Finland—The Complete Living Lab for the Energy Transition: Accelerating Energy Transition Through Integrated Research, Industry Collaboration, and System-Level Innovation

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Accelerating Energy Transition Through Integrated Research, Industry Collaboration, and System-Level Innovation

By Katja Sirviö & Tuula Mäkinen

The energy transition is defined not only by technologies but by the ability to integrate them into secure, well-functioning energy systems. Real progress requires system-level learning: the capacity to test, validate and deploy solutions under real conditions.

Finland stands out as a national-scale ecosystem where research, industry and regulation co-evolve across the energy value chain. This model emphasizes grid-edge intelligence, power electronics, and co-development pathways accelerating standardization, scale-up, and deployment.

Living Labs as Engines of Systemic Learning

Living labs enable system-level learning by validating flexibility, sector coupling and digital control within real infrastructure, markets and operations. In practice, this involves:

- ✓ system-level modelling and simulation
- ✓ hardware-in-the-loop and digital twins
- ✓ certification
- ✓ multi-scale pilots in industrial, urban and utility environments
- ✓ direct feedback from markets and users

Early exposure to real constraints accelerates deployment and reduces risk.

Finland's Integrated Energy Innovation Ecosystem

Finland's strength lies in ecosystems enabling rapid learning and deployment. A highly reliable, digitalized power system, transparent markets and research infrastructures create a data-rich innovation environment. Advanced metering, automated grid operations and national data platforms support continuous experimentation, while open ancillary service markets and clear regulatory frameworks provide predictable pathways from research to commercialisation.

Public funding, industrial co-investment and European programs form a financial backbone enabling high-risk experimentation prior to scale-up. This alignment between infrastructure, markets and co-

funding explains why Finnish pilots often evolve into operational solutions rather than remaining isolated demonstrations.

A development pipeline – from modelling to HIL testing, pilots and system integration – supports innovation. Research infrastructures and shared test facilities enable co-development, scale-up and export-ready demonstrations. Ecosystems extend this pipeline into operational contexts: the *EnergyVaasa* provides an extensive industrial platform while hydrogen-focused *H2 cluster Finland* concentrate sector-coupling expertise.

These structures create feedback architectures where operational experience informs design, regulation, and system planning. Innovation becomes an iterative learning loop rather than a linear transfer from research to deployment.

Examples from the Finnish Ecosystem

In Finland, global technology companies, start-ups, infrastructure operators, energy end-users, cities, and research institutes co-develop solutions within the same operational system – building capabilities for global deployment.

> ***Transmission system operator provides the backbone for systemic coordination by integrating market development, system operation, and service innovation.*** *Fingrid develops a stable and dynamic energy system in close cooperation with market actors, service providers and authorities. Market-based processes, broad stakeholder participation in ancillary service markets and highly digitalized, datahub-driven operations create a globally distinctive platform for developing energy solutions with international relevance.*
> *– Asta Sihvonen-Punkka, CEO, Fingrid*

Global technology providers use Finland as a development platform for exportable energy solutions, spanning power systems, fuels, electrification and smart automation. Technologies validated locally – from multi-fuel power plants and energy storage to grid protection and electrification platforms – are deployed internationally.

> ***Innovation opportunities extend from land to sea.*** *Wärtsilä benefits from a unique test environment in the Vaasa–Umeå ferry route, where one of the vessel's dual-fuel engines is dedicated to R&D. Equipped with advanced environmental technologies, the ferry functions as a living lab for next-generation marine and power plant solutions.*
> *– Juha Kytölä, CTO, Wärtsilä*

> ***Finland's industrial culture encourages lead from the front, co-development and early adoption.*** *Innovations such as WindSTAR™ transformers are developed for global off-shore wind power markets, but origins of the technology started emerging from the domestic development for the Helsinki Metro together with ABB´s frequency converter technology and further driven by the local forest industry's demand for world-class performance, exemplifying pioneering spirit*

> *and co-innovation. Similarly, MicroSCADA emerged through forward-looking utility customers, willing to be frontrunners and co-developers of advanced digital technology, allowing also testing in real-time environment demonstrating strong culture of trust.*
> *– Matti Vaattovaara, Managing Director, Hitachi Energy*

> ***Finland's energy system provides an ideal environment for piloting advanced grid-edge technologies.*** *Finland's highly decarbonised energy system, integrated district heating and growing electrification provide a strong foundation for piloting next-generation inverter, DC power conversion and intelligent drive technologies. The electrification of heat — including industrial process heat — remains an emerging domain. The culture of open collaboration and data sharing, combined with high public R&D investment and funding programmes, makes Finland a distinctive living lab for industry-driven innovation.*
> *– Janne Kuivalainen, CTO, Danfoss Drives*

Local utilities and cities extend Finland's industrial platform into user-scale demonstration environments, where integrated electricity, heating, and digital services are developed under everyday conditions. This connects system-level innovation directly to practical deployment and end-use performance.

> ***Local utilities play a key role in enabling system-level development.*** *Vaasan Sähkö Group is a central partner within the EnergySampo innovation ecosystem. By providing its energy network as a real operating-environment test platform for RDI projects, the company enables large-scale co-development that would be difficult to realize elsewhere.*
> *– Stefan Damlin, Managing Director, Vaasan Sähkö*

Research organisations and infrastructures form the backbone for continuous development from concept validation to system integration. VTT Technical Research Centre of Finland accelerates scale-up of new technologies and solutions into industrial use through its piloting and research infrastructures, like VTT FutureGrid, a smart grid research platform.

Universities underpin the energy transition by generating system-level knowledge and expertise. At the University of Vaasa, the Energy Transition Valley concept integrates research, infrastructure and industry collaboration into a shared development platform, ensuring technical depth, system-level understanding and multidisciplinary relevance.

A Platform for Global Solutions

Finland's energy system operates under demanding conditions shaped by strict reliability requirements, deep digitalization, resilience-oriented design, and coordinated multi-vector energy management. Harsh climate and long transmission distances stress-test infrastructure performance and operational security. Its geopolitical position imposes additional resilience requirements. Solutions validated locally face stringent operating conditions.

As the energy transition accelerates, demanding speed, integration and resilience, system-level learning is becoming a strategic capability. Finland demonstrates how coordinated digital infrastructure, transparent markets and strong collaboration embed continuous, real-world experimentation into everyday operations.

Finland's example highlights a broader insight: progress depends as much on collective capability as on technology itself. Systems integrating knowledge creation, experimentation and coordinated deployment will drive global energy development.

Biographies

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Katja Sirviö (DSc Tech) is a Senior Researcher and R&D Manager for Research Infrastructures at the University of Vaasa, Finland. Her work focuses on smart grids, active distribution networks, real-time co-simulation, and hardware-in-the-loop validation of future power systems. She has over 25 years of experience in electrical engineering across industry and academia, including leadership roles in R&D and research infrastructure development at ABB and VTT Technical Research Centre of Finland. She serves on the Board of Vaasan Sähköverkko and contributes to European energy system development through ETIP-SNET Working Group 4 and CIGRE Working Group C1.052. She also serves as a reviewer for IEEE and IET journals.

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Tuula Mäkinen (MSc Tech) is a senior energy-sector leader with extensive experience in green electrification, smart energy systems, and sustainable energy technologies. She currently leads VTT's Green Electrification framework, advancing strategic partnerships and research-driven innovation toward low-carbon and resilient energy systems. Previously, she held several leadership positions at VTT, including Vice President roles in Smart Energy and system integration, leading large-scale RDI portfolios and international collaboration. She has contributed internationally through roles in the EERA European Energy Research Alliance and the IEA Technology Collaboration Programmes and has served on national advisory boards supporting energy transition and innovation policy.