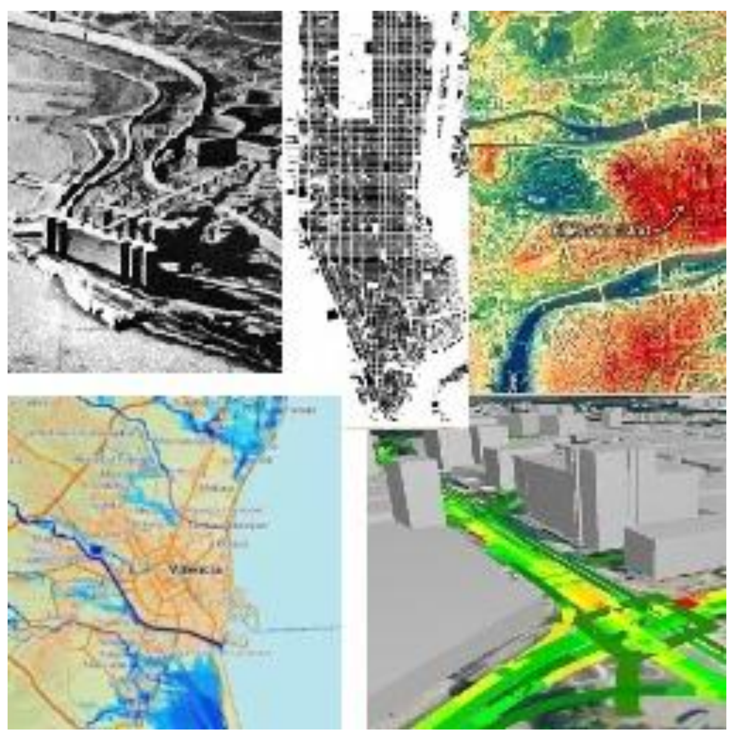

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A methodology for determining power demands across urban transport routes

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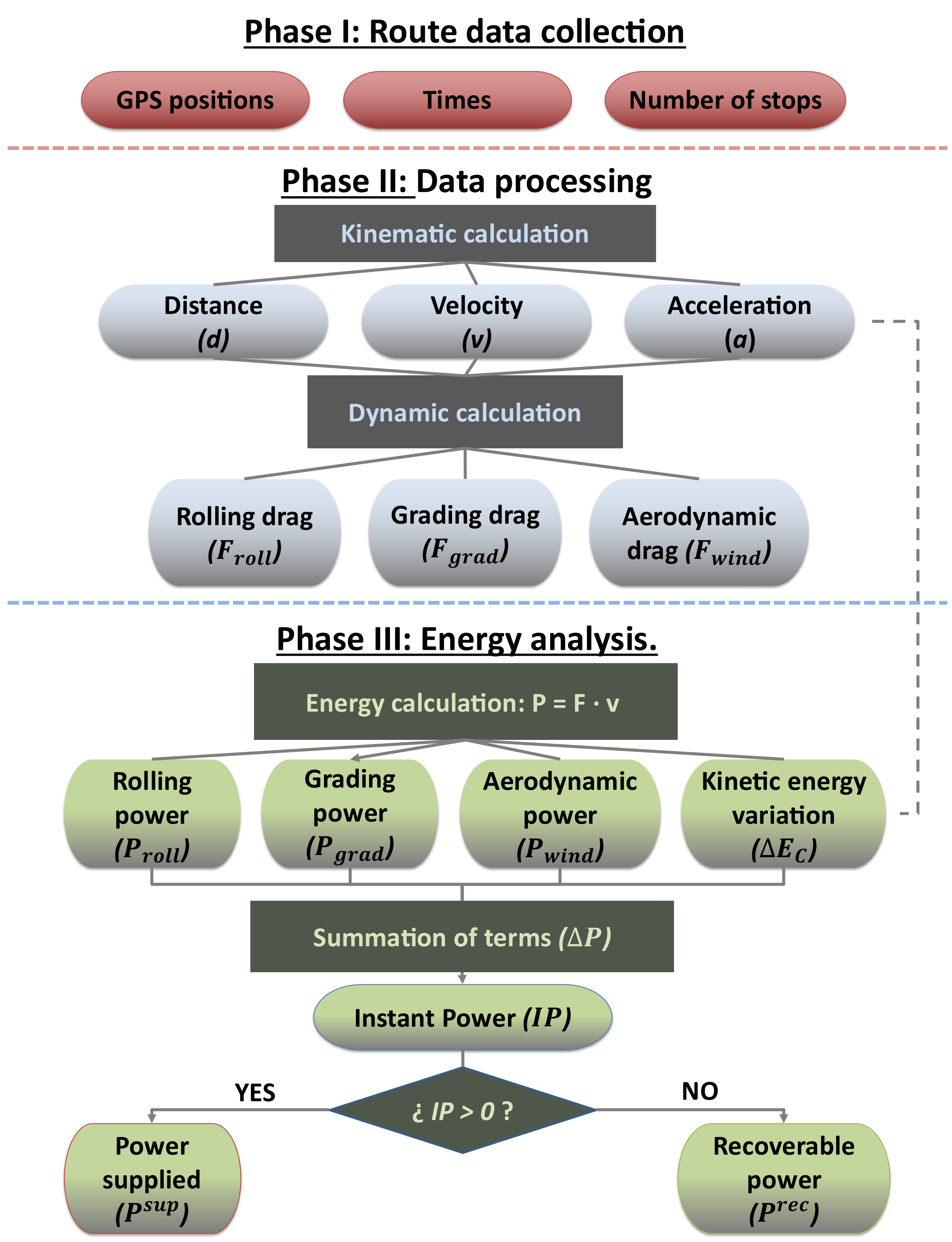
INTRODUCTION

Improving energy efficiency is crucial for urban vehicle fleets, especially in public transport. **Regenerative braking systems** are a key strategy, allowing energy recovery that would otherwise be lost as heat, thus reducing costs and environmental impact. By capturing and reusing this energy, operators can not only lower operational costs but also contribute to cleaner and more environmentally friendly cities.

However, in many cases, **regenerative braking systems are not optimally sized** for the specific characteristics of the routes being serviced. Undersized systems are incapable of capturing the full amount of recoverable energy during intense braking events, leading to energy loss. Conversely, oversized systems often operate below their nominal efficiency for most of the duty cycle, resulting in suboptimal performance and unnecessary costs.

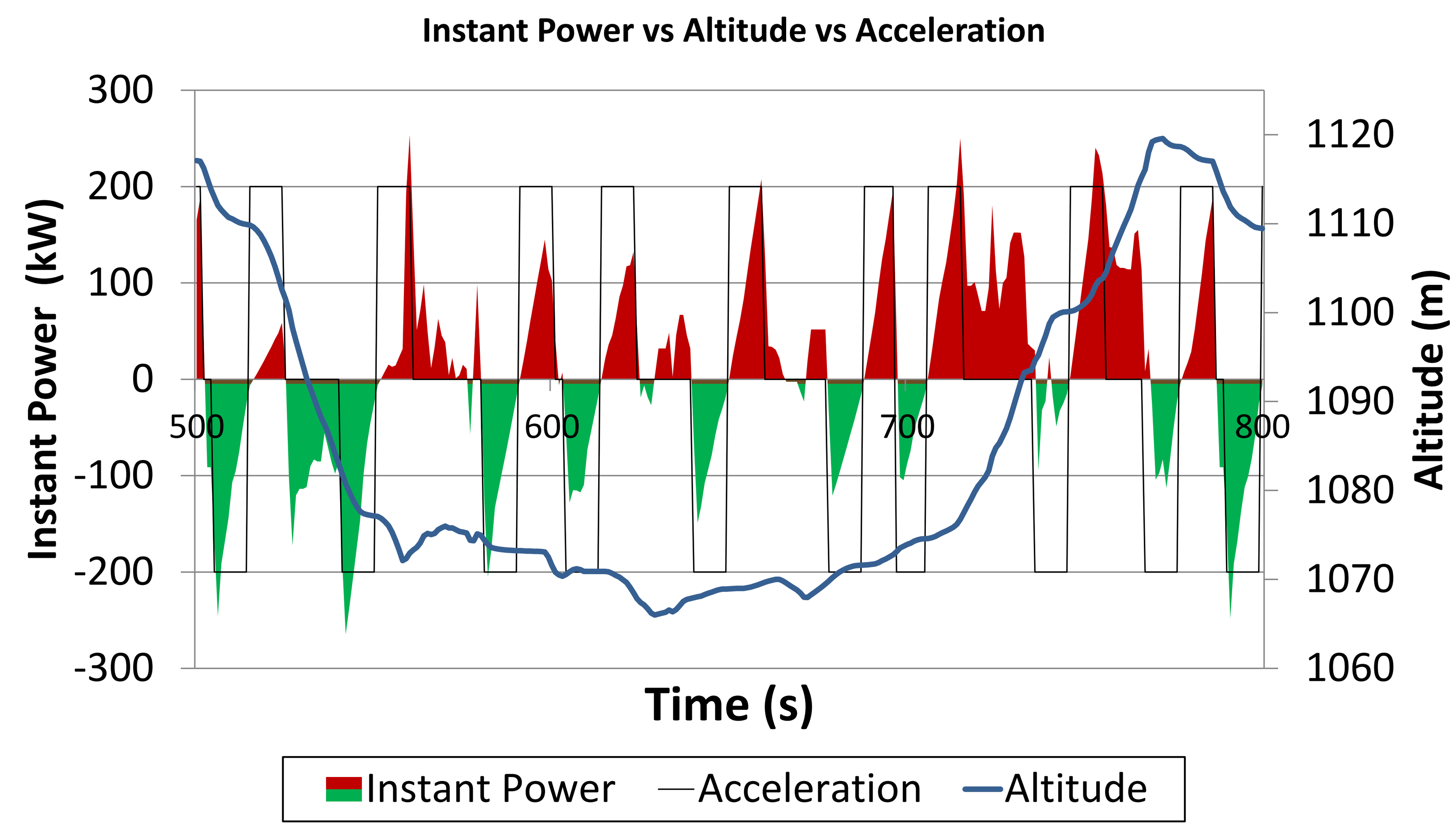
METHODS



RESULTS & DISCUSSION

A detailed energy simulation was performed on the six urban bus lines of Ávila, estimating **topographic profiles**, **instantaneous power**, and **recoverable energy** via regenerative braking. An example is the Figure.

- The study revealed significant variability in both peak and average recoverable power, highlighting the **influence of route characteristics** such as stop density and terrain slope.



- A **strong linear relationship between recoverable energy per kilometer** and two key variables: number of stops per kilometer and accumulated slope of the route.
- Regression models were developed to **estimate both energy supplied, and energy recovered**, enabling predictive insights into the efficiency of different routes.
- Routes with more stops and steeper slopes show higher potential for regenerative braking benefits.
- Implementing regenerative braking can reduce fuel consumption and emissions.
- The findings suggest that **routes with more frequent stops and steeper slopes have greater potential for energy recovery through regenerative braking systems.**
- While the analysis assumes ideal operational conditions, the results offer a practical framework for prioritizing routes in sustainable fleet planning and optimizing the integration of energy-efficient technologies.

CONCLUSIONS

- The urban transport sector is moving rapidly towards **sustainability and decarbonization** by improving energy efficiency, with regenerative braking systems playing a key role in this transition.
- Due to limited resources, local administrations often cannot replace entire bus fleets at once; thus, **prioritizing investments based on route characteristics is essential for maximizing benefits.**
- This model quantifies the relative contribution of these variables to **energy consumption and recovery**, enabling more efficient route design and energy optimization for urban transport.
- Applying the model to Ávila's six urban bus lines established a clear priority order for fleet renewal, ensuring that regenerative braking systems are first implemented where energy recovery potential—and thus resource efficiency—is greatest.