

Introduction

Vibrational Energy Harvesting (VEH) converts ambient mechanical vibrations into usable electrical energy. While solar and wind energy have well-established assessment frameworks, **ground vibrations** remain a largely untapped and uncharacterized energy resource, despite being continuously generated by both natural and human activity.

Mining environments produce persistent ground motion from diverse sources: earthquakes, microseisms, mining blasts, and heavy vehicle traffic. These vibrations span a range of frequencies (1–20 Hz) and amplitudes that are potentially compatible with low-frequency **electromagnetic energy harvesters (EMEHs)**. As a first approximation, only the vertical ground motion component is considered, simplifying the system while enabling an initial estimate of harvesting potential.

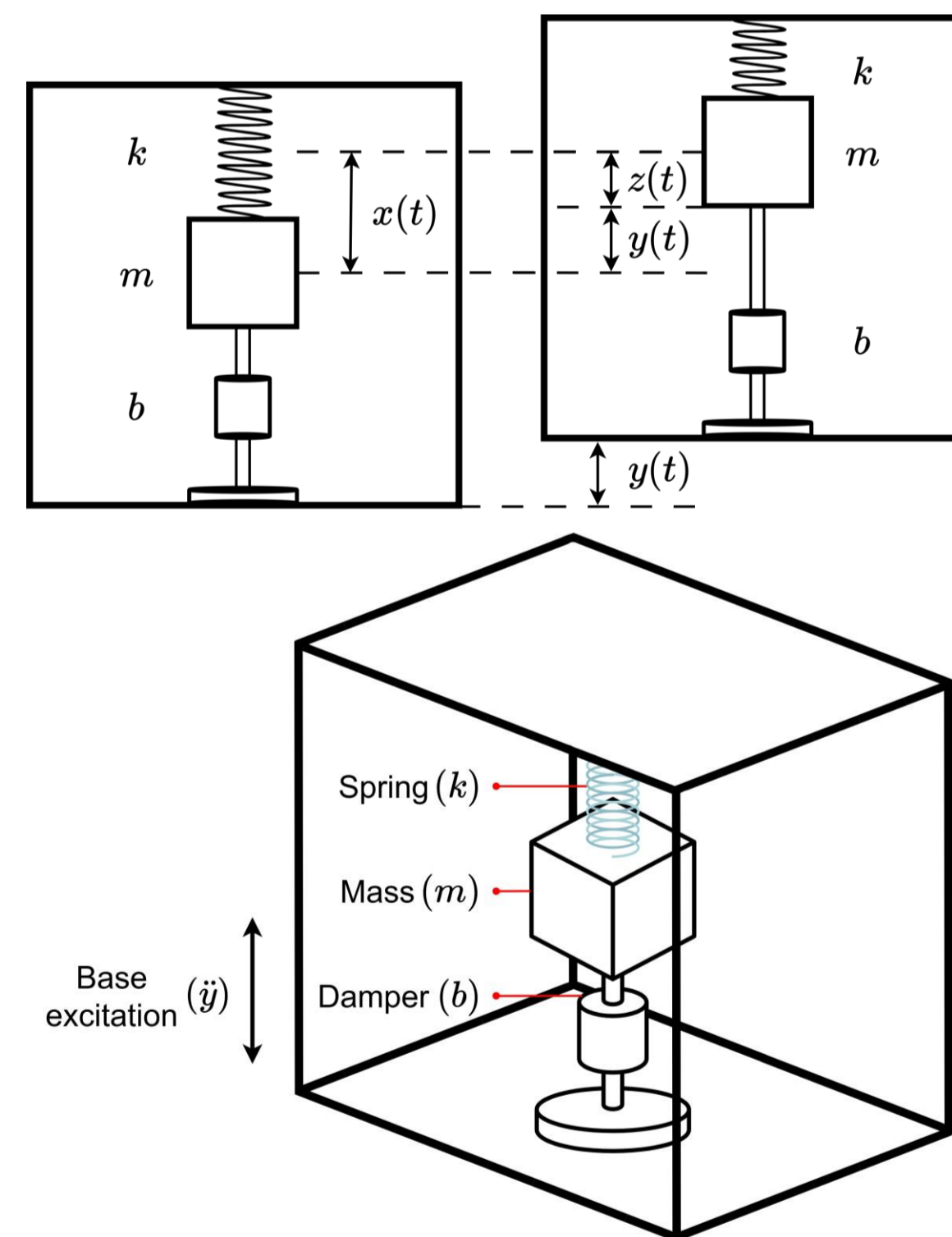


Figure 1: Schematic of a simple electromagnetic energy harvester.

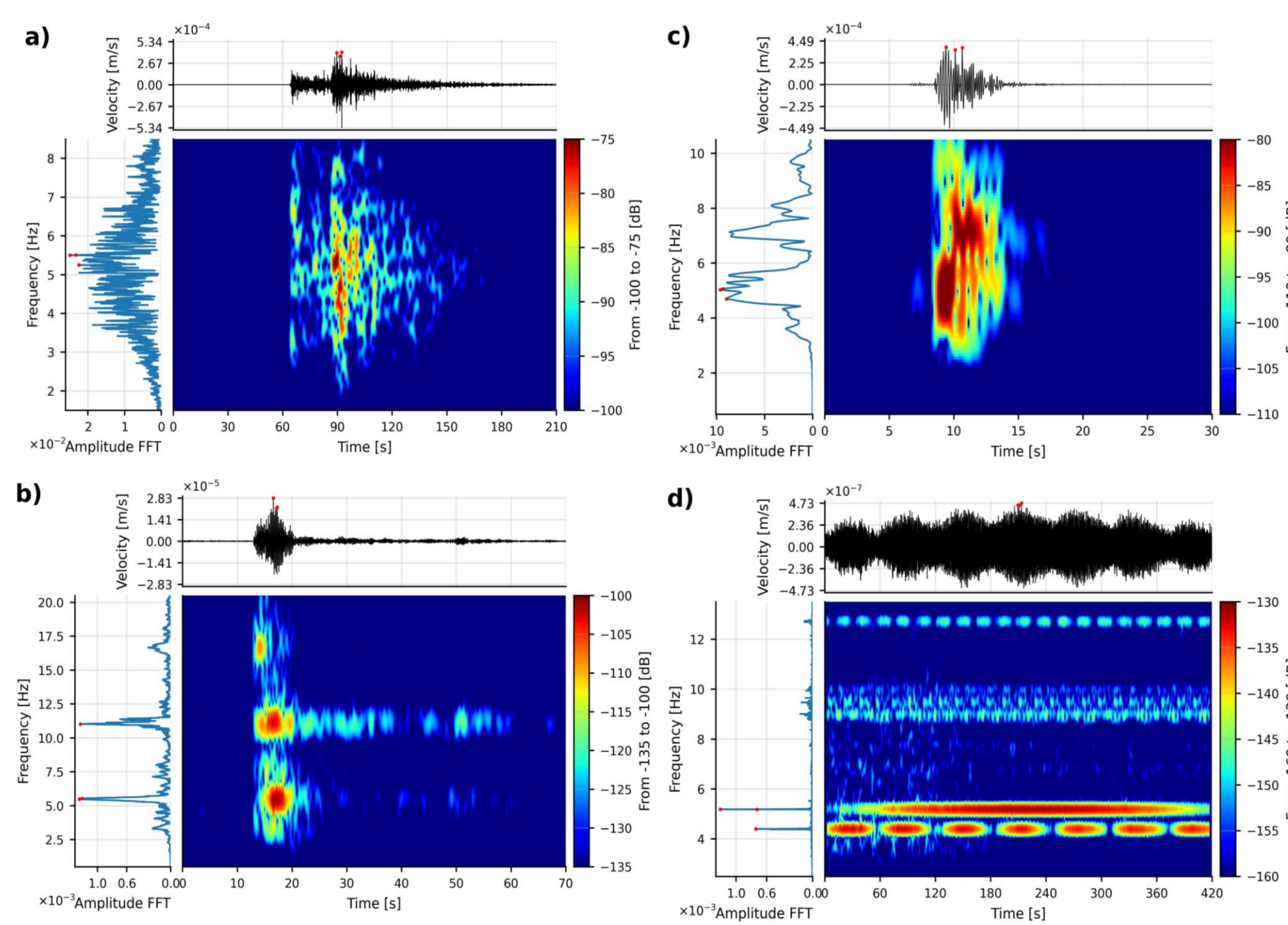


Figure 2: Time-lapse spectral characterization for representative events: a) earthquake, b) microseism, c) mining blast, and d) for truck circulation.

VEH systems operate in the **microwatt-to-milliwatt range**, making them well-suited for powering autonomous sensors, IoT devices and wireless sensor nodes (WSNs). This technologies increasingly critical for remote monitoring in mining and infrastructure-limited environments. However, the absence of a **standardized resource-level assessment framework** prevents the strategic deployment of such systems at sites where seismic energy is persistently available.

Objective: This work introduces a systematic, replicable workflow to evaluate the theoretical vibrational energy harvesting potential from real seismic records, demonstrated at a mining site in northern Chile.

Methodology

The proposed sequential workflow establishes a **reproducible framework** to systematically assess VEH potential, facilitating comparative analysis across different environments.

The process begins with data acquisition and preprocessing, continues with detection and qualification of events, followed by classification and characterization in the **time-frequency** domains.

Validated events drive **numerical simulations** of a tuned EMEH model, yielding instantaneous power and cumulative harvested energy estimates across stations and temporal scales.

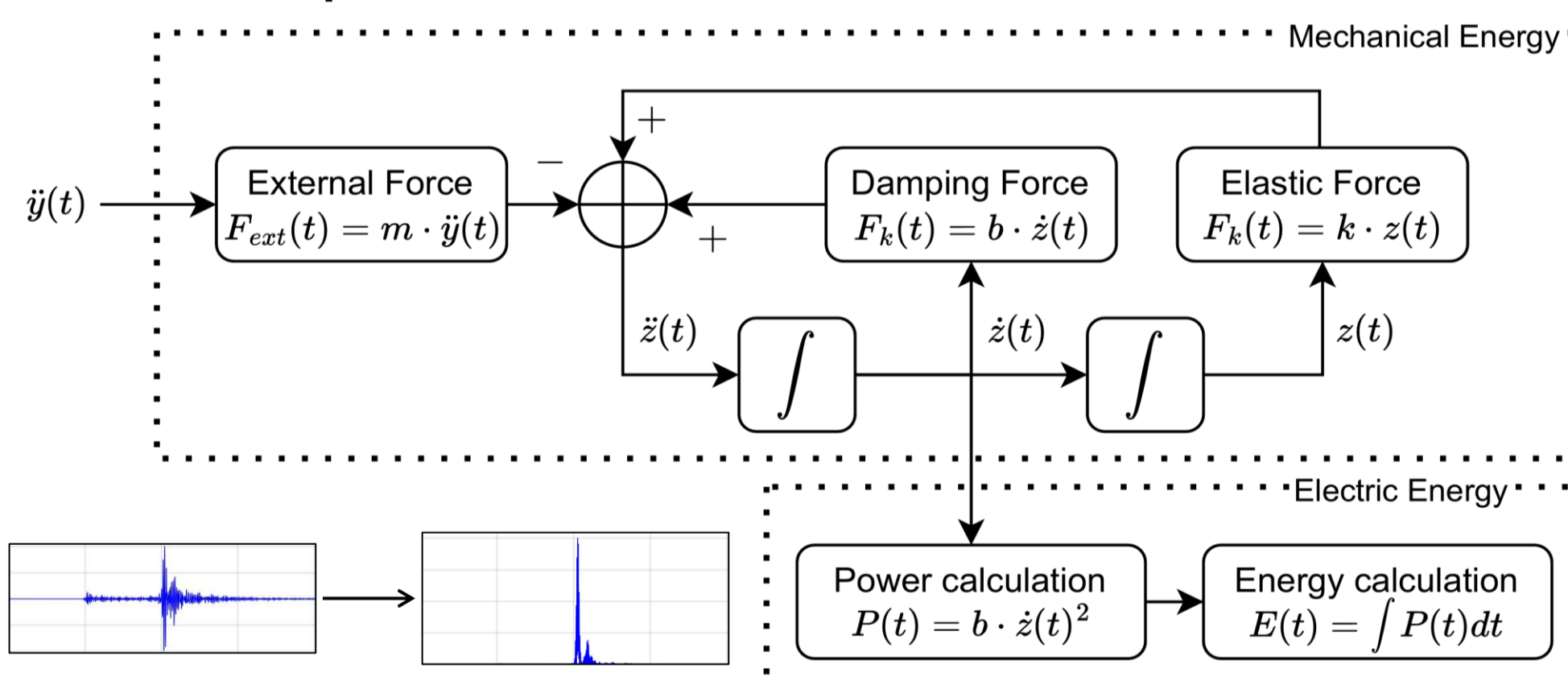


Figure 4: Schematic representation of the Simulink model for EMEH.

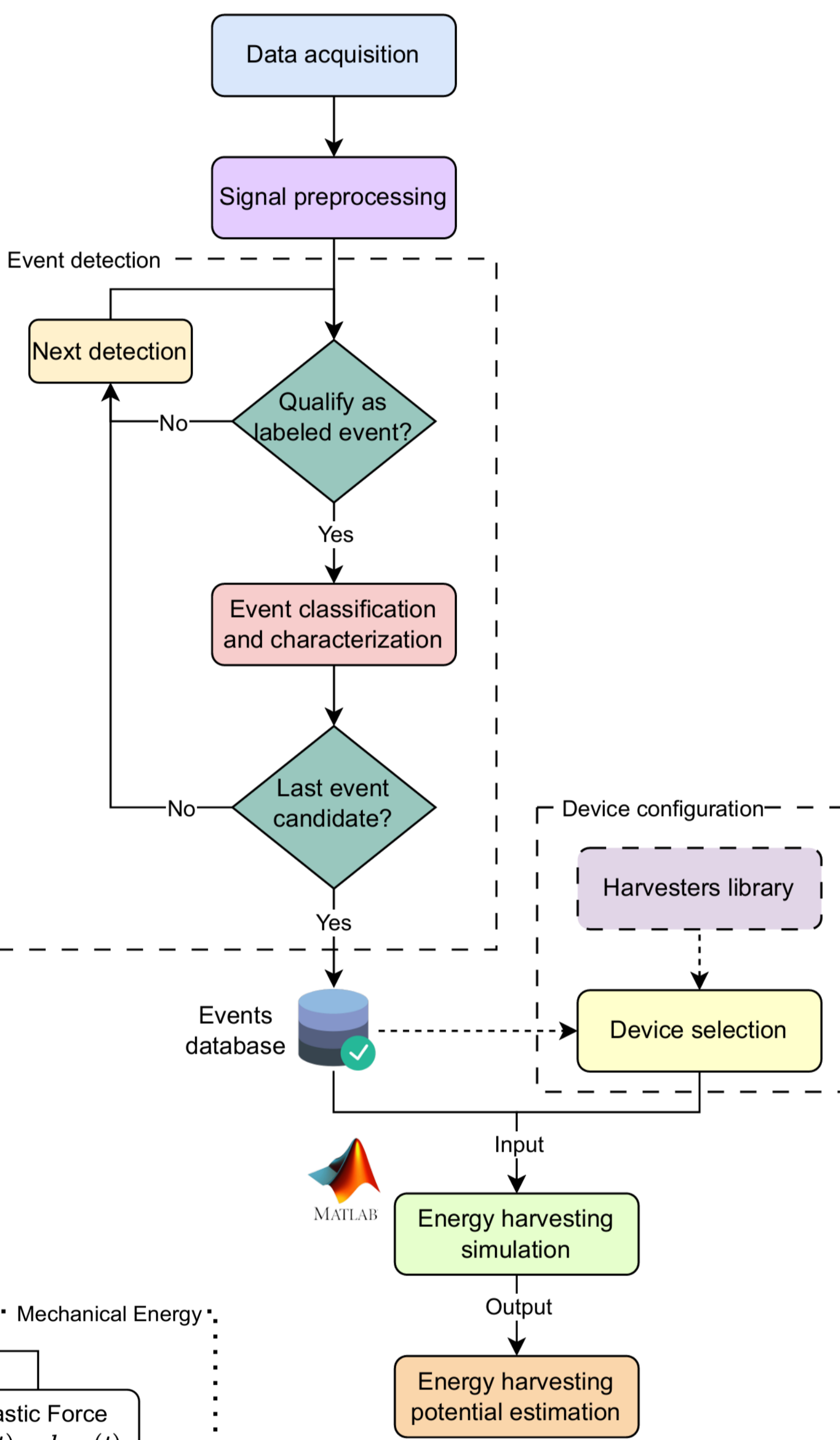


Figure 3: Methodology workflow for estimating energy harvesting potential for seismic events.

Figure 4: Schematic representation of the Simulink model for EMEH.

Results: Case study

Model simulations reveal **distinct power signatures** across event classes: earthquakes and mining blasts yield the highest theoretical energy outputs, while microseisms and truck circulation contribute only marginal amounts.

Spatial analysis across the monitoring network identifies persistent **energy "hotspots"** whose distribution varies by event type, reflecting the dominant influence of source proximity and local geology on harvestable energy.

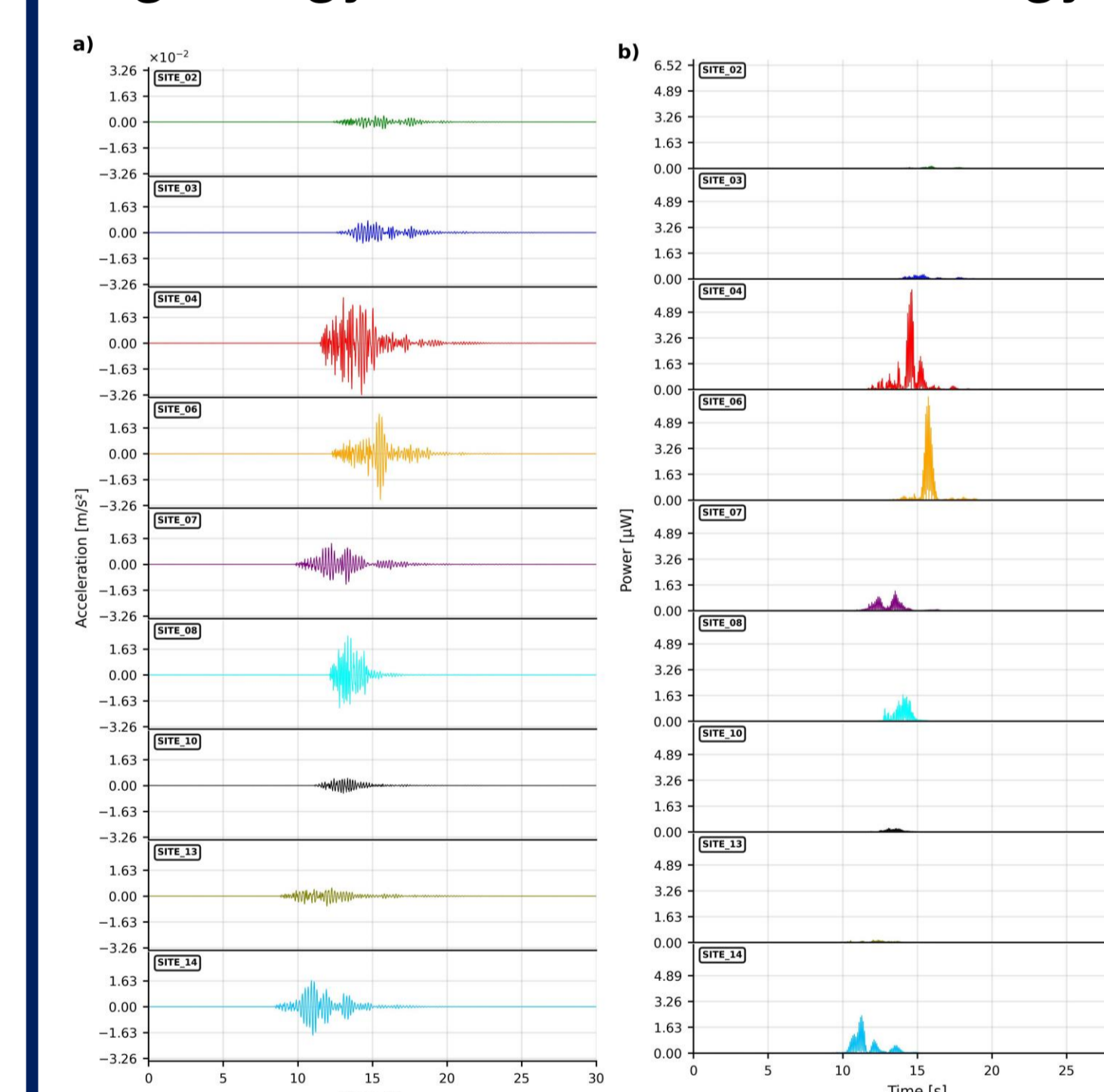


Figure 7: Multi-station plots for a mining blast event: a) excitation input and b) power output.

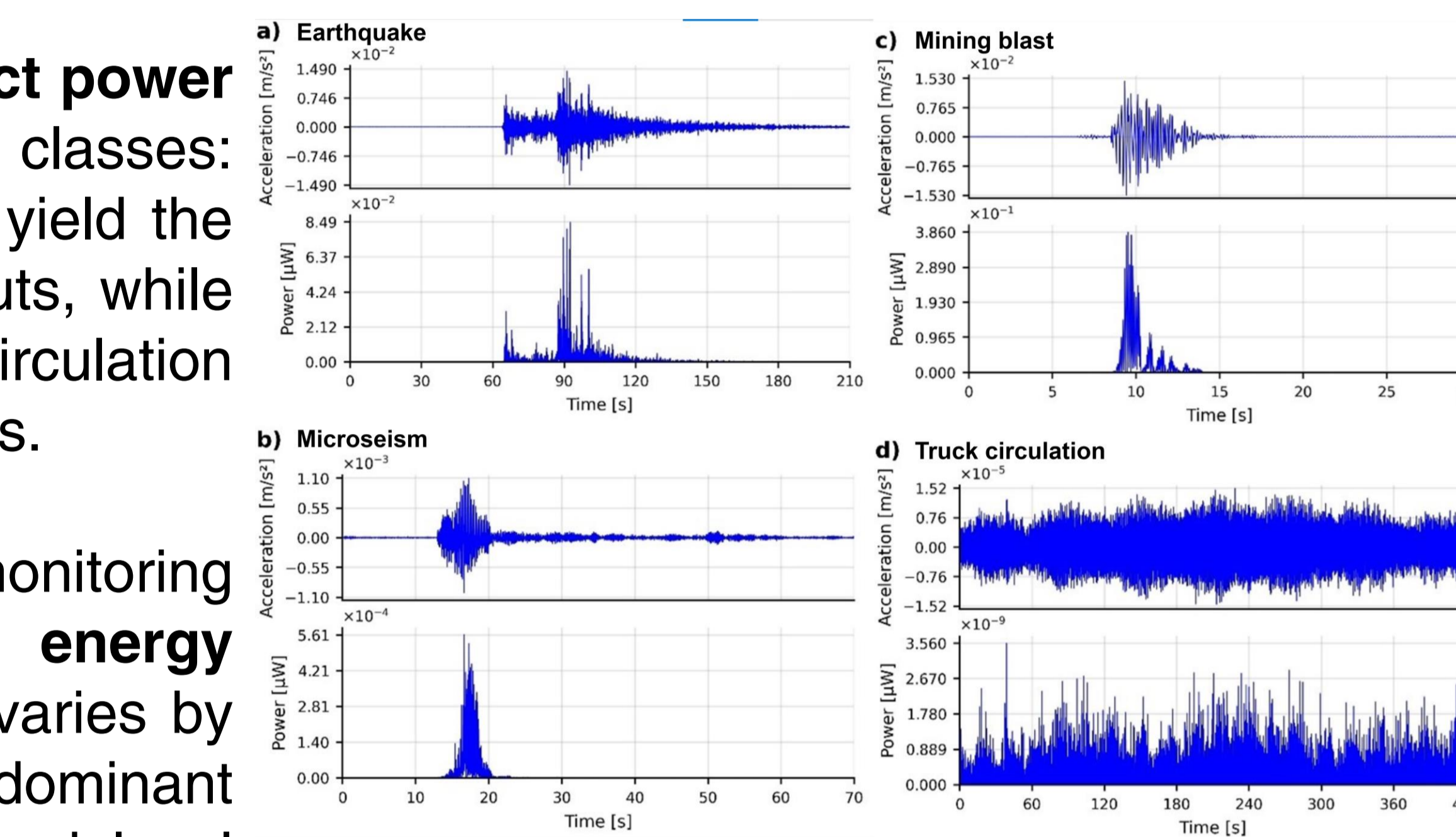


Figure 6: Acceleration (model input) vs Power (model output) for representative events.

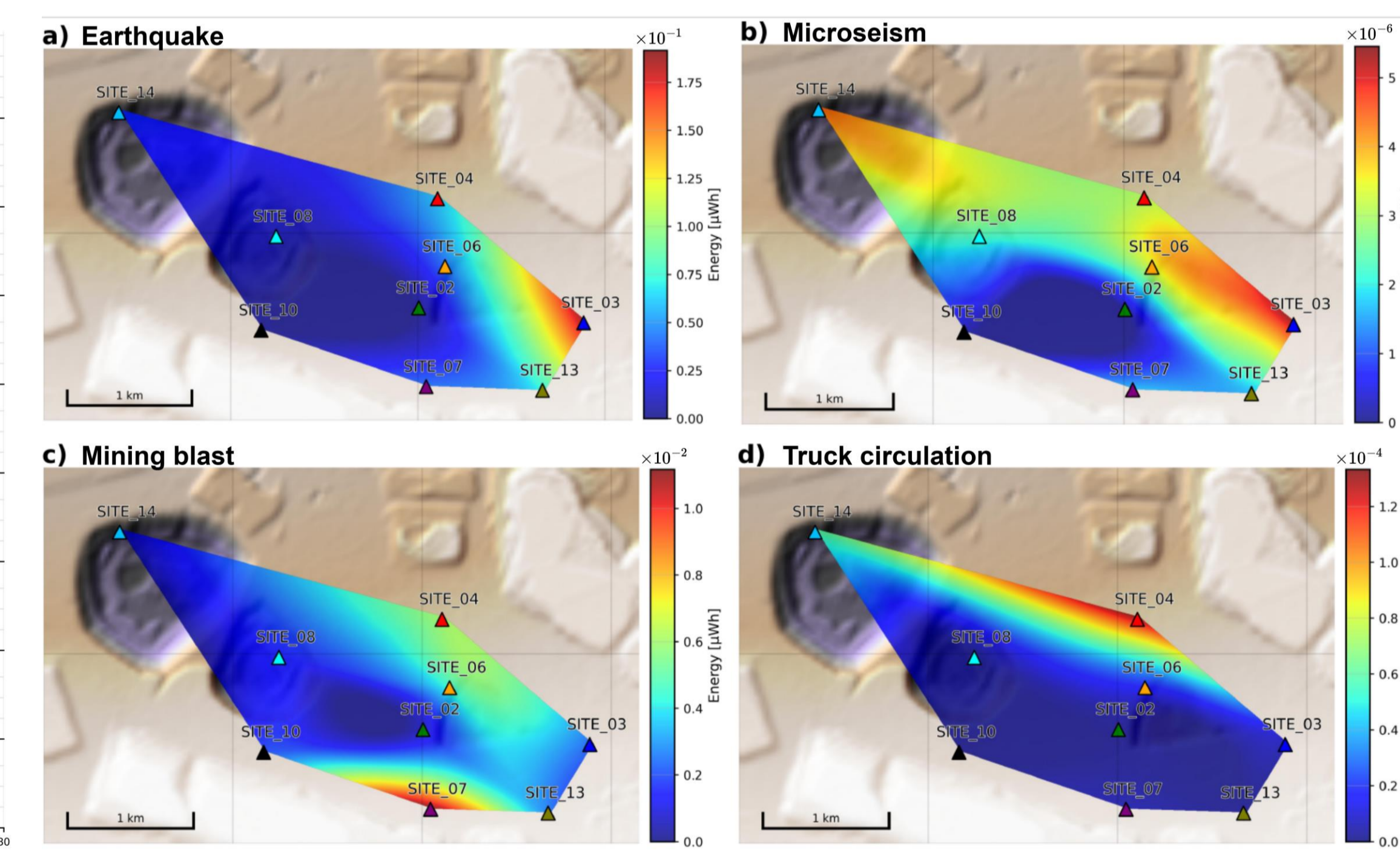


Figure 8: Spatial energy density map for the study period divided by event type.

Conclusions

- A **six-stage workflow** was developed to assess seismic VEH potential, filling a methodological gap in the existing literature.
- The study demonstrates that seismic environments contain **exploitable vibrational energy**, and that the proposed workflow establishes a basis for evaluating its potential and supporting low-power monitoring applications.
- Harvestable energy exhibits **strong spatial variability** across monitoring stations, with persistent "hotspots" across event types.

Future work

- **Refinement of the numerical model** through incorporation of horizontal seismic components, explicit electrical circuit coupling, and multi-device array configurations to improve power output estimates.
- **Experimental validation** using a physical EMEH prototype under controlled and field seismic conditions.
- Incorporation of **ground attenuation models** to replicate local geological conditions, improving the representation of site-specific vibration transmission.

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Abstract



References