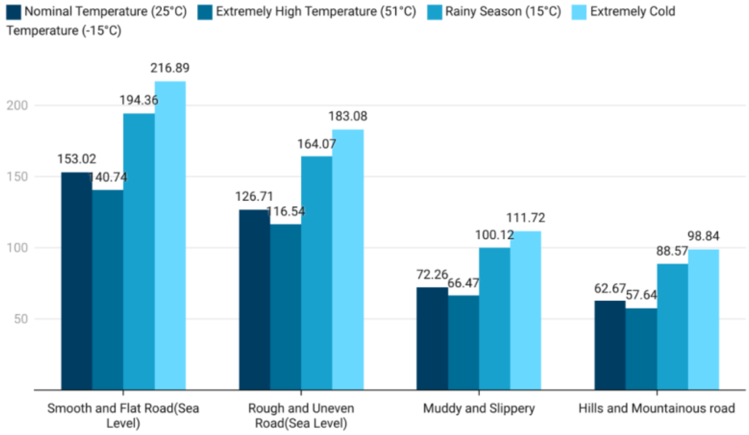

Fig. 4. Aerodynamic drag force for various pavements in different weather conditions

Table 3. Determination of rolling resistance force for various pavements in different weather conditions.

Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Smooth and Flat Road						
Nominal temperature (25°C)	1800	9.81	0.005	0°	1	88.290
Extremely High Temperature (51°C)	1800	9.8	0.01	0°	1	176.400
Rainy Season (15°C)	1800	9.8	0.05	0°	1	882.000
Extremely Cold Temperature (-15° C)	1800	9.8	0.02	0°	1	352.800
Rough and Uneven Road						
Season/Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Nominal temperature (25°C)	1800	9.8	0.035	0°	1	617.400
Extremely High Temperature (51°C)	1800	9.8	0.04	0°	1	705.600
Rainy Season (15°C)	1800	9.8	0.055	0°	1	970.200
Extremely Cold Temperature (-15° C)	1800	9.8	0.03	0°	1	529.200
Muddy and Slippery Road						
Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Nominal temperature (25°C)	1800	9.8	0.05	0°	1	882.000
Extremely High Temperature (51°C)	1800	9.8	0.04	0°	1	705.600
Rainy Season (15°C)	1800	9.8	0.1	0°	1	1764.00
Extremely Cold Temperature (-15° C)	1800	9.8	0.12	0°	1	2116.80
Hilly and Mountainous Road						
Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Nominal temperature (25°C)	1800	9.8	0.01	5°	0.99	174.636
Extremely High Temperature (51°C)	1800	9.8	0.025	5°	0.99	436.590
Rainy Season (15°C)	1800	9.8	0.14	5°	0.99	2444.9
Extremely Cold Temperature (-15° C)	1800	9.8	0.12	5°	0.99	2095.6

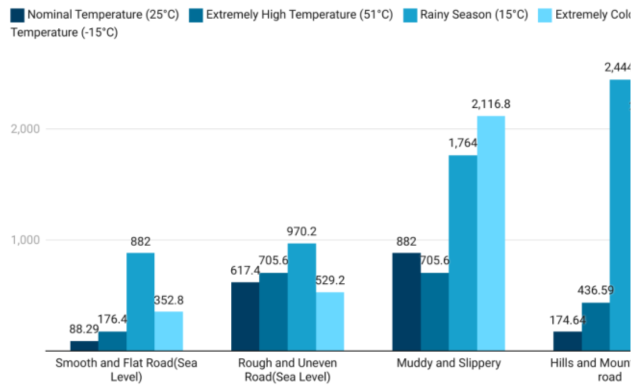

Fig. 5 – Rolling resistance force for various pavements in different weather conditions

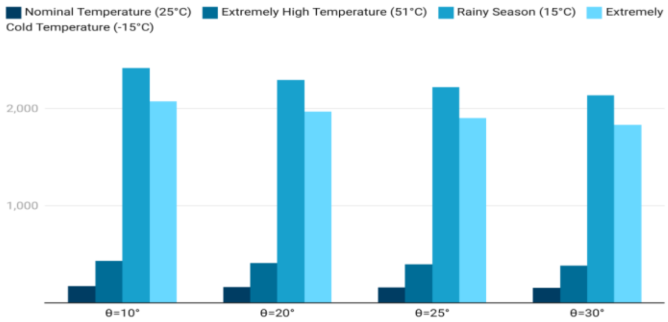

Fig. 6. Rolling resistance force for various hill slopes in different weather conditions

Table 4. Rolling resistance force for various hill slopes on a mountainous road in different weather conditions.

Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
θ = 10°						
Nominal temperature (25°C)	1800	9.8	0.01	10°	0.98	172.872
Extremely high temperature (51°C)	1800	9.8	0.025	10°	0.98	432.180
Rainy season (15°C)	1800	9.8	0.14	10°	0.98	2420.208
Extremely cold temperature (-15° C)	1800	9.8	0.12	10°	0.98	2074.46
θ = 20°						
Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Nominal temperature (25°C)	1800	9.8	0.01	20°	0.93	164.052
Extremely high temperature (51°C)	1800	9.8	0.025	20°	0.93	410.130
Rainy season (15°C)	1800	9.8	0.14	20°	0.93	2296.72
Extremely cold temperature (-15° C)	1800	9.8	0.12	20°	0.93	1968.624
θ = 25°						
Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Nominal temperature (25°C)	1800	9.8	0.01	25°	0.9	158.760
Extremely high temperature (51°C)	1800	9.8	0.025	25°	0.9	396.900
Rainy season (15°C)	1800	9.8	0.14	25°	0.9	2222.640
Extremely cold temperature (-15°C)	1800	9.8	0.12	25°	0.9	1905.12
θ = 30°						
Season/ Temperature	Vehicle mass	Standard gravity	Rolling resistance coefficient	Slope	Cos θ	F_{rr} (N)
Nominal temperature (25°C)	1800	9.8	0.01	30°	0.866	152.762
Extremely high temperature (51°C)	1800	9.8	0.025	30°	0.866	381.906
Rainy season (15°C)	1800	9.8	0.14	30°	0.866	2138.67
Extremely cold temperature (-15° C)	1800	9.8	0.12	30°	0.866	1833.14

The gradient force for smooth and flat roads, rough and uneven roads, and muddy and slippery roads is zero as there is no inclination or slope for the vehicle to move; therefore, the Sine of 0° is zero. Gradient force is calculated for mountainous roads, and Table 4 gives an idea of gradient force for slopes of 5°,10°, 15°, 20° and 30°. The gradient force does not depend upon the seasonal variation, and hence, the force is the same for even different temperatures. Fig. 15 shows the distinctions of forces for alternative values of inclination. From Fig. 7, it is clear that the gradient resistance force increases as the slope or inclination of the pavement increases. Gradient resistance force primarily hinges on road slope and condition. Elevated force is evident on steep, rough, and uneven hills with a 30° incline, leading to diminished EV range. Notably, the force peaks on rough and uneven mountain roads with a 30° slope, particularly during rainy seasons, exacerbating battery energy requirements and diminishing EV range.

Traction force peaks during hill climbing, as shown in Fig. 8, greatly reduce EV range, making them unsuitable for mountainous and very cold conditions. Charging stations on hills may alleviate range anxiety, but range issues persist. Aerodynamic drag is significant in winter, complicating EV use in mountains. Rolling resistance increases on slippery, uneven, and rainy roads, stressing the EV range further. Gradient resistance poses challenges on ascending slopes, particularly on wet mountain routes. Traction force is much higher on hilly roads in rainy, cold conditions compared to smooth roads in summer. Hence, the EV range is most affected during the rainy season. EVs are best suited for smooth, flat roads in summer and spring, with temperatures from 25°C to 51°C. Though rough roads need more traction force, their range remains higher than on mountains.

Table 5. Determination of gradient force for various hill slopes on a mountainous road in different weather conditions.

θ = 5°					
Season/ Temperature	Vehicle mass	Standard gravity	Slope	Sine θ	F_{gr} (N)
Nominal temperature (25°C)	1800	9.8	5°	0.08	1411.2
Extremely high temperature (51°C)	1800	9.8	5°	0.08	1411.2
Rainy season (15°C)	1800	9.8	5°	0.08	1411.2
Extremely cold temperature (-15°C)	1800	9.8	5°	0.08	1411.2
θ = 10°					
Season/ Temperature	Vehicle mass	Standard gravity	Slope	Sine θ	F_{gr} (N)
Nominal temperature (25°C)	1800	9.8	10°	0.17	2998.8
Extremely high temperature (51°C)	1800	9.8	10°	0.17	2998.8
Rainy season (15°C)	1800	9.8	10°	0.17	2998.8
Extremely cold temperature (-15° C)	1800	9.8	10°	0.17	2998.8
θ = 15°					
Season/Temperature	Vehicle mass	Standard gravity	Slope	Sine θ	F_{gr} (N)
Nominal temperature (25°C)	1800	9.8	15°	0.25	4410
Extremely high temperature (51°C)	1800	9.8	15°	0.25	4410
Rainy season (15°C)	1800	9.8	15°	0.25	4410
Extremely cold temperature (-15°C)	1800	9.8	15°	0.25	4410
θ = 20°					
Season/ Temperature	Vehicle mass	Standard gravity	Slope	Sine θ	F_{gr} (N)
Nominal temperature (25°C)	1800	9.8	20°	0.34	5997.6
Extremely high temperature (51°C)	1800	9.8	20°	0.34	5997.6
Rainy season (15°C)	1800	9.8	20°	0.34	5997.6
Extremely cold temperature (-15° C)	1800	9.8	20°	0.34	5997.6
θ = 25°					
Season/ Temperature	Vehicle mass	Standard gravity	Slope	Sine θ	F_{gr} (N)
Nominal temperature (25°C)	1800	9.8	25°	0.42	7408.8
Extremely high temperature (51°C)	1800	9.8	25°	0.42	7408.8
Rainy season (15°C)	1800	9.8	25°	0.42	7408.8
Extremely cold temperature (-15° C)	1800	9.8	25°	0.42	7408.8
θ = 30°					
Season/Temperature	Vehicle mass	Standard gravity	Slope	Sine θ	F_{gr} (N)
Nominal temperature (25°C)	1800	9.8	30°	0.5	8820
Extremely high temperature (51°C)	1800	9.8	30°	0.5	8820
Rainy season (15°C)	1800	9.8	30°	0.5	8820
Extremely cold temperature (-15° C)	1800	9.8	30°	0.5	8820

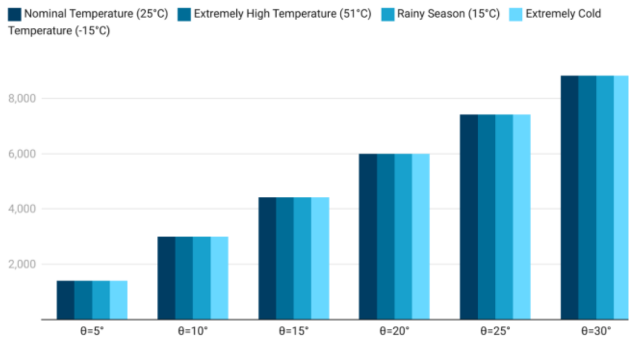

Fig. 7. Gradient resistance force for mountainous road

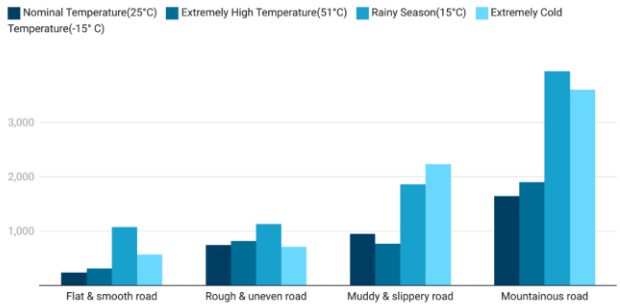

Fig. 8. Traction force required by the EV at different pavements in various seasons

5. CONCLUSION

In summary, this research highlights the optimal conditions for EV performance, demonstrating that serene, smooth roads during the summer months offer the best range potential, with energy consumption lowest between temperatures of 25°C and 51°C. Conversely, hilly, rainy, and uneven roads impose the greatest strain on EV batteries, leading to varied performance requirements depending on the prevailing road conditions. Particularly challenging are combinations of adverse weather, temperature, and season, such as driving on steep mountainous routes during the rainy season, which result in heightened battery usage and diminished range. While the deployment of charging stations can mitigate these challenges to some extent, our findings caution against EV usage for hill climbing and extreme winters in current Indian scenarios. However, these insights provide valuable guidance for EV design enhancements, paving the way for improved performance on rough, muddy, and hilly roads during inclement weather conditions.

Moreover, our research provides a foundation for informed decision-making and innovation in sustainable transportation. Future efforts should refine predictive models, conduct field tests, and integrate advanced technologies to enhance EV range optimization and transition to greener mobility. These findings are beneficial for engineers and policymakers to improve EV design, focusing on aerodynamic efficiency, traction performance, and road surface challenges to use this data for planning and investing in infrastructure, supporting road maintenance, and EV charging infrastructure deployment. However, acknowledging uncertainties in activity data and exploring factors like vehicle dynamics and driver behaviour is essential for advancing EV range technologies and promoting wider adoption in India.

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