



# A Context-Aware Energy Planner for Battery Dimensioning and Technology Selection in 6G-Ready Cellular IoT

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**Abstract**—Energy efficiency and sustainability are becoming first-class design objectives for current 5G and future 6G networks, particularly for large-scale battery-powered IoT deployments. While multiple cellular technologies such as NB-IoT, RedCap, enhanced RedCap (eRedCap), and 5G NR coexist, application designers lack practical tools to quantitatively compare their energy performance under realistic deployment conditions. In this demo paper, we present a context-aware Energy Planner and Eco Score that enables interactive evaluation and optimization of energy consumption, battery life and capacity across heterogeneous cellular technologies. By integrating application traffic characteristics, deployment context, and technology-specific energy models, the planner provides comprehensive energy optimization options. Supporting emerging cellular device categories, the Energy Planner serves as a practical design tool and a research platform towards energy-aware 6G networks.

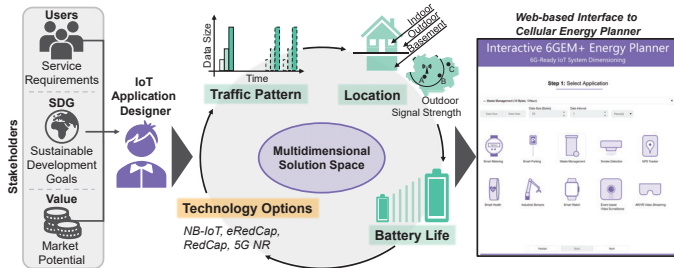


Fig. 1: Multidimensional requirements and solutions as a base for designing the Cellular Energy Planner, accessible via: <https://energyplanner.kn.e-technik.tu-dortmund.de>.

Demo video available at: <http://tiny.cc/EnergyPlanner>

## I. INTRODUCTION

**B**ATTERY-powered Internet of Things (IoT) devices are a key enabler for smart cities, industrial monitoring, and large-scale infrastructure. Many of these devices are expected to operate for months to years without maintenance. However, conservative worst-case battery dimensioning is commonly applied in practice, leading to excessive overprovisioning, increased material consumption, and avoidable battery waste.

At the same time, cellular networks provide a growing variety of communication solutions, ranging from ultra-low-power NB-IoT to broadband 5G NR. Recently introduced intermediate device categories, such as RedCap and eRedCap, aim to balance energy efficiency and performance. Selecting the most suitable technology with respect to service requirements, sustainable development goals and market potential is challenging, as the energy consumption of IoT devices strongly depends on deployment context, including traffic pattern, operator-specific network characteristics, and location.

As sustainability becomes a core objective for future 6G networks [1], energy-efficient and context-aware design methodologies are required. The lack of intuitive tools that allow application designers to explore energy trade-offs across technologies and deployment scenarios motivates the *Energy Planner* (Fig. 1) demonstrated in this work.

## II. CONTEXT-AWARE CELLULAR ENERGY PLANNER

The proposed *Energy Planner* is an interactive, web-based interface that enables comparative energy analysis and opti-

mization of IoT applications across multiple cellular technologies. It combines three classes of inputs:

- Application parameters, such as payload size, transmission interval and length,
- Deployment context, including geographic location, indoor placement, and selected network operator,
- Energy constraints, specified either as a target battery life or a given battery capacity.

Based on these inputs, the *Energy Planner* integrates protocol-aware power state modeling, including active, idle, extended Discontinuous Reception (eDRX), and Power Saving Mode (PSM) states. The underlying models are based on extensive simulations [2, 3], laboratory measurements using off-the-shelf devices [4] and data-driven Artificial Intelligence (AI) models trained on real-world empirical measurements [5]. This allows fair cross-technology assessment of cellular solutions without requiring in-depth knowledge of cellular protocols by application designers (cf. Fig. 2).

## III. SUSTAINABILITY-DRIVEN OPTIMIZATION AND RESEARCH TOWARDS 6G

The *Energy Planner* encourages to optimize applications by selecting a more energy-efficient cellular technology, adapting traffic characteristics to enable efficient transmission modes, and optimizing battery capacity to avoid unnecessary overdimensioning. This transforms the *Energy Planner* into an interactive assistant for energy-efficient IoT system design, which is illustrated by a new proposed cellular *Eco Score*.

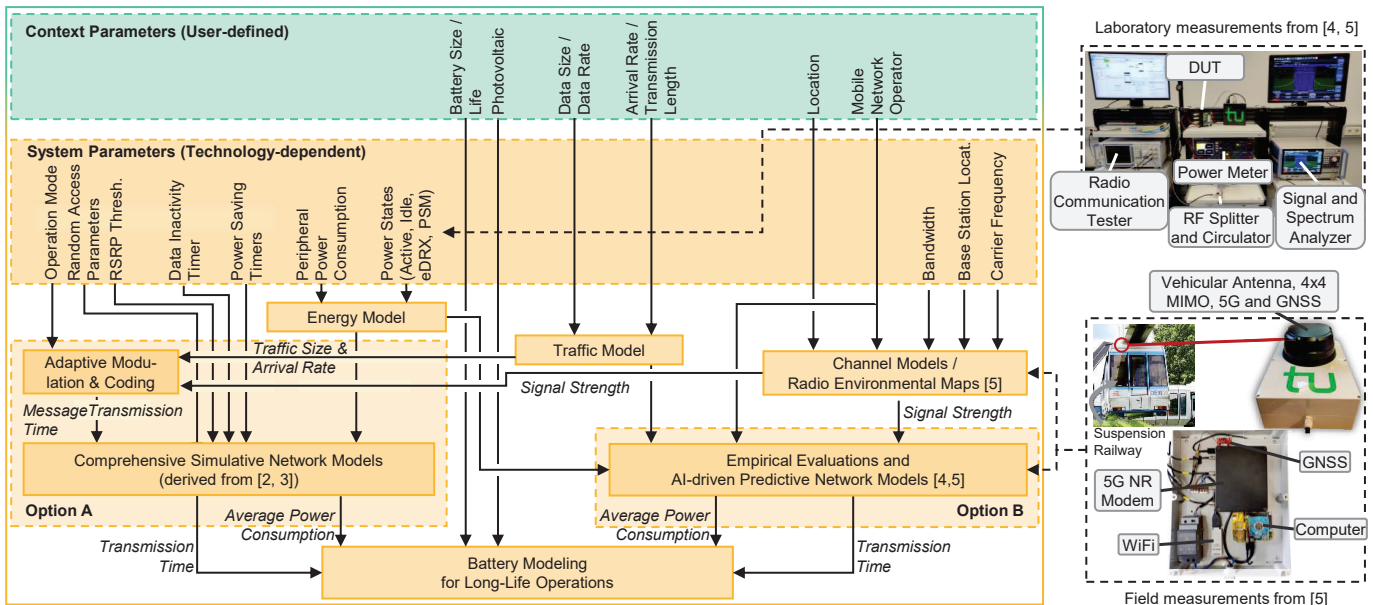


Fig. 2: The Energy Planner provides intuitive access to complex context- and system-parametrization-aware models for battery life and capacity estimations including simulative and AI-driven predictive network models based on empirical measurements.

The *Eco Score* complements and extends the scope of the EU Energy Label for Smartphones [6] by moving beyond static application sequences and incorporating real-world cellular communication behaviour. It provides a granular, application-specific assessment that the EU Energy Label cannot capture.

From a sustainability perspective, battery production, replacement, and disposal significantly contribute to the environmental footprint of large-scale IoT deployments. Static battery designs neglect spatial and contextual heterogeneity and lead to unused battery capacity and increased maintenance effort. The *Energy Planner* enables context-aware battery dimensioning, allowing battery capacity to be tailored to the actual energy demand of individual devices. As demonstrated in Fig. 3, this approach reduces battery waste and maintenance events through technology-dependent battery life estimation towards application-specific performance targets.

Beyond current 5G deployments, the planner is explicitly designed as a research platform for future 6G networks. Its modular architecture allows the integration of new device categories, protocol features, predictive models, and energy-centric key performance indicators, requiring complementing simulation or empirical approaches for modeling and validating these extensions. In general, these optimization strategies anticipate

central 6G design principles, including native sustainability, energy efficiency as a primary metric, and intelligent, context-aware network-assisted optimization.

#### IV. CONCLUSION

This demo presents a context-aware cellular *Energy Planner* and *Eco Score* based on extensive simulation and AI-driven predictive network models that support sustainability-driven and energy-efficient IoT design. By combining realistic deployment context, cross-technology comparison, and optimization guidance, the demonstrated interface enables informed design decisions for current 5G systems and provides a strong foundation for research towards sustainable 6G networks.

#### ACKNOWLEDGMENT

This work was supported by the 6GEM+ and GEM-X projects, funded by the Federal Ministry of Research, Technology and Space under the Funding IDs 16KIS2412 resp. 16KISS005, and the ReCoDE project under Funding ID 03EI6093B by the Federal Ministry for Economic Affairs and Energy.

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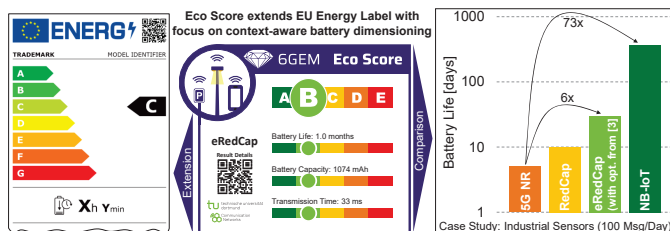


Fig. 3: Example use case enabled by demonstrated cellular Energy Planner and labeled by proposed Eco Score.