# Integrated Electro-Thermal-Mechanical Modeling For Next-Generation Transportation Infrastructure

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## Abstract

Electric vehicles (EVs) present a sustainable alternative to internal combustion engine vehicles. However, their widespread adoption remains hindered by limited driving range and insufficient charging infrastructure. Wireless power transfer (WPT) technologies, particularly those enabling dynamic in-motion charging, offer a promising solution to address range anxiety—especially for commercial and long-haul electric trucks, as shown in Figure 1. Among various WPT methods, inductively coupled power transfer (ICPT) has emerged as a favorable approach due to its compatibility with roadway integration and operational efficiency (Soares and Wang, 2022; Kalwar et al., 2015; Aziz et al., 2019). While pilot ICPT roadway projects have been implemented in Asia, Europe, and the U.S. (Stamati and Bauer, 2013; Olsson, 2013; Suul and Guidi, 2018; Saldarini et al., 2024), key challenges remain regarding electromagnetic behavior, thermal effects, and structural integrity. This study presents a comprehensive multiphysics simulation framework using COMSOL Multiphysics® to evaluate the coupled electro-thermal-mechanical performance of electrified road systems. Figure 2 illustrates the modeling processes.

Electromagnetic modeling simulates WPT efficiency between embedded primary coils and vehicle-mounted secondary coils, assessing magnetic field strength, coupling efficiency, and power transfer efficiency (PTE). The effects of roadway materials—including their electrical conductivity, magnetic permeability, and geometry—are incorporated to evaluate field distribution and energy losses. Results show that typical pavement materials have minimal impact on PTE, whereas coil embedment depth and alignment significantly affect performance. Building on the EM results, a transient thermal model is developed to analyze heat generation and dissipation due to electromagnetic losses. The model incorporates convective, conductive, and radiative heat transfer, accounting for environmental conditions. Simulations reveal that under worst-case scenarios, both embedded coil and pavement temperatures increase can be up to 50 °C, leading to the pavement surface temperature exceed 100 °C in hot climates. Such elevated temperatures pose risks to both pavement durability and coil functionality, underscoring the need for active thermal management or system improvements. By importing the temperature field from thermal modeling, a solid mechanics module is then used to assess the structural performance of the pavement under moving vehicle loads. Temperature-dependent, nonlinear material properties—such as viscoelasticity property of asphalt mxitures—are considered to capture realistic mechanical behavior. The coupled analysis quantifies stress distribution, rutting potential, and fatigue damage under thermal and traffic-induced conditions.

This integrated electro-thermal-mechanical modeling approach provides a robust decision-support tool for optimizing electrified roadway systems. It enables evaluation of material selection, geometric design, heat management, and long-term infrastructure resilience. The insights gained support the development of next-generation transportation infrastructure that meets the growing demands of vehicle electrification while maintaining structural and operational reliability.

## Reference

1. Soares, L., & Wang, H. (2022). A study on renewed perspectives of electrified road for wireless power transfer of electric vehicles. Renewable and Sustainable Energy Reviews, 158, 112110.
2. Kalwar, K. A., Aamir, M., & Mekhilef, S. (2015). Inductively coupled power transfer (ICPT) for electric vehicle charging–A review. Renewable and Sustainable Energy Reviews, 47, 462-475.
3. Aziz, A. F. A., Romlie, M. F., & Baharudin, Z. (2019). Review of inductively coupled power transfer for electric vehicle charging. IET Power Electronics, 12(14), 3611-3623.
4. Stamati TE, Bauer P. On-road charging of electric vehicles. In: 2013 IEEE transportation electrification conference and expo (ITEC). IEEE; 2013, June. p. 1–8.
5. Olsson, O. (2013). Slide-in electric road system, inductive project report, phase 1. In Friday, October 25, 2013. Scania CV AB.
Saldarini, A., Molinari, F., Longo, M., Brenna, M., Zaninelli, D., Mastroviti, G., & Lupi, G. (2024). Electric Vehicle Modelling Applied to Dynamic Wireless Charging: Case Study. IFAC-PapersOnLine, 58(13), 374-379.

## Figures used in the abstract

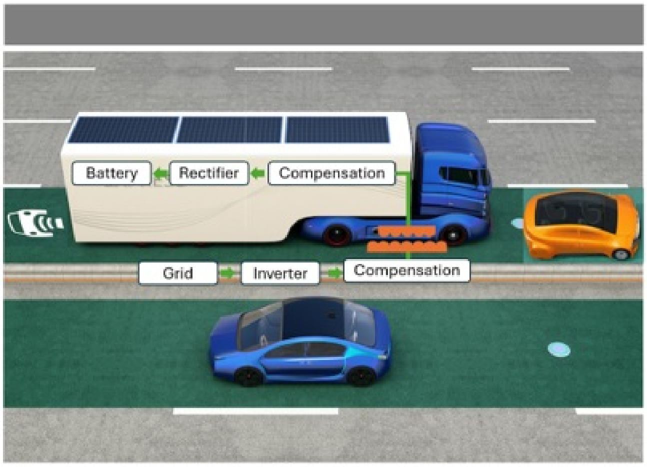


**Figure 1** : Dynamic wireless charging of EV on roadway

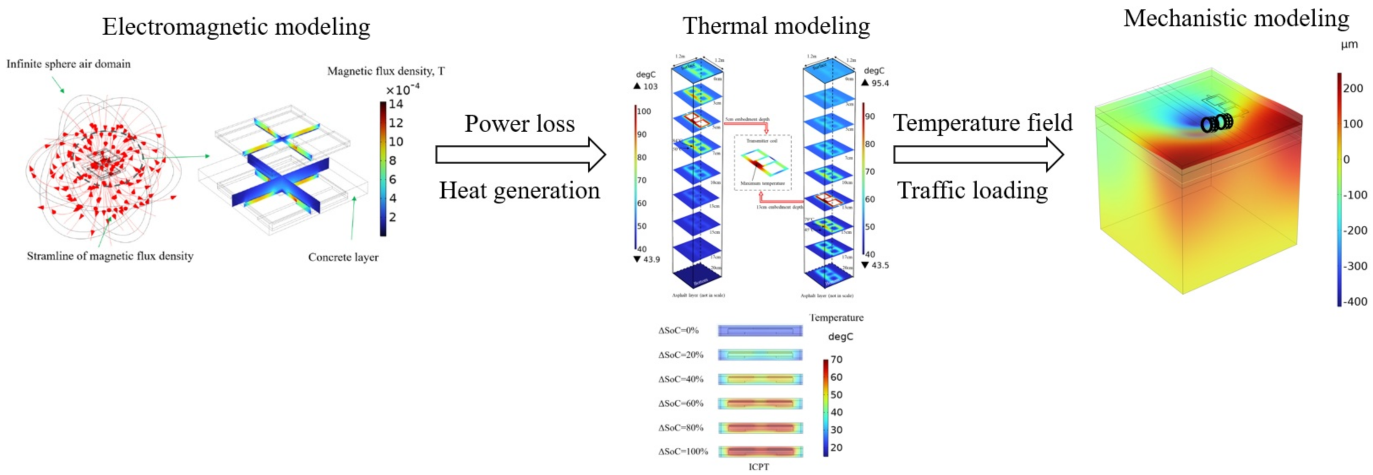


**Figure 2** : Integrated Electro-Thermal-Mechanical Modeling