EV Range

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1 Introduction

The aerodynamic drag power P_d is given by:

$$P_d = \frac{1}{2}\rho C_d A v^3$$

Where:
ρ = air density (kg/m^3)
C_d = drag coefficient (dimensionless)
A = frontal area (m^2)
v = vehicle speed (m/s)

Since power is force times velocity, drag force scales with v^2, and power with v^3.

Energy consumption due to acceleration can be approximated by kinetic energy changes:

$$E_{acc} = \frac{1}{2}m(v_f^2 - v_i^2)$$

Where:
m = vehicle mass (kg)
v_i, v_f = initial and final speeds (m/s)

Net energy consumption accounts for regenerative braking efficiency η_{regen}:

$$E_{net} = E_{acc} \times (1 - \eta_{regen})$$

Typical η_{regen} ranges from 50% to 70%.

Vehicle Weight - Heavier vehicles require more energy for acceleration and climbing. - Rolling resistance force F_r is proportional to vehicle weight:

$$F_r = mgC_r$$

Where:
g = gravitational acceleration (9.81 m/s²)
C_r = rolling resistance coefficient (0.01–0.015)

A 15% increase in vehicle weight can cause a 4–9% increase in energy consumption (ScienceDirect, 2025).

HVAC Energy Consumption Patterns in EVs

Key Insights
- HVAC systems are among the largest auxiliary loads, especially in extreme temperatures.
- HVAC can reduce driving range by 20–40%.
- Energy consumption depends on ambient temperature, solar heat gain, and HVAC system efficiency.

Quantitative Modeling
HVAC power consumption P_{HVAC} can be modeled as:

$$P_{HVAC} = f(T_{ambient}, T_{set}, Q_{solar}, \eta_{HVAC})$$

Where:
$T_{ambient}$ = outside temperature
T_{set} = cabin set temperature
Q_{solar} = solar heat gain
η_{HVAC} = HVAC system efficiency

Dynamic models (ResearchGate, 2014; MDPI, 2023) simulate HVAC load variation over time.

Elevation/Slope Effects on EV Energy Usage

Key Insights
- Uphill driving increases energy consumption due to gravitational work.
- Downhill driving can recover energy via regenerative braking.
- Slope impact can improve energy consumption estimation accuracy by 5–8%.

Quantitative Relationship
Gravitational power component:

$$P_{slope} = mgv \sin(\theta)$$

Where:
θ = road slope angle (radians)

Energy over distance Δd:

$$E_{slope} = mg\sin(\theta)\Delta d$$

Ambient Temperature Effects on Battery Performance

Key Insights
- Battery efficiency and capacity degrade outside optimal temperature range (15–35°C).
- Cold temperatures increase internal resistance, reducing available energy and increasing HVAC heating demand.
- Hot temperatures increase cooling load and can reduce battery lifespan.

Quantitative Effects
- Range can drop by 20–40% in cold weather (Vaisala, 2024; Geotab, 2023).
- Battery capacity C_{bat} and efficiency η_{bat} are temperature-dependent:

$$C_{bat}(T) = C_{nominal} \times f(T)$$

$$\eta_{bat}(T) = \eta_{nominal} \times g(T)$$

Where:
$f(T)$ and $g(T)$ are empirically derived temperature correction factors.

Comprehensive Formula Framework for Synthetic EV Range Prediction Data Generation

Overview

The total energy consumption
EC for a trip segment can be modeled as the sum of propulsion energy, auxiliary loads (including HVAC), and regenerative energy recovery:

$$EC = EC_{propulsion} + EC_{auxiliary} + EC_{HVAC} - EC_{regenerative}$$

Where each term is detailed below.

$$EC_{propulsion} = \sum \left[(F_{aero} + F_{roll} + F_{gravity} + F_{acc}) \times \Delta d\right] / \eta_{drivetrain}$$

With forces:

— Force — Formula — Description —

— Aerodynamic Drag — $F_{aero} = \frac{1}{2}\rho C_d A v^2$ — Air resistance —
— Rolling Resistance — $F_{roll} = mgC_r \cos(\theta)$ — Tire-road friction —
— Gravitational — $F_{gravity} = mg\sin(\theta)$ — Road slope effect —
— Acceleration — $F_{acc} = ma$ — Inertial force from acceleration —

Δd = distance increment
$\eta_{drivetrain}$ = drivetrain efficiency (0.85–0.95)

Auxiliary Loads (excluding HVAC)

Includes lighting, infotainment, electronics:

$$EC_{auxiliary} = P_{aux} \times \Delta t$$

Where:
P_{aux} is average auxiliary power (typically 100–500 W).

HVAC Energy Consumption

Modeled dynamically as:

$$EC_{HVAC} = \sum P_{HVAC}(t) \times \Delta t$$

Where:
$P_{HVAC}(t)$ depends on ambient temperature, solar load, and HVAC system state.

Regenerative Energy Recovery

$$E_{regenerative} = \eta_{\text{regen}} \times \sum \frac{1}{2} m(v_i^2 - v_f^2) \quad \text{for} \quad v_i > v_f$$

Initial Battery State of Charge (SoC) and Temperature Adjustment

The usable battery energy E_{usable} is:

$$E_{usable} = C_{bat}(T) \times SoC_{init} \times V_{bat}$$

Where:
SoC_{init} = initial state of charge (fraction)
V_{bat} = nominal battery voltage

Final Range Estimation

The predicted range R is:

$$R = \frac{E_{usable}}{EC_{per\_km}}$$

Where EC_{per_km} is average energy consumption per km derived from the above components.