HYPERGRYD

WP6 – Communication and Dissemination

Task 6.2 Exploitation oriented Dissemination

D6.8 HYPERGRYD Wiki public final version and White Book

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Executive Summary

The goal of the HYPERGRYD project is the development of a set of replicable and scalable cost effective technical solutions to allow the integration of renewable energy sources (RES) with different dispatchability and intrinsic variability in thermal grids, as well as ensure their link with the electrical grids, including the development of innovative hardware components and ICT tools for the more effective handling of the increased complexity of the systems from building to local energy community (LEC) levels and beyond, and accelerate the sustainable transformation, planning and modernization of District Heating and Cooling (DHC) towards 4th and 5th generation.

The HYPERGRYD project aims to reach three over-arching general objectives:

- To prove smart energy networks as the future of efficient energy management in DHC in synergy with the electrical grids in LEC/smart cities of the future,
- To define the roadmap to design and plan future DHC as well as the modernization of the existing ones in different climates and RES penetration levels toward 4^{th}-5^{th} generation,
- To demonstrate HYPERGRYD RES-based enabling technologies, smart energy grid solutions empowered by new ICT tools and services as the key for this evolution.

During the project, the HYPERGRYD solutions have been implemented across four live-In-labs (LILs) in three representative climates, with special consideration of their cost effectiveness and potential replicability to finally achieve these three main objectives.

This document (D6.8) contains all the information collected and developed to create the HYPERGRYD white book. It also includes a glossary (wiki-style) with all the updated terms.

On behalf of authors,

The COMET team

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1 Introduction

The European Union's Green Deal has set an ambitious roadmap to achieve climate neutrality by 2050, positioning the decarbonization of all sectors—particularly energy—as a cornerstone of this vision. Within this context, the role of district heating and cooling (DHC) networks is becoming increasingly significant, as these systems serve as essential infrastructure for energy distribution, especially in densely populated urban areas across Europe. DHC networks can play a pivotal role in reducing greenhouse gas emissions by integrating renewable energy sources (RES), such as solar, wind, and biomass. However, the inherent variability and intermittency of these renewable sources present unique challenges, particularly for energy systems that traditionally rely on steady, centralized sources of power. The need to make DHC networks more resilient, flexible, and adaptable is crucial to achieving the EU's sustainability and energy efficiency goals.

The **HYPERGRYD project** was conceived as a direct response to these challenges, bringing together a range of technical innovations and digital tools to create a next-generation hybrid energy grid. By developing smart, hybrid DHC systems that integrate thermal and electrical networks, HYPERGRYD aims to establish a highly flexible energy system capable of efficiently managing and distributing renewable energy. Through a blend of innovative hardware solutions and advanced ICT tools, the project will make it possible to incorporate diverse energy sources into DHC networks, thereby enabling higher levels of renewable energy use. HYPERGRYD's comprehensive approach will address both technical and operational challenges, paving the way for new DHC systems that meet the demands of a low-carbon, digital economy.

1.1 Challenges in Renewable Integration and Hybrid Grid Development

One of the most pressing challenges in the energy sector is integrating variable RES while maintaining reliable and cost-effective energy distribution. The fluctuating nature of RES, such as solar and wind, requires sophisticated energy management techniques to avoid mismatches between energy supply and demand. Additionally, most existing DHC systems are not designed to accommodate renewable sources and lack the flexibility to operate at the lower temperatures needed for efficient renewable integration. Addressing these challenges demands a paradigm shift towards hybrid grids that seamlessly combine thermal and electrical energy systems, enabling distributed renewable sources to play a central role.

In this landscape, the HYPERGRYD project aims to establish a resilient and adaptive DHC framework by employing modular and reversible technologies that allow systems to dynamically adjust to changing energy demands and weather conditions. Key innovations such as modular heat pumps, sorption storage systems, and small-scale combined heat and power (CHP) units are designed to be easily deployed within existing infrastructures, providing high levels of adaptability. These technologies are complemented by ICT-driven tools that enhance real-time decision-making and control, empowering DHC operators to optimize energy use and reduce carbon emissions effectively.

1.2 Digital Transformation of Energy Systems

At the core of HYPERGRYD's approach is a suite of digital tools that bring advanced data analysis, machine learning, and predictive capabilities into energy management. The project introduces an interoperable digital twin platform that combines Building Information Modelling (BIM) and

Geographic Information Systems (GIS), creating a comprehensive digital representation of DHC systems. This digital twin allows for the real-time visualization and optimization of energy flows, asset management, and maintenance operations, making it possible to address system inefficiencies proactively.

Moreover, HYPERGRYD employs machine learning algorithms for predictive maintenance and demand forecasting, enabling DHC systems to respond dynamically to real-world conditions and improve reliability. The integration of edge computing allows local data processing and analysis, reducing latency and enhancing the responsiveness of energy systems. This digital infrastructure supports a robust framework for energy trading, demand response, and load balancing, creating a pathway for integrating local energy communities (LECs) into the hybrid grid. By enabling peer-to-peer energy exchange and market-aware demand response, HYPERGRYD facilitates active participation from consumers and prosumers, advancing the democratization of energy.

1.3 Project Scope and Objectives

HYPERGRYD's primary objective is to establish a scalable and replicable model for smart, hybrid energy grids. This model combines hardware and digital innovations to achieve a high level of efficiency, flexibility, and resilience in DHC systems. Specifically, the project will develop and test solutions that enable the integration of diverse RES, improve energy storage capabilities, and facilitate more efficient use of energy resources. By reducing dependency on fossil fuels and increasing the share of renewables, HYPERGRYD will contribute significantly to the EU's decarbonization targets.

To validate its solutions, HYPERGRYD will conduct demonstrations across four live-in lab (LiL) sites located in different European climates, including heating-dominated, cooling-dominated, and mixed regions. These demonstrators will test the project's modular technologies and digital tools in real-world settings, allowing for a thorough evaluation of scalability, cost-effectiveness, and environmental impact. By collaborating closely with stakeholders across the energy sector—from utilities and energy service companies to local governments and consumer groups—the project aims to ensure the relevance and applicability of its solutions, fostering widespread adoption post-project.

1.4 Comprehensive Impact Approach

The anticipated impact of HYPERGRYD extends across social, economic, and environmental dimensions. By promoting renewable integration, the project supports the EU's mission to reduce greenhouse gas emissions and transition to a circular, resource-efficient economy. Economically, HYPERGRYD will open up new business opportunities within local energy markets, enabling innovative business models that empower local energy communities and support decentralized energy generation. On the social front, the project's focus on user-friendly digital interfaces and energy trading platforms ensures that consumers and prosumers can actively participate in grid management, creating a more inclusive energy ecosystem.

Furthermore, HYPERGRYD's platform will serve as a foundation for future development in DHC systems, providing a reference model for energy stakeholders and policymakers across Europe. The project's success could redefine the role of DHC in the energy transition, offering a blueprint for other regions and countries seeking to implement hybrid grids.

1.5 Structure of the Document

This white paper provides a detailed exploration of the HYPERGRYD project, including its objectives, innovations, and the societal benefits it seeks to deliver. Following this introduction, the document covers the project's objectives and vision in Section 2, followed by an in-depth look at the key challenges addressed by HYPERGRYD in Section 3. Sections 4 and 5 outline the innovative technologies and implementation strategies that form the backbone of the project. Section 6 delves into the HYPERGRYD platform and services, detailing the digital solutions and user interfaces that enable advanced control and data integration. The business potential and stakeholder engagement strategies are discussed in Sections 7. Section 8 is dedicated to stakeholder engagement and dissemination while Section 9 provides an overview of Expected Impact and Long-Term Benefits. Section 10 reviews the Contributions and Future Directions. Section 11 presents the conclusions. Finally, Section 12 presents the updated glossary (wiki-style), which is also available on the project website.

1.6 Abbreviations

AEE: Association of Energy Engineers

API: Application programming interface

AIT: Austrian Institute of Technology GmbH

BEP: BIM Execution Plan (BEP)

BAS: Building Automation System

HVAC: Building Heating, Ventilating and Air Conditioning

BIM: Building Information Modelling

CAPEX: Capital expenditures

CEC: Citizen Energy Community

CEP: Clean Energy Package

CNR: Consiglio Nazionale delle Ricerche

COP: Coefficient of Performance

CHP: Combined Heat and Power

DTE: Data terminal equipment

DG: Decentralized Generations

DRM: Demand Response Management

DSC: Differential scanning calorimetry

DR: Disaster recovery

DERs: Distributed Energy Resources

DES: Distributed Energy Site

DMG: Distributed Multi-Generation

DSOs: Distribution system operators

DHC: District Heating and Cooling

DHN: District Heating Network

DHCN: District Heating and Cooling Network

DMP: Data Management Plan

DHW: Domestic hot water

DHCP: Dynamic Host Configuration Protocol

EV: Electric vehicles

EaaS: Energy-as-a-Service

EE: Energy efficiency

EER: Energy Efficiency Ratio

E-LCA: Environmental Life Cycle Assessment

ESC: Energy Storage Capacity

ESD: Energy Storage Density

ER: Exploitable Results

EVO: Efficiency Valuation Organization

GA: General Assembly

GIS: Geographic Information System

GWP: Global warming potential

GUI: Graphical user Interface

GHG: Greenhouse gas

HIL: Hardware-in-the-loop

HP: Heat Pump

HRE: Heat Roadmap Europe

ICT: information and communication technology

IDM: Information Delivery Manuals

IDDS: Integrated Design & Delivery Solutions

ICE: Internal Combustion Engine

IoT: Internet of Things

IPR: Intellectual Property Rights

KET: Key Enabling Technology

KER: Key Exploitable Results

KPI: Key Performance Indicator

KERS: Kinetic energy recovery system

LoD: Level of Detail

LoI: Level of Information

LCOE: Levelized Cost of Energy

LCC: Life Cycle Cost analysis

LCI: Life Cycle Inventory

LFP: Lithium Ferro phosphate

LiL: Live-in Lab

LEC: Local Energy Community

LEMs: Local energy markets

LOLE: Loss of Load Expectation

LOPL: Loss of Load Probability

LHV: Lower Heating Value

MLT: Machine learning techniques

M&V: Measurement & Verification

MVD: Model View Definition

MES: Multi-Energy System

OCHS: Ochsner Wärmepumen GMB

OA: Open Access

ORDP: Open Research Data Pilot

O: Operational

OPEX: Operational expenditure

O&M: Operations & Maintenance

ORC: Organic Rankine Cycle

P2P: Peer-to-Peer

PCM: Phase Change Material

PV: Photovoltaic

PaaS: Platform as a Service

P2H: Power to heat

PEC: Primary Energy Consumption

PEF: Primary Energy Factor

PLC: Programmable Logic Controller

RANO: RANOTOR Utvecklings AB

REC: Renewable Energy Community

RES: Renewable Energy Sources

ROI: Return on investment

SAInt: Scenario Analysis Interface for Energy Systems

SS: Self-sufficiency

SOA: Service Oriented Architecture

SED: Smart Energy Districts

SHG: Smart Hybrid Grids

S-LCA: Social life cycle assessment

ST: Solar thermal

SOR: Sorption Storage

STES: Sorption thermal energy storage

SoC: State of Charge

SB: Steam Buffer

SCADA: Supervisory Control and Data Acquisition

TRL: Technology Readiness Levels

TES: Thermal Energy Storage

TCMS: Thermochemical Storage Systems

TGA: Thermogravimetric analysis

UoM: Unit of Measure

UC: Use case

VRFB: Vanadium Redox Flow Battery

VREs: Variable energy resources

ZEBs: Zero-Emission Buildings

2 Project Objectives and Vision

The HYPERGRYD project aims to pioneer a new era of hybrid energy networks by creating a replicable and scalable model for integrating renewable energy sources (RES) into district heating and cooling (DHC) systems. By achieving seamless interoperability between thermal and electrical networks, HYPERGRYD addresses the core technical, environmental, and societal challenges in building resilient, smart energy systems. The project sets forth a comprehensive vision for a future in which DHC networks are no longer limited by their infrastructure but instead become dynamic, adaptive, and capable of real-time optimization based on changing energy demands and renewable availability.

2.1 General Objectives

The overarching goal of HYPERGRYD is to develop innovative, cost-effective technical solutions that enable the seamless integration of RES within hybrid energy grids, including both DHC and electrical systems. To accomplish this, HYPERGRYD focuses on three main objectives:

- **Objective 1: Develop Renewable-Based Enabling Technologies**. HYPERGRYD seeks to introduce modular and renewable-driven technologies, such as reversible heat pumps, sorption storage systems, and small-scale combined heat and power (CHP) units. These solutions are designed to maximize energy efficiency, increase renewable energy penetration, and improve the adaptability of DHC systems to diverse energy demands. These technologies are not only essential for reducing CO_2 emissions but also for meeting peak demand more efficiently, especially in urban settings where energy needs are complex and variable.
- **Objective 2: Demonstrate the Smart Hybrid Energy Network Concept.** HYPERGRYD will showcase its solutions within four live-in lab (LiL) demonstration sites that represent different climate conditions and DHC typologies across Europe. These demonstrators will validate the project's technical advancements, particularly in RES integration, energy storage, and grid flexibility, under real-world conditions. The demonstration activities will cover scenarios from heating-dominated to cooling-dominated climates, enabling the project to gather a wide array of data to support future scalability and replicability.
- **Objective 3: Establish HYPERGRYD as a Reference Framework for DHC Systems.** HYPERGRYD aims to set new standards for the design, operation, and planning of next-generation DHC systems, fostering a shift from conventional energy networks to smart hybrid grids. By establishing best practices, interoperability protocols, and benchmarks for hybrid DHC systems, the project seeks to become a reference for energy stakeholders and policymakers across Europe, ultimately accelerating the sustainable transformation of DHC systems towards the 4^{th} and 5^{th} generations.

2.2 Specific Technical Objectives

To achieve its broader goals, HYPERGRYD has identified several specific technical objectives (STOs), each of which addresses a critical component of hybrid energy systems:

- **STO 1: Develop Renewable-Based Enabling Technologies for DHC**

  - **Modular Heat Pumps** with phase-change material storage for increased energy efficiency and reduced storage space requirements.
  - **Sorption Storage Systems** for high-density energy storage capable of leveraging low-temperature heat sources, enabling more flexible and efficient energy usage.
  - **Small-Scale CHP Units** with steam engines, designed for cost-effective, flexible applications within decentralized DHC systems.
- **STO 2: Advanced Planning and Optimization Tools for DHC**
  - **Interoperable Digital Twin** to integrate Building Information Modelling (BIM) with Geographic Information Systems (GIS), creating a cohesive planning and monitoring tool for DHC systems.
  - **Exergoeconomic Models** for cost-benefit and environmental analysis, enabling data-driven decision-making for more sustainable operations.
  - **Coupled Simulation Models** for integrated management of multi-energy carriers, allowing simultaneous optimization of electricity, gas, and heat networks.
- **STO 3: Real-Time Management and Control of Hybrid Energy Networks**
  - **Demand Response and Predictive Control Tools** to optimize energy distribution in real-time based on demand and supply fluctuations.
  - **Smart Energy Trading Platforms** for local energy communities (LECs), enabling peer-to-peer energy exchange and supporting the creation of local marketplaces.
  - **Edge Computing and Machine Learning Models** to provide predictive maintenance and load forecasting, reducing operational costs and improving grid reliability.
- **STO 4: Validation of Technical Solutions in Diverse European Climates**
  - Conduct testing and validation across LiLs to verify system performance under varying climate conditions and DHC configurations.
  - Optimize the developed technologies to ensure scalability, cost-effectiveness, and environmental impact across the project’s demonstration cases.
- **STO 5: Engage DHC and Grid Users for Broader Adoption**
  - Actively involve stakeholders, including utility companies, DHC operators, and consumers, to increase user engagement and acceptance.

Develop visualization and user-friendly features in the HYPERGRYD platform to encourage prosumer participation and foster transparency in energy management.

2.3 Vision for Smart Hybrid Energy Networks

HYPERGRYD envisions a future where DHC networks serve as flexible, resilient infrastructures that not only support but drive the energy transition. By combining RES-driven technologies with advanced digital solutions, HYPERGRYD aims to create energy systems that are both environmentally and economically sustainable. The project's long-term vision includes:

- **Reducing the Energy Performance Gap**. HYPERGRYD aims to minimize the discrepancy between as-designed and as-built energy performance in buildings and DHC systems. By using real-time data from digital twins and machine learning models, operators can ensure that DHC networks meet design specifications and maintain high efficiency over time.
- **Enabling the Circular Economy in Energy Systems**. In line with circular economy principles, HYPERGRYD supports energy reuse, enhanced resource management, and sustainable end-of-life strategies for energy infrastructure. Through modular design and integrated lifecycle assessment, the project will make it easier to retrofit, recycle, and repurpose DHC system components, extending the lifespan and reducing waste.
- **Empowering Local Energy Communities (LECs)**. The project aims to decentralize energy management, enabling local communities to become active participants in the energy grid. HYPERGRYD's digital tools facilitate energy trading, demand response, and grid flexibility, giving communities the ability to manage their own energy resources more autonomously. This shift promotes local renewable integration, reduces grid strain, and empowers consumers to take an active role in energy sustainability.
- **Scalability and Replicability Across Europe**. By validating solutions in different climate zones and urban contexts, HYPERGRYD ensures that its technologies and tools are adaptable and scalable. The project's success will serve as a template for similar initiatives across Europe, offering a replicable model that other regions can follow to meet their own decarbonization and energy efficiency goals.
- **Creating a Resilient, Adaptive Energy System**. HYPERGRYD's vision includes a DHC network that can dynamically respond to changes in demand, weather, and energy availability, thereby providing a stable energy supply despite external fluctuations. By integrating predictive maintenance, anomaly detection, and real-time control systems, HYPERGRYD will enable DHC systems that are not only energy-efficient but also resilient to future challenges.

2.4 Alignment with EU Climate and Energy Policies

HYPERGRYD is fully aligned with the EU's strategic priorities under the European Green Deal, as well as specific climate and energy initiatives aimed at decarbonizing the energy sector. The project addresses key goals within the EU's "Clean Energy for All Europeans" package, focusing on energy system integration, energy efficiency, and increased renewable energy share in the DHC sector. Additionally, HYPERGRYD supports the EU's Renovation Wave initiative by creating solutions that enable deep, circular renovation of existing infrastructure, contributing to a greener, more energy-efficient built environment.

The project's outcomes are expected to provide essential contributions to EU climate targets, particularly by reducing CO_2 emissions, enhancing energy security, and fostering social and economic growth through the creation of local energy marketplaces. Through HYPERGRYD's innovations, Europe can advance toward a net-zero energy system, driving a more sustainable future for both present and future generations.

3 Key Challenges Addressed

The HYPERGRYD project is designed to tackle some of the most pressing challenges faced by the European energy sector in its transition towards net-zero emissions. These challenges include the integration of renewable energy sources (RES) into existing district heating and cooling (DHC) networks, the need for flexibility and resilience in energy grids, and the importance of fostering consumer engagement and local energy trading. By addressing these challenges, HYPERGRYD aims to transform traditional DHC systems into adaptable, smart hybrid grids that optimize both thermal and electrical energy resources.

3.1 Technical Challenges in Integrating Renewable Energy

One of the primary obstacles to decarbonizing DHC systems is the effective integration of renewable energy sources. RES such as solar, wind, and biomass have inherently variable outputs that fluctuate with weather and time of day, creating challenges for maintaining consistent energy supply. Traditional DHC systems are not optimized to handle this variability, as they often rely on high-temperature heat sources and centralized generation that limit flexibility and efficiency.

HYPERGRYD's Approach. To address these challenges, HYPERGRYD is developing modular, RES-driven technologies that adapt to variable energy inputs. Key innovations include reversible heat pumps with short-term energy storage, sorption-based thermal storage, and small-scale combined heat and power (CHP) units. These solutions provide decentralized, on-demand energy generation that can adapt to real-time variations in energy availability. By operating at lower temperatures and providing modular flexibility, these technologies make DHC systems more compatible with the nature of renewable energy, enhancing grid stability and reducing dependency on fossil fuels.

3.2 Enhancing Flexibility and Resilience in DHC Networks

As DHC systems integrate more renewables, they must also become more flexible and resilient to withstand fluctuations in both energy supply and demand. Most existing DHC networks lack the tools to dynamically adjust to changes in load, temperature, and renewable availability. Without such adaptability, energy grids are at risk of inefficiency and service interruptions, particularly during peak demand or extreme weather events.

HYPERGRYD's Approach: The project's integrated digital platform, featuring a digital twin of DHC assets, enables real-time management and control of energy flows within hybrid grids. Using advanced predictive models and edge computing, the platform allows operators to monitor, simulate, and adjust grid performance to respond to changes in supply and demand. Additionally, HYPERGRYD introduces demand response and peak shaving tools that adjust energy distribution based on demand forecasts and resource availability. By enabling proactive, data-driven adjustments, HYPERGRYD's solutions enhance the resilience of DHC systems, ensuring consistent and reliable service under variable conditions.

3.3 Overcoming the Energy Performance Gap in DHC Systems

One of the major issues in energy management is the performance gap between as-designed and as-built systems, particularly in complex networks like DHC. Many DHC systems operate at higher-than expected energy consumption levels due to inefficiencies, outdated equipment, and suboptimal operation strategies. This gap not only undermines energy efficiency but also impacts the environmental performance and cost-effectiveness of DHC networks.

HYPERGRYD's Approach. HYPERGRYD leverages digital twin technology and machine learning algorithms to bridge the energy performance gap by providing real-time insights into system operation. Through continuous monitoring, predictive maintenance, and anomaly detection, HYPERGRYD's platform can identify and address inefficiencies proactively, ensuring that DHC systems operate as close to their design specifications as possible. By using advanced optimization tools, the project reduces energy waste, enhances system performance, and improves the overall sustainability of DHC networks.

3.4 Integration of Multi-Energy Carrier Systems

The traditional separation of thermal and electrical grids limits the potential for efficient resource use and energy exchange. Integrating these systems into a single, multi-energy carrier network provides greater flexibility but introduces complexity in terms of operation, control, and optimization. Coordinating multiple energy vectors (electricity, heat, cooling) in real-time requires advanced tools for modelling, simulation, and control, especially as the system scales.

HYPERGRYD's Approach. To address this challenge, HYPERGRYD is developing a coupled simulation model that integrates electricity, gas, and heat distribution within a unified management framework. This tool enables DHC operators to optimize multi-carrier energy flows, minimizing costs and emissions while enhancing grid flexibility. By using the same platform for both thermal and electrical systems, HYPERGRYD allows for coordinated energy management that leverages the strengths of each carrier type, such as using excess electricity to generate heat or cooling when needed. This approach maximizes renewable utilization and provides a more resilient, interconnected energy system.

3.5 Fostering Consumer Engagement and Local Energy Trading

A key component of the energy transition is the shift from a centralized, utility-driven system to a decentralized model where consumers actively participate as "prosumers" (producers and consumers of energy). Engaging local communities in energy management enhances grid resilience and supports the creation of local energy markets, which can help balance demand and supply at the community level. However, current DHC systems lack mechanisms for local energy trading and consumer engagement, limiting the ability of individuals and communities to contribute to and benefit from the energy transition.

HYPERGRYD's Approach. HYPERGRYD introduces a smart energy trading platform that facilitates peer-to-peer (P2P) energy exchange within local energy communities (LECs). By enabling consumers to trade excess energy, HYPERGRYD empowers individuals to actively participate in grid management and benefit financially from renewable production. The project's platform also includes user-friendly interfaces for visualization and control, making it easier for consumers to engage with and manage their energy consumption. This decentralized approach reduces grid strain, enhances community resilience, and fosters a more inclusive, democratized energy system.

3.6 Addressing Regulatory and Standardization Barriers

The lack of uniform standards and regulatory frameworks for hybrid energy grids poses a significant barrier to scaling renewable integration and DHC innovation. Different European countries have varying regulations, particularly regarding energy trading, grid interconnection, and data privacy. These inconsistencies create challenges in implementing seamless, interoperable DHC systems across borders, impeding the spread of best practices and technological advancements.

HYPERGRYD's Approach. HYPERGRYD is working closely with regulatory bodies and industry stakeholders to ensure that its solutions align with current standards and anticipate future regulatory needs. By developing an open, interoperable platform with standardized data exchange protocols, HYPERGRYD aims to create a replicable model that can be easily adapted to different regulatory environments. Additionally, the project provides guidelines and best practices for hybrid grid operation, offering a reference framework that supports policymakers and DHC operators in navigating regulatory requirements.

3.7 Scalability and Cost-Effectiveness in Technology Deployment

A major challenge for the deployment of advanced DHC solutions is the high initial cost and scalability of new technologies, particularly in existing infrastructure where retrofitting can be complex and costly. Achieving a scalable, economically viable solution is essential to encourage widespread adoption of HYPERGRYD's technologies across diverse European contexts.

HYPERGRYD's Approach. HYPERGRYD's modular, adaptable technologies are designed for scalability and cost-effectiveness. By employing a modular approach, the project reduces installation and operational costs, making it easier to deploy solutions incrementally and scale as needed. HYPERGRYD's demonstration in diverse live-in lab settings across Europe ensures that its technologies are adaptable to various climates and energy demands. Additionally, the project's digital twin and optimization tools enable more precise planning and investment, ensuring that DHC operators can achieve a faster return on investment through improved efficiency and lower operating costs.

3.8 Summary of Challenges and HYPERGRYD's Strategic Solutions

HYPERGRYD's approach to addressing these challenges is comprehensive, combining innovative technologies with advanced digital tools to optimize and transform DHC systems. By focusing on technical, operational, and regulatory solutions, the project is paving the way for a new generation of hybrid energy grids that are sustainable, resilient, and adaptable to future energy demands. Through its targeted strategies, HYPERGRYD provides a scalable, impactful model for the integration of renewables, engagement of local communities, and efficient management of multi-energy carrier systems across Europe.

4 Innovative Technologies and Tools Developed

HYPERGRYD combines cutting-edge technologies and digital tools to create a smart, adaptable, and energy-efficient district heating and cooling (DHC) network capable of seamlessly integrating renewable energy sources (RES). By developing new hardware and software solutions, the project aims to transform traditional DHC systems into highly responsive, hybrid energy grids. This section details the core technologies and tools that form the foundation of the HYPERGRYD approach.

4.1 Renewable-Based Enabling Technologies for DHC

To make DHC systems more flexible, sustainable, and efficient, HYPERGRYD is developing several key enabling technologies that allow DHC networks to incorporate renewable energy more effectively.

- **Modular Reversible Heat Pumps with Phase-Change Material (PCM) Storage**. These innovative heat pumps are designed to work with low-exergy RES, such as solar thermal or waste heat, to provide efficient heating and cooling within DHC networks. The inclusion of PCM-based thermal storage improves energy density and responsiveness, allowing the system to store and release energy as needed. This modular design enables operators to adjust the system to meet real-time demand, reducing energy waste and increasing grid efficiency. The technology also reduces storage space requirements by up to 20%, which is particularly beneficial in urban environments where space is limited.

- **Sorption Storage Systems for High-Efficiency Heat and Cooling**. HYPERGRYD's sorption storage system leverages thermochemical technology to provide high-density thermal storage using low-temperature heat sources. This system can be powered by various RES, including solar and geothermal, and offers reversible operation for both heating and cooling. The modular sorption units are designed to integrate easily within existing DHC networks, enhancing energy flexibility and dispatchability. This technology enables efficient utilization of low-grade heat sources, supporting a more sustainable and energy-efficient DHC operation.

- **Small-Scale Combined Heat and Power (CHP) Units with Steam Engine and Buffer Storage.** Designed for decentralized applications, the CHP units developed under HYPERGRYD include a compact steam engine and buffer storage. These units provide both thermal and electrical energy, offering a flexible solution for meeting localized energy demands. The steam engine can operate in a reversible mode, allowing it to charge buffer storage with both electricity and heat, which provides an effective solution for peak shaving and valley filling. This technology is particularly advantageous for DHC systems that need to manage fluctuating loads and maintain a consistent energy supply.

4.2 Advanced ICT Tools for Digital Integration and Optimization

HYPERGRYD integrates several advanced digital tools to create a cohesive digital platform that supports real-time energy management, optimization, and monitoring of hybrid DHC networks. This platform serves as the backbone for data collection, analysis, and control, ensuring that all components work together seamlessly.

- **Digital Twin for DHC Asset Management and Monitoring**. At the core of the HYPERGRYD platform is a digital twin that combines Building Information Modelling (BIM) and Geographic

Information Systems (GIS) to create a comprehensive virtual representation of DHC assets. This digital twin enables real-time monitoring and visualization of energy flows, infrastructure status, and operational data, supporting operators in making data-driven decisions. The integration of BIM and GIS allows for a high level of interoperability, providing a shared data environment that enhances collaboration and efficiency. This tool also includes features for preventive and predictive maintenance, reducing downtime and optimizing asset management.

- **Exergoeconomic and Optimization Models**. HYPERGRYD includes sophisticated exergoeconomic models that evaluate both energy and economic performance of DHC components, enabling a multi-objective optimization approach. These models allow for dynamic decision-making, considering not only technical efficiency but also cost and environmental impacts. By integrating these models with the digital twin, operators can simulate various scenarios and optimize the operation of DHC networks in real-time, balancing energy efficiency, operational costs, and environmental benefits.

- **Coupled Simulation Models for Multi-Energy Carrier Systems.** To achieve comprehensive energy management, HYPERGRYD developed a simulation model that integrates electricity, gas, and heat networks within a single platform. This model enables coordinated optimization of energy flows across all carriers, allowing for efficient resource use and greater grid resilience. By simulating different demand and supply scenarios, the model helps operators predict and manage energy flows dynamically, supporting better integration of renewable energy and minimizing grid constraints.

4.3 Real-Time Control and Smart Energy Trading Tools

HYPERGRYD's platform includes real-time control features and energy trading tools that allow for efficient load balancing, demand response, and local energy exchange, creating an interactive and decentralized energy ecosystem.

- **Demand Response and Predictive Control Tools**. These tools optimize energy distribution in real time based on demand and supply fluctuations, reducing peak loads and maximizing renewable utilization. Predictive control uses machine learning algorithms to forecast energy needs, allowing operators to pre-emptively adjust grid operations. This demand response functionality not only reduces strain on the grid but also enhances energy efficiency, lowering overall operational costs and emissions.

- **Smart Energy Trading Platforms for Local Energy Communities (LECs)**. HYPERGRYD's platform enables peer-to-peer (P2P) energy trading within local energy communities, allowing prosumers to trade surplus energy with neighbours or buy renewable energy locally. This tool creates an accessible and transparent energy market where consumers and producers can interact directly. The platform also incorporates a market-aware demand response feature, adapting trading strategies to real-time market conditions and promoting flexible, decentralized energy systems. By empowering consumers, this tool fosters community engagement and supports the transition to a more democratized energy system.

- **Edge Computing and IoT for Distributed Control.** HYPERGRYD leverages edge computing to support distributed control and data processing at the device level. This setup reduces latency and enables local control of energy assets, improving responsiveness and efficiency. IoT sensors collect data on energy production, consumption, and asset conditions, feeding real-time information into the platform. Edge-based machine learning models provide predictive maintenance and anomaly detection capabilities, allowing for proactive asset management and reducing the risk of system failures.

4.4 Predictive Maintenance and Anomaly Detection

A major advantage of the HYPERGRYD platform is its ability to provide predictive maintenance and anomaly detection, helping operators manage and maintain DHC assets more effectively.

- **Predictive Maintenance Algorithms**. The platform uses data-driven predictive maintenance to identify potential failures before they occur, minimizing downtime and maintenance costs. Machine learning algorithms analyse data from IoT sensors to detect patterns associated with wear and tear, allowing maintenance teams to act pre-emptively. This approach not only enhances the lifespan of assets but also reduces the need for reactive maintenance, leading to significant cost savings and operational reliability.
- **Anomaly Detection for Improved System Reliability.** By continuously monitoring energy flows and component performance, HYPERGRYD's anomaly detection system identifies irregularities and alerts operators in real time. This functionality enables rapid response to unexpected changes in grid performance, preventing minor issues from escalating into major failures. Through automated diagnostics, the platform provides actionable insights for operators, supporting faster and more accurate troubleshooting.

4.5 Advanced Visualization and User Engagement Interfaces

To make the complex data and insights generated by HYPERGRYD accessible to users, the project includes advanced visualization tools and user-friendly interfaces.

- **Intuitive Dashboards and Real-Time Visualization**. HYPERGRYD's platform features interactive dashboards that provide a comprehensive view of DHC network performance, with real-time visualizations of key metrics like energy demand, supply, and storage levels. These tools help operators monitor system performance and make informed decisions quickly. The platform is designed with accessibility in mind, making it easy for users to interpret complex data and engage with the system effectively.
- **User-Friendly Interfaces for Prosumers**. HYPERGRYD includes interfaces tailored for local energy communities and prosumers, allowing them to actively participate in energy trading and demand response activities. By providing clear, actionable information on energy consumption, production, and trading options, these interfaces encourage community engagement and empower consumers to take an active role in managing their energy. This approach fosters a sense of ownership and promotes a culture of sustainable energy practices within local communities.

4.6 Integration and Scalability of the HYPERGRYD Platform

HYPERGRYD's platform is designed to be flexible and scalable, supporting the integration of additional modules, energy sources, and grid configurations. By leveraging open APIs and standardized protocols, the platform ensures compatibility with existing systems and provides the adaptability needed for deployment across diverse European climates and regulatory environments.

- **Open API for Seamless Integration**. The platform's open API facilitates interoperability with other energy management systems, enabling the integration of third-party tools and datasets. This feature makes it easier to scale the HYPERGRYD platform across different DHC networks, supporting widespread adoption and adaptability.
- **Scalability Across Diverse Climatic and Regulatory Contexts**. HYPERGRYD's modular design enables it to scale from small urban installations to large regional DHC networks. The platform's flexibility allows operators to tailor the system to the specific needs of their location, accommodating varying energy demands, climate conditions, and regulatory constraints.

5 Implementation and Validation

The HYPERGRYD project's innovative solutions will be rigorously tested and validated to ensure they are effective, scalable, and adaptable for diverse real-world scenarios. Implementation and validation activities are essential to confirm the project's technical and operational feasibility across different climates, DHC configurations, and regulatory contexts. To achieve this, HYPERGRYD will utilize a multi-faceted approach involving four live-in lab (LiL) demonstration sites representing varied European climates and energy demands. This section outlines the key implementation strategies, validation processes, and performance metrics that will underpin the HYPERGRYD project.

5.1 Live-in Lab Demonstration Sites

HYPERGRYD will conduct its demonstrations in four live-in lab environments across Europe, chosen to represent distinct climate conditions and urban contexts. These sites are located in areas with different heating and cooling needs, which allows the project to test its solutions under varied operational conditions. Each LiL will provide critical data and insights into the performance, scalability, and adaptability of HYPERGRYD's technologies and tools.

- **Site 1: Cold Climate Demonstration**. This site is designed to test HYPERGRYD's ability to manage high heating demands typical of northern and colder regions in Europe. The focus will be on the efficient integration of RES-driven heating solutions, such as modular heat pumps and sorption storage, which must provide stable heating even during periods of extreme cold. This site will validate the effectiveness of low-temperature energy solutions and thermal storage capabilities in minimizing energy waste and maximizing renewable use.
- **Site 2: Mild Climate Demonstration**. Located in a region with moderate heating and cooling demands, this LiL will focus on balancing heating and cooling within a single network. Technologies such as reversible heat pumps and small-scale CHP units will be tested for their dual capabilities, providing both heating and cooling as required. This site will provide insights into how HYPERGRYD can optimize mixed energy demands in temperate climates, enhancing overall energy efficiency and grid flexibility.
- **Site 3: Cooling-Dominated Climate Demonstration**. In southern European regions where cooling is the primary demand, this demonstration will validate HYPERGRYD's cooling capabilities within DHC networks. The site will test the system's ability to efficiently utilize renewable cooling sources, including sorption-based cooling and modular heat pumps. Additionally, this LiL will assess the potential for seasonal energy storage to meet cooling needs, especially during peak summer periods, enhancing the DHC network's ability to handle high cooling loads sustainably.
- **Site 4: Multi-Energy Carrier System Integration Demonstration.** This site, located in a region with both high heating and cooling demands, will demonstrate HYPERGRYD's integration of multi-energy carrier systems, incorporating electricity, gas, and heat networks. The goal is to validate the system's ability to coordinate multiple energy vectors, optimize resource use, and provide flexible energy management for complex demand profiles. This LiL will be critical for testing HYPERGRYD's coupled simulation models, which enable dynamic energy balancing across different carriers.

5.2 Validation Process and Methodology

HYPERGRYD's validation process is structured to assess technical performance, cost-effectiveness, scalability, and user acceptance of its solutions. Validation activities will involve a combination of on-site monitoring, performance testing, and stakeholder engagement, with a focus on gathering comprehensive data to optimize each component and validate overall system performance.

- **Data Collection and Real-Time Monitoring**. Each LiL site will be equipped with IoT sensors and edge computing devices to collect real-time data on energy flows, temperature, equipment performance, and user interactions. This data will be fed into the HYPERGRYD digital platform, enabling continuous monitoring and analysis. Real-time data will allow operators to identify any discrepancies or inefficiencies in the system, ensuring accurate performance assessments and enabling rapid troubleshooting if needed.
- **Performance Testing Against Key Metrics**. HYPERGRYD's technologies and tools will be evaluated against specific performance metrics designed to measure their effectiveness in achieving project objectives. Key metrics include:
  - **Renewable Energy Penetration**: Percentage of total energy consumption met by renewable sources.
  - **Energy Efficiency Gains**: Reduction in energy consumption compared to baseline DHC systems.
  - **Cost-Effectiveness**: Operational savings achieved through energy efficiency and optimization.
  - **CO_2 Emissions Reduction**: Reduction in greenhouse gas emissions relative to conventional DHC systems.
  - **Grid Flexibility and Stability**: System resilience in adapting to fluctuations in demand and renewable availability.

By benchmarking these metrics, HYPERGRYD will assess each solution's contribution to energy efficiency, sustainability, and economic viability, providing quantifiable results that support further deployment and scalability.

- **User Engagement and Feedback Mechanisms.** To ensure that HYPERGRYD's solutions are both user-friendly and practical, each LiL will actively engage with stakeholders, including DHC operators, local authorities, prosumers, and end-users. Through direct feedback, users will provide input on the usability, effectiveness, and perceived benefits of HYPERGRYD's technologies and platform. This feedback will be invaluable in refining the system's design, particularly the user interfaces and energy trading tools, and ensuring that the solutions meet the needs of all stakeholders.

5.3 Key Implementation Strategies

The implementation of HYPERGRYD's technologies involves several strategic approaches designed to ensure smooth deployment, interoperability, and adaptability within the existing infrastructure. These strategies facilitate seamless integration with current DHC networks and enhance the replicability of solutions across various settings.

- **Modular Deployment of Technologies**. HYPERGRYD's modular approach allows components such as heat pumps, sorption storage units, and CHP systems to be added incrementally, providing flexibility in implementation. This modularity enables operators to scale the deployment based on specific demand profiles, budget constraints, and infrastructure limitations. By allowing for phased implementation, HYPERGRYD makes it feasible to gradually transition DHC networks towards renewable and hybrid configurations, minimizing disruption and cost.
- **Interoperability and Open API Integration**. The HYPERGRYD platform is designed with interoperability as a core feature, allowing it to integrate seamlessly with existing systems and third-party tools. Through an open API, the platform supports data exchange with other energy management software and enables the integration of external sensors, meters, and control devices. This openness ensures that the platform can adapt to a range of regulatory, operational, and technological contexts, supporting scalability across Europe.
- **Automated Control and Predictive** Maintenance. By incorporating predictive control algorithms and automated demand response capabilities, HYPERGRYD enables real-time optimization of energy flows and load balancing. The predictive maintenance tools reduce the need for reactive repairs by identifying potential issues before they escalate, thus minimizing downtime and operational costs. This proactive approach improves the reliability of DHC systems and enhances user confidence in the technology.

5.4 Scalability and Replicability

The core goal of HYPERGRYD is to create solutions that can be widely adopted and replicated across different European regions. To ensure scalability, the project is validating its technologies in diverse climates and DHC configurations. The insights gained from the LiL demonstrations will inform a set of guidelines and best practices for future deployments.

- **Technical Scalability**. HYPERGRYD's solutions are designed to scale from small district-level installations to large, city-wide DHC networks. This adaptability is supported by the platform's modular structure, which allows for flexible expansion based on demand growth or network requirements. The project's technical validation ensures that its solutions can accommodate varying scales without compromising efficiency or reliability.
- **Regulatory and Market** Adaptability. By developing an open, interoperable platform, HYPERGRYD aims to address regulatory and market barriers that may arise in different regions. The project provides templates for compliance with regulatory requirements and offers adaptable business models for local energy markets, ensuring that the platform can be easily implemented across various European contexts. HYPERGRYD's market-aware demand response and energy trading tools also enable communities to participate actively in local energy markets, supporting a decentralized energy model.

5.5 Long-Term Monitoring and Continuous Improvement

To sustain HYPERGRYD's impact beyond the project's duration, a long-term monitoring plan will be established for each LiL site. This plan will continue to collect and analyse data on the performance, reliability, and efficiency of the installed technologies, providing a foundation for continuous improvement. Additionally, HYPERGRYD's open API will allow for the integration of future technologies and system upgrades, ensuring that the platform remains adaptable to new advancements in the energy sector.

- **Post-Project Support and Knowledge** Sharing. HYPERGRYD will develop a repository of knowledge, best practices, and technical documentation based on insights gained from the LiL demonstrations. This knowledge base will support future DHC operators, policymakers, and researchers interested in adopting or adapting HYPERGRYD solutions. Through workshops, conferences, and collaborative networks, HYPERGRYD will continue to share its findings and drive adoption across Europe, encouraging widespread transition to smart hybrid grids.

6 Platform and Services

The HYPERGRYD platform serves as the digital backbone for transforming district heating and cooling (DHC) systems into efficient, smart, and hybrid energy networks. By integrating advanced ICT tools, real-time monitoring capabilities, and user-centric interfaces, the platform empowers operators and stakeholders to optimize energy flows, enhance system reliability, and support the transition to renewable-driven DHC. This section elaborates on the platform's architecture, its modular and scalable design, and the suite of services it provides to meet the complex demands of modern energy management.

6.1 Digital Twin for Comprehensive System Management

The digital twin is the cornerstone of the HYPERGRYD platform, providing a virtual representation of physical DHC systems and assets. It combines **Building Information Modelling (BIM)** and **Geographic Information Systems (GIS)** to create an interconnected, real-time digital environment that mirrors the operation of the actual DHC network.

- **Real-Time Monitoring and Asset Visualization**. The digital twin enables operators to monitor the status of all assets, such as heat pumps, thermal storage units, and distribution networks. Key metrics like energy consumption, system efficiency, and equipment conditions are displayed in real time, offering a clear, actionable view of the network's performance.
- **Scenario Simulation and Optimization**. Through dynamic modelling, the digital twin allows operators to simulate various operational scenarios, including demand surges, equipment failures, or shifts in renewable energy availability. This capability helps in proactive decision-making, ensuring that the system operates at peak efficiency under different conditions.
- **Predictive Maintenance and Lifecycle Management**. Integrated machine learning algorithms analyse historical and real-time data to predict equipment failures or performance declines. By scheduling maintenance activities in advance, operators can reduce downtime, lower maintenance costs, and extend the lifespan of assets.

6.2 Smart Demand Response and Predictive Control

The HYPERGRYD platform features advanced demand response and predictive control tools designed to balance energy flow dynamically and optimize resource utilization.

- **Real-Time Load Balancing**. The platform's demand response capabilities adjust energy distribution based on fluctuations in demand and supply. For example, during periods of high renewable energy availability, the system prioritises renewable inputs, reducing reliance on fossil fuels. Conversely, during peak demand, energy flows are optimized to prevent grid strain.
- **Machine Learning for Forecasting**. Predictive control algorithms analyse data trends, such as weather patterns, consumption behaviour, and energy market signals, to forecast demand and adjust operations pre-emptively. This not only enhances efficiency but also ensures a stable energy supply to meet consumer needs.

- **Flexibility for Multi-Energy Carrier Systems**. The platform supports the integration of multiple energy carriers, including electricity, gas, and heat. It dynamically optimizes these carriers based on availability and cost, maximizing energy efficiency across the system.

6.3 Peer-to-Peer (P2P) Energy Trading and Local Market Development

HYPERGRYD fosters decentralized energy management by enabling local energy communities (LECs) to trade energy directly through its integrated smart trading platform.

- **Decentralized Energy Markets**. The platform allows prosumers (energy producers and consumers) to sell excess energy generated from renewable sources, such as rooftop solar or small-scale combined heat and power (CHP) units, to their neighbours. Consumers can purchase locally produced renewable energy, reducing dependence on centralized grids.
- **Dynamic Pricing and Transparent Transactions**. A dynamic pricing model incentivizes energy transactions based on real-time supply and demand, ensuring fair and efficient energy exchange. Blockchain-based smart contracts are employed to provide transparency and security in all transactions.
- **Market-Aware Demand Response**. By integrating energy market data, the platform adjusts energy trading strategies to maximize the benefits for both prosumers and consumers, ensuring optimal energy utilization and cost savings.

6.4 Edge Computing and IoT Integration

To enable real-time decision-making and improve system responsiveness, the HYPERGRYD platform incorporates edge computing and IoT-enabled devices.

- **Distributed Control and Data Processing**. Edge computing devices process data locally at the point of generation, reducing latency and enabling faster adjustments to system operations. This is particularly useful for managing complex hybrid networks with variable renewable energy inputs.
- **IoT-Driven Automation**. IoT sensors deployed across the DHC network continuously monitor system parameters, such as temperature, pressure, and energy flows. These sensors provide granular insights into system performance and enable automated responses to change in demand or supply conditions.
- **Enhanced Reliability and Security**. Localized data processing reduces reliance on centralized servers, improving the platform’s resilience to outages and cyber threats. Built-in encryption and secure communication protocols ensure the privacy and integrity of data.

6.5 Advanced Visualization and User Interfaces

To ensure that both operators and end-users can easily interact with the platform, HYPERGRYD includes intuitive visualization tools and user-friendly interfaces.

- **Interactive Dashboards for Operators**. The platform provides operators with customizable dashboards that display key performance indicators (KPIs) such as energy efficiency, renewable share, and storage utilization. Operators can drill down into detailed metrics or view high-level summaries, enabling both strategic planning and operational monitoring.

- **Prosumers and Community Interfaces**. User-specific interfaces allow prosumers to track their energy production, monitor trading activity, and view environmental impact metrics. These interfaces also provide energy-saving tips and recommendations, fostering greater engagement and awareness.
- **3D and GIS-Based Visualizations**. The integration of 3D models and GIS mapping tools offers a spatial view of the DHC network, making it easier to identify and address issues in specific locations. This feature is particularly useful for large or complex networks with multiple interconnected nodes.

6.6 Scalability and Interoperability

The HYPERGRYD platform is designed to be flexible and scalable, ensuring that it can adapt to diverse operational contexts and future technological advancements.

- **Modular and Incremental Deployment**. Operators can implement the platform in stages, starting with core functionalities and adding advanced modules as needed. This approach minimizes disruption and allows for gradual investment.
- **Open API for Integration**. The platform's open API facilitates interoperability with third-party systems, including energy management software, smart home devices, and utility platforms. This ensures seamless integration with existing infrastructure and enhances compatibility with future technologies.
- **Support for Diverse Climate and Network Conditions**. HYPERGRYD's modular structure allows it to operate effectively across varying climates, from heating-dominated to cooling-dominated regions. It can also accommodate networks of different sizes and configurations, from small-scale microgrids to large urban systems.

6.7 Security and Data Privacy

Given the critical nature of energy infrastructure, HYPERGRYD incorporates robust security measures to protect sensitive data and ensure operational reliability.

- **Data Encryption and Access Controls**. The platform uses end-to-end encryption for all data exchanges and implements role-based access controls to prevent unauthorized access.
- **Anonymized Data for Compliance**. Personal data collected through IoT devices is anonymized to comply with data protection regulations, such as the EU General Data Protection Regulation (GDPR).
- **Built-In Redundancy**. The platform's architecture includes fail-safe mechanisms to ensure uninterrupted operation, even during hardware or network failures.

6.8 Comprehensive Services for Operators and Communities

Beyond its core functionalities, the HYPERGRYD platform offers a range of services to support operators, policymakers, and local energy communities.

- **Energy Forecasting and Planning**. Operators can use forecasting tools to anticipate energy demand and supply trends, enabling better planning and resource allocation.
- **Training and Support**. The platform includes training materials and user guides to help stakeholders maximize its potential. On-demand technical support is available to resolve issues quickly.
- **Community Engagement and Awareness Campaigns**. HYPERGRYD provides tools for engaging communities through educational campaigns, interactive events, and transparent communication about energy usage and environmental impact.

The HYPERGRYD platform combines cutting-edge digital tools, modular technologies, and user-centric interfaces to enable the efficient management of hybrid DHC systems. By providing a scalable and interoperable solution, the platform empowers operators to enhance energy efficiency, integrate renewables, and engage communities in sustainable energy practices. This digital backbone is not just a technological innovation but also a key enabler of the energy transition, paving the way for a cleaner and more resilient future.

7 Business and Market Potential

The HYPERGRYD project stands at the intersection of technological innovation and market transformation, addressing some of the most pressing challenges in the global energy sector. By enabling the integration of renewable energy sources (RES) into district heating and cooling (DHC) networks, fostering decentralized energy markets, and empowering local energy communities (LECs), HYPERGRYD offers a compelling value proposition for utilities, municipalities, businesses, and consumers. This section provides a comprehensive exploration of the project's market potential, innovative business models, and its role in reshaping the energy landscape.

7.1 The Growing Market for Renewable-Driven DHC Solutions

As the global energy transition accelerates, the market for renewable-based and hybrid DHC systems is experiencing significant growth. This demand is driven by stringent climate policies, the phasing out of fossil fuels, and the increasing adoption of RES. However, many existing DHC networks are outdated, inefficient, and reliant on high-temperature, centralized systems that are incompatible with modern energy goals.

HYPERGRYD provides a solution to these challenges by offering scalable, cost-effective technologies designed to enhance the flexibility, resilience, and efficiency of DHC systems, making them future-ready.

7.1.1 Market Growth Drivers

The demand for innovative DHC systems is underpinned by several key factors:

- **Policy and Regulation**. Governments across Europe are implementing policies aimed at reducing greenhouse gas (GHG) emissions and increasing the share of RES in energy systems. The EU's Green Deal and "Fit for 55" package are prime examples of this regulatory push.
- **Aging Infrastructure**. Much of Europe's existing DHC infrastructure was built decades ago and requires modernisation to meet current energy efficiency and decarbonization standards.
- **Urbanization**. As cities expand, there is a growing need for sustainable energy systems capable of serving dense urban populations while minimizing environmental impact.
- **Consumer Demand**. End-users are increasingly seeking sustainable, cost-effective energy solutions, driving demand for technologies that provide renewable energy integration and decentralized management.

7.1.2 Target Market Segments

HYPERGRYD's solutions cater to a broad range of stakeholders, including:

- **Utilities and DHC Operators**. Seeking to modernize their networks, reduce operational costs, and comply with stricter environmental regulations.
- **Municipalities and Public Authorities**. Looking to invest in sustainable urban infrastructure as part of their smart city initiatives.

- **Residential and Commercial Users**. Interested in affordable, efficient, and environmentally friendly heating and cooling solutions for homes, offices, and industrial facilities.
- **Local Energy Communities (LECs)**. Empowering prosumers to generate, store, and trade renewable energy locally.

7.1.3 Market Size and Opportunity

The European DHC market is projected to grow significantly in the coming decades, driven by investments in 4th and 5th generation systems. The International Energy Agency (IEA) estimates that 50% of Europe's building heat demand could be met by DHC systems by 2050. HYPERGRYD's solutions are uniquely positioned to capture this opportunity, offering a pathway for operators to modernise their networks and align with future energy trends.

7.2 Innovative Business Models for Energy Transition

HYPERGRYD introduces a range of innovative business models that create value for operators, consumers, and prosumers. These models align with the broader shift toward decentralization, digitalization, and sustainability in the energy sector.

7.2.1 Energy-as-a-Service (EaaS)

The EaaS model transforms the traditional energy supply business by focusing on service-oriented offerings rather than selling energy as a commodity. HYPERGRYD enables operators to deliver services such as:

- **Dynamic Energy Supply**. Providing tailored energy solutions based on real-time demand and availability of RES.
- **Predictive Maintenance**. Using HYPERGRYD's digital twin and IoT sensors to anticipate and resolve issues before they escalate, reducing downtime and operational costs.
- **Optimization Services**. Offering energy optimization and efficiency improvement as value-added services to consumers.

This model diversifies revenue streams and strengthens customer relationships, ensuring long-term sustainability for energy providers.

7.2.2 Peer-to-Peer (P2P) Energy Trading

HYPERGRYD's platform facilitates decentralized energy trading within LECs, allowing prosumers to sell excess energy directly to other consumers. This approach:

- Encourages local renewable energy production and consumption.
- Reduces reliance on centralized grid infrastructure.
- Promotes transparency and fair pricing in energy markets.
- Empowers communities to become self-sufficient energy hubs.

7.2.3 Demand Response Monetization

HYPERGRYD's demand response tools enable DHC operators to participate in ancillary markets, offering services such as load balancing and frequency regulation. By providing these services, operators can generate additional revenue while contributing to grid stability and resilience.

7.3 Scalability and Replicability of HYPERGRYD Solutions

A key strength of HYPERGRYD lies in its scalability and adaptability. Its modular technologies and interoperable digital platform are designed to accommodate diverse energy contexts and regulatory frameworks, ensuring widespread applicability.

7.3.1 Technical Scalability

HYPERGRYD's solutions can be deployed incrementally, allowing operators to start small and expand as needed. For example:

- **Heat Pumps and Sorption Storage**. Can be installed in specific network segments and scaled up gradually.
- **CHP Units**. Provide localized energy solutions that can be expanded to cover larger areas.

7.3.2 Geographic Applicability

The solutions are tested across diverse climates and energy demands in Europe through live-in-lab demonstrations:

- Cold climates, focusing on high heating demand.
- Cooling-dominated regions, addressing the challenges of peak cooling loads.
- Temperate zones with mixed energy needs, optimizing heating and cooling simultaneously.

7.3.3 Targeted Market Segments

- **Residential**: Retrofit solutions for existing housing and efficient designs for new developments.
- **Commercial and Industrial**. flexible energy systems tailored to specific operational requirements.
- **Municipal Infrastructure**. Smart energy solutions for public facilities, such as schools and hospitals.

7.4 Stakeholder Benefits and Value Creation

HYPERGRYD delivers tangible benefits for all stakeholders, ensuring strong market adoption and engagement.

7.4.1 For DHC Operators

- Improved operational efficiency through real-time monitoring and optimization.

- Reduced costs via predictive maintenance and enhanced energy utilization.
- New revenue streams through ancillary services and energy trading.

7.4.2 For Local Energy Communities (LECs)

- Empowerment of prosumers to actively participate in the energy market.
- Cost savings and revenue opportunities through local energy production and trading.
- Increased community resilience and energy independence.

7.4.3 For Policymakers and Regulators

- Tools to achieve national and regional energy and emissions targets.
- Support for creating sustainable, inclusive energy ecosystems.
- Data-driven insights for better policy planning and implementation.

7.5 Economic Viability and Long-Term Potential

HYPERGRYD emphasizes economic viability to ensure its solutions are attractive for stakeholders.

7.5.1 Cost-Effectiveness

- **Lower Capital Expenditure**. Modular deployment reduces upfront costs.
- **Operational Savings**. Predictive maintenance and energy optimization lower operating expenses.
- **Revenue Generation**. Ancillary services, energy trading, and efficiency gains provide additional income streams.

7.5.2 Return on Investment (ROI)

HYPERGRYD delivers a clear ROI for stakeholders, with operational savings and new revenue streams offsetting initial investments. Its flexible business models further enhance financial viability.

7.6 Alignment with Policy and Market Trends

HYPERGRYD's solutions are strategically aligned with major EU policies and market trends, including:

- **European Green Deal.** Direct contribution to reducing GHG emissions and increasing renewable energy share.
- **Renovation Wave Initiative**. Supporting deep renovation of existing infrastructure to improve energy efficiency.
- **Digital Transition**. Leveraging digital twins, IoT, and advanced analytics to modernize energy systems.

7.7 Long-Term Vision and Global Impact

HYPERGRYD is not only a solution for Europe but also a template for global energy systems. Its scalable, modular approach can be adapted to meet the needs of other regions, including emerging markets. The project’s focus on sustainability, flexibility, and community empowerment positions it as a leader in the global transition to decentralised, renewable energy systems.

8 Stakeholder Engagement and Dissemination

Stakeholder engagement and effective dissemination of results are central to the success of the HYPERGRYD project. By fostering collaboration across the energy value chain and raising awareness among key actors, HYPERGRYD ensures that its innovative solutions reach the widest possible audience and gain traction for implementation and replication. This section outlines the strategies and activities designed to engage stakeholders, disseminate project outcomes, and maximise the project's impact.

8.1 Stakeholder Engagement Strategy

HYPERGRYD's stakeholder engagement strategy focuses on involving a diverse range of actors from the energy sector, public authorities, and local communities. This collaborative approach ensures that the project's solutions address real-world challenges and align with stakeholder needs.

- **Key Stakeholder Groups**:
    - **DHC Operators and Utility Companies**. Collaborating to validate and implement HYPERGRYD solutions in existing and new networks.
    - **Policymakers and Regulators**. Providing insights into policy compliance and identifying opportunities for regulatory support.
    - **Local Energy Communities (LECs)**. Engaging prosumers and end-users to test P2P trading and demand response tools.
    - **Technology Providers and SMEs**. Partnering to co-develop and integrate innovative technologies.
    - **Researchers and Academia**. Leveraging research institutions for knowledge exchange and advancing hybrid grid technologies.
- **Engagement Mechanisms**:
    - Workshops and stakeholder forums to gather input and share progress.
    - Interactive demonstrations at live-in lab (LiL) sites, allowing stakeholders to experience the technologies firsthand.
    - Partnerships with industry associations and energy networks to disseminate knowledge and attract new collaborators.

8.2 Public Awareness and Outreach

HYPERGRYD recognizes the importance of educating and involving the broader public in the energy transition. Public awareness campaigns are designed to highlight the benefits of renewable integration, smart grids, and local energy communities.

- **Public Engagement Activities**:
    - Open days and site tours at LiL demonstrators to showcase project achievements.

- Interactive webinars and online events to explain the project's goals and solutions to non-technical audiences.
- Collaboration with schools and universities to promote energy literacy and sustainability.

- **Communication Tools**:
  - Engaging visuals, infographics, and explainer videos tailored to different audiences.
  - A user-friendly website and social media presence for sharing updates, results, and success stories.
  - Localized campaigns to address community-specific challenges and opportunities.

8.3 Dissemination Activities and Channels

Dissemination is critical to ensuring that HYPERGRYD's outcomes are widely understood and adopted. The project employs a multi-channel dissemination strategy to reach diverse audiences, including technical experts, policymakers, and the general public.

- **Academic and Technical Dissemination**:
  - Publication of research findings in high-impact journals and conference proceedings.
  - Presentation of project results at international conferences and industry events, such as European Utility Week and Smart Energy Systems.
  - Development of white papers and technical reports detailing the project's methodologies and innovations.
- **Policy-Oriented Dissemination**:
  - Policy briefs and recommendations targeting local, national, and EU policymakers to support regulatory alignment and adoption.
  - Participation in policy workshops and consultations to influence energy policy frameworks.
  - Collaboration with the European Commission such a Green Deal Support Office and other EU bodies to align with broader decarbonization initiatives.
- **Industry-Focused Dissemination**:
  - Case studies and best practices shared with DHC operators, energy service companies, and technology providers.
  - Training sessions and webinars tailored for industry professionals, focusing on the practical implementation of HYPERGRYD solutions.
  - Partnership opportunities with SMEs and startups to foster technology transfer and commercialisation.

8.4 Knowledge Sharing and Capacity Building

HYPERGRYD emphasizes knowledge sharing and capacity building to enable the widespread adoption of its technologies and methodologies. By providing open-access tools, training resources, and technical documentation, the project empowers stakeholders to implement and scale its solutions.

- **Open-Access Resources**:
  - An online knowledge hub featuring technical documentation, simulation models, and datasets from the LiL demonstrators.
  - Training materials, including user manuals, instructional videos, and e-learning modules, tailored to different stakeholders.
- **Workshops and Training Sessions**:
  - Targeted training for DHC operators on integrating and managing hybrid energy grids.
  - Capacity-building workshops for policymakers on leveraging HYPERGRYD's tools to achieve decarbonization goals.
  - Community-focused sessions to educate LEC members on energy trading, demand response, and system optimization.
- **Collaborative Networks and Partnerships**:
  - Participation in EU-level energy and climate networks to share findings and foster collaborations.
  - Establishing connections with other Horizon 2020 and Horizon Europe projects to exchange best practices and avoid duplication of efforts.

8.5 Leveraging Demonstration Sites for Dissemination

HYPERGRYD's live-in lab (LiL) sites serve as powerful tools for stakeholder engagement and dissemination. These sites demonstrate the real-world application and benefits of HYPERGRYD's solutions, providing tangible evidence of their effectiveness.

- **Demonstration Activities**:
  - Guided tours and live demonstrations showcasing hybrid DHC technologies in action.
  - Collection of performance data and insights to create compelling case studies and reports.
  - Stakeholder workshops at LiL sites to foster collaboration and gather feedback.
- **Knowledge Transfer**:
  - Documentation of lessons learned from LiL implementations to inform future projects.
  - Sharing of replicable frameworks and methodologies for scaling HYPERGRYD solutions across Europe.

8.6 Impact Maximization Through Stakeholder Collaboration

HYPERGRYD's collaborative approach ensures that its innovations are practical, scalable, and widely adopted. By engaging with a broad range of stakeholders and disseminating results effectively, the project maximizes its impact across social, environmental, and economic dimensions.

- **Accelerating Adoption**. Dissemination activities directly support the adoption of HYPERGRYD technologies by increasing awareness, reducing knowledge barriers, and providing actionable insights.
- **Creating Market Momentum**. Through industry engagement and public awareness, HYPERGRYD fosters demand for renewable-driven DHC systems and hybrid energy solutions, driving market growth.
- **Empowering Communities**. By engaging local energy communities, HYPERGRYD helps democratize energy management and ensures that its solutions benefit end-users directly.

HYPERGRYD's stakeholder engagement and dissemination strategy is comprehensive and inclusive, designed to ensure that the project's solutions are widely understood, adopted, and replicated. By fostering collaboration, raising awareness, and sharing knowledge, HYPERGRYD builds a strong foundation for long-term impact, contributing to the decarbonization and modernization of Europe's energy systems.

9 Expected Impact and Long-Term Benefits

The HYPERGRYD project is poised to deliver transformative impacts across environmental, social, and economic dimensions. By addressing critical challenges in the energy transition and creating innovative solutions for renewable integration into district heating and cooling (DHC) systems, HYPERGRYD contributes to achieving the European Union's decarbonization and climate neutrality goals. This section outlines the project's expected short-term impacts and the long-term benefits it seeks to deliver.

9.1 Environmental Impact

HYPERGRYD will significantly reduce the environmental footprint of energy systems by enabling greater integration of renewable energy sources (RES), improving energy efficiency, and minimizing emissions.

- **Reduction in Greenhouse Gas (GHG) Emissions.** By transitioning DHC networks to hybrid systems that incorporate RES and advanced optimization tools, HYPERGRYD is expected to achieve substantial reductions in CO_2 emissions. Its technologies enable operators to phase out fossil fuels, aligning with EU climate targets under the Green Deal and Fit for 55 packages.
- **Increased Renewable Energy Penetration.** HYPERGRYD's modular technologies and smart tools allow for seamless integration of variable renewable sources, such as solar, wind, and geothermal energy. This increases the share of renewable energy in DHC systems, contributing to energy decarbonization.
- **Enhanced Energy Efficiency.** Through real-time optimization, predictive control, and demand response, HYPERGRYD reduces energy waste and ensures efficient operation of DHC systems. This leads to lower overall energy consumption and reduced environmental impact.
- **Support for Circular Economy Principles.** The project promotes the reuse and recycling of energy infrastructure components and prioritises low-exergy solutions, aligning with circular economy goals. The use of modular, upgradeable technologies extends the lifecycle of DHC assets and reduces resource consumption.

9.2 Social Impact

HYPERGRYD empowers communities and enhances the quality of life for citizens by democratizing energy management and fostering local energy independence.

- **Empowerment of Local Energy Communities (LECs).** The project supports the creation of LECs by providing tools for peer-to-peer (P2P) energy trading and decentralized energy management. This enables communities to take control of their energy production, reduce costs, and increase resilience to energy disruptions.
- **Reduction in Energy Poverty.** By improving the efficiency and cost-effectiveness of DHC systems, HYPERGRYD makes clean energy more accessible and affordable. This can help mitigate energy poverty in underserved regions.

- **Community Engagement and Awareness.** HYPERGRYD's educational outreach and user-friendly tools foster greater public understanding of sustainable energy practices. This engagement encourages active participation in the energy transition and promotes a culture of sustainability.
- **Improved Air Quality and Urban Environments.** The reduction in fossil fuel use and emissions from DHC systems directly improves air quality, particularly in urban areas. This enhances public health and creates more liveable cities.

9.3 Economic Impact

HYPERGRYD supports economic growth by creating new business opportunities, reducing energy costs, and fostering innovation in the energy sector.

- **Cost Savings for DHC Operators and Consumers.** HYPERGRYD's optimization tools and modular technologies reduce operational costs for DHC operators, which can be passed on to consumers in the form of lower energy bills. Predictive maintenance and improved efficiency further minimize costs associated with system downtime and energy waste.
- **Creation of New Markets.** The project fosters the development of decentralized energy markets, including P2P trading and demand response services. These markets create opportunities for new business models, such as Energy-as-a-Service (EaaS) and flexible grid services, expanding the economic potential of hybrid energy systems.
- **Support for Job Creation and Regional Development.** The deployment of HYPERGRYD solutions drives job creation in areas such as renewable energy installation, digital platform development, and DHC network upgrades. This contributes to regional economic development and supports the transition to a green economy.
- **Scalable and Exportable Solutions.** HYPERGRYD's technologies are designed to be scalable and adaptable, creating opportunities for deployment across Europe and in global markets. This positions HYPERGRYD as a leader in the growing market for hybrid energy solutions.

9.4 Technological Advancements and Innovation

HYPERGRYD advances the state of the art in energy technology by integrating innovative hardware and digital tools into DHC systems.

- **Development of Next-Generation DHC Technologies.** HYPERGRYD introduces cutting-edge technologies, including modular heat pumps, sorption storage systems, and small-scale combined heat and power (CHP) units. These solutions set new benchmarks for efficiency, flexibility, and sustainability in DHC systems.
- **Pioneering Smart Grid Integration.** By combining digital twins, edge computing, and machine learning, HYPERGRYD enables real-time optimization and advanced control of hybrid energy systems. This integration enhances grid reliability, flexibility, and responsiveness to changing energy demands.

- **Open Platform for Continuous Innovation.** HYPERGRYD's interoperable platform and open API provide a foundation for future technological advancements. This fosters collaboration with other projects, technology providers, and energy stakeholders, ensuring that the platform remains adaptable to emerging innovations.

9.5 Contribution to EU Policy Goals

HYPERGRYD directly supports the European Union's strategic energy and climate goals by addressing key policy objectives and providing replicable solutions.

- **Green Deal and Fit for 55 Targets.** The project contributes to achieving the EU's GHG emission reduction targets and advancing the transition to climate neutrality by 2050. HYPERGRYD's solutions align with the goals of increasing renewable energy share and improving energy efficiency.
- **Renovation Wave Initiative.** HYPERGRYD supports the deep renovation of existing DHC infrastructure, aligning with the EU's Renovation Wave Initiative. The project's modular approach makes it easier to upgrade aging systems, ensuring compliance with sustainability standards.
- **Digitalization of Energy Systems.** By integrating advanced ICT tools, HYPERGRYD promotes the digital transformation of the energy sector, a key objective of the EU's energy policy. The project's platform enables data-driven decision-making and enhances the overall intelligence of DHC systems.
- **Promotion of Energy Security and Resilience.** HYPERGRYD enhances energy resilience by reducing dependency on imported fossil fuels and increasing the reliability of hybrid grids. This contributes to the EU's goal of ensuring secure and sustainable energy for all citizens.

9.6 Long-Term Vision and Benefits

HYPERGRYD's long-term vision is to establish hybrid energy grids as the standard for sustainable energy management, creating lasting benefits for the environment, society, and economy.

- **Sustainable and Resilient Energy Systems.** By providing a scalable model for renewable-driven DHC systems, HYPERGRYD sets a foundation for future energy systems that are efficient, adaptable, and resilient to external disruptions.
- **Global Leadership in Hybrid Energy Solutions.** HYPERGRYD positions Europe as a global leader in the development and deployment of hybrid energy technologies. Its innovations provide a replicable model for addressing energy challenges worldwide.
- **Accelerated Energy Transition.** Through its holistic approach, HYPERGRYD accelerates the transition to a clean, decentralized, and democratized energy system. The project's outcomes ensure that the benefits of the energy transition are shared broadly across stakeholders and regions.

HYPERGRYD delivers significant environmental, social, economic, and technological impacts, supporting the EU's climate neutrality goals and advancing the global energy transition. By creating sustainable, scalable, and community-driven energy solutions, HYPERGRYD paves the way for a future where hybrid energy grids play a central role in achieving a clean and resilient energy system.

10 Contributions and Future Directions

The HYPERGRYD project marks a transformative step in the modernization of district heating and cooling (DHC) systems, paving the way for a sustainable, resilient, and renewable-driven energy future. By integrating cutting-edge technologies with innovative business models and digital tools, HYPERGRYD delivers a comprehensive framework for transforming traditional energy systems into dynamic hybrid energy grids. This section provides a detailed summary of the project's contributions, highlights the challenges ahead, and sets a vision for scaling and advancing these innovations in the future.

10.1 Summary of Contributions

HYPERGRYD has successfully addressed some of the most pressing challenges in the energy transition, offering solutions that are technically robust, economically viable, and environmentally sustainable. The following key contributions of the project illustrate its broad impact.

10.1.1 Technological Innovations

- **Next-Generation DHC Technologies**:
    - Developed modular and scalable technologies, such as reversible heat pumps, sorption storage systems, and small-scale combined heat and power (CHP) units, to enable renewable energy integration.
    - Enhanced flexibility and efficiency of DHC networks through advanced low-exergy technologies that adapt to varying energy demands and climatic conditions.
- **Digital Tools for Optimization and Control**:
    - Introduced a digital twin platform that integrates Building Information Modelling (BIM) and Geographic Information Systems (GIS) for real-time monitoring, predictive maintenance, and system optimization.
    - Advanced predictive control and demand response tools powered by machine learning (ML) to balance energy loads dynamically and optimize resource utilization.
- **Interoperable, Open-Access Platform**:
    - Built a modular, open-access platform capable of integrating with existing systems and accommodating future technologies, ensuring long-term adaptability and scalability.

10.1.2 Economic and Market Innovations

- **Cost-Effective Solutions**:
    - Designed modular technologies that reduce installation costs and allow for phased implementation, lowering barriers for adoption.

    - Demonstrated clear return on investment (ROI) through operational savings, efficiency improvements, and new revenue streams from demand response and local energy trading.
- **New Business Models**:
    - Enabled innovative models like Energy-as-a-Service (EaaS) and peer-to-peer (P2P) energy trading within local energy communities (LECs), fostering decentralized energy markets.
- **Market Applicability**:
    - Validated solutions across diverse climate zones and operational contexts, ensuring that technologies can be applied to various DHC systems in Europe and beyond.

10.1.3 Environmental and Social Impact

- **Significant Reduction in CO_2 Emissions**:
    - Increased the penetration of renewable energy sources (RES) within DHC networks, directly contributing to greenhouse gas (GHG) emissions reduction and climate neutrality goals.
- **Empowered Communities**:
    - Provided tools for local energy communities to actively participate in energy management, reduce energy costs, and enhance energy independence.
- **Support for Circular Economy**:
    - Promoted modular design principles, reuse, and recycling of energy infrastructure components, aligning with EU circular economy goals.

10.2 Challenges Ahead

Despite the significant achievements of HYPERGRYD, several challenges must be addressed to enable widespread adoption and scaling of hybrid energy grids.

10.2.1 Regulatory and Policy Barriers

- **Inconsistent Regulations Across Europe**:
    - Variations in energy policies, market rules, and regulatory frameworks across EU member states create barriers to uniform implementation of hybrid energy solutions. Harmonizing these frameworks is critical.
- **Lack of Incentives for Hybrid Systems**:

Financial incentives and subsidies are often tailored to traditional renewable energy systems and may not adequately support hybrid grid solutions or modular technologies.

10.2.2 Market and Financial Barriers

- **High Initial Investments**:
  - While the long-term cost savings of HYPERGRYD solutions are clear, the upfront capital required for retrofitting existing systems or deploying new technologies may deter some stakeholders.
- **Market Readiness**:
  - Transitioning from centralized energy models to decentralized systems requires market mechanisms that incentivize local energy trading and RES integration.

10.2.3 Technological Challenges

- **Integration with Legacy Systems**:
  - Existing DHC networks may require significant upgrades to accommodate hybrid technologies and digital tools.
- **Scalability and Adaptability**:
  - While HYPERGRYD solutions have been validated in diverse settings, scaling these technologies to different regions with unique energy demands and infrastructure challenges will require further adaptation.

10.3 Future Directions

HYPERGRYD's success provides a strong foundation for future advancements. The following directions outline key pathways for expanding, refining, and scaling its solutions.

10.3.1 Advancing Hybrid Energy Technologies

- **Development of High-Efficiency Technologies**:
  - Enhance the efficiency and cost-effectiveness of reversible heat pumps, sorption storage systems, and CHP units.
  - Explore the integration of emerging energy carriers, such as hydrogen, and advanced storage solutions, like thermal batteries and phase-change materials.
- **Integration of Carbon Capture**:
  - Combine hybrid energy grids with carbon capture and utilization (CCU) technologies to further reduce emissions in hard-to-decarbonize sectors.

10.3.2 Expanding Digital Innovation

- **AI and Machine Learning for Optimization**:
  - Integrate advanced AI models into digital twins to enable real-time, self-optimizing DHC networks that continuously learn and adapt to new conditions.

- **Blockchain for Energy Markets**:
  - Use blockchain technology to ensure secure, transparent transactions in P2P energy trading and demand response markets.
- **Edge Computing and IoT Enhancements**:
  - Expand the use of edge computing to process larger datasets locally, enhancing system responsiveness and reducing reliance on central servers.

10.3.3 Policy and Market Development

- **Harmonized Regulations**. Work with policymakers to create unified standards and regulations that facilitate the deployment of hybrid energy grids across Europe.
- **Financial Mechanisms**. Establish new funding models, such as green bonds and public-private partnerships, to support the initial deployment of HYPERGRYD solutions.

10.3.4 Scaling and Global Deployment

- **Adapting to Global Markets**:
  - Modify HYPERGRYD technologies to address the energy challenges of developing countries, such as unreliable grids and limited RES infrastructure.
- **Urban and Rural Applications**:
  - Expand applications of hybrid grids to support sustainable urbanization and rural electrification projects.

10.3.5 Knowledge Sharing and Collaboration

- **Capacity Building**:
  - Train operators, policymakers, and community leaders to effectively use and manage hybrid energy systems.
- **Cross-Sector Collaboration**:
  - Partner with industries such as transportation and manufacturing to explore synergies between hybrid grids and other sectors.

10.4 Vision for the Future

HYPERGRYD envisions a future where hybrid energy grids are at the heart of sustainable, resilient energy systems, empowering communities and supporting economic growth while safeguarding the planet. Key elements of this vision include.

- **Decentralized Energy Systems**:
  - Hybrid grids enable localized energy production and management, reducing dependency on centralized infrastructure and enhancing resilience.

- **Global Leadership in Renewable Integration**:
    - Europe becomes a global leader in hybrid grid solutions, exporting expertise and technologies to accelerate the global energy transition.
- **Inclusive and Equitable Energy Transition**:
    - HYPERGRYD ensures that the benefits of clean energy are accessible to all, addressing energy poverty and fostering social equity.

11 Conclusion

HYPERGRYD has laid a strong foundation for the future of energy systems, demonstrating that hybrid, renewable-driven DHC networks can deliver tangible environmental, economic, and social benefits. The project's innovations, validated in real-world scenarios, provide a replicable model for modernizing energy systems globally. As hybrid energy grids become the new standard, HYPERGRYD's contributions will inspire continued advancements, catalysing a global shift towards sustainable, decentralized, and resilient energy systems.

By combining technical excellence, stakeholder engagement, and visionary planning, HYPERGRYD ensures that the transition to a clean energy future is not only achievable but inevitable.

12 Glossary

Ancillary Services: Support services provided by energy systems to maintain grid stability and reliability. These include frequency regulation, voltage control, load balancing, and other functions critical to grid operation.

Application programming interface (API): Code that allows two software programs to communicate with each other.

ArcGIS: Is a family of client software, server software, and online geographic information system (GIS) services.

Artificial Neural Network: Brain-inspired computing system able to detect patterns and relationships in data and to learn from it.

Austrian Institute of Technology GmbH (AIT): Research institute.

BIM Execution Plan (BEP): The intent of the BIM Execution Plan (BEP) is to define a foundational framework to ensure successful deployment of advanced design technologies on your BIM enabled project. The BEP is about optimizing work and model flow across the project, as contrasted with optimizing siloed interests.

BMS: Central computerised system for running the building services in the most efficient way, (e.g., adjusting the heating levels, turning lights on or off)

BootStrap technology: Is a free and open-source CSS framework directed at responsive, mobile-first front-end web development. It contains HTML, CSS and (optionally) JavaScript-based design templates for typography, forms, buttons, navigation, and other interface components.

Borehole thermal storages: Borehole thermal energy storage involves using the ground as the storage medium, allowing heat to be added to the ground during the summer months, and extracted to meet the heating demands in the winter heating season.

Building Automation System (BAS): Is a network designed to connect and automate certain functions inside a building. All of the building control systems, from lighting and HVAC (Heating, Ventilation & Air Conditioning) to fire and security systems—all wired through one set of controls.

Building Heating, Ventilating and Air Conditioning (HVAC) loads: Hating, ventilating and air conditioning (HVAC) systems are the largest energy end use in the nondomestic sector, with energy consumption. Different HVAC systems have different energy requirements when responding to the same building heating and cooling demands. Building heating and cooling demands depend on various parameters such as building fabrics, glazing ratio, building form, occupancy pattern, and many others. HVAC system energy requirements and building energy demands can be determined by mathematical modelling.

Building Information Modelling (BIM): Digital form of construction and asset operations that brings together technology, process improvements and digital information to radically improve client and project outcomes and asset operations.

Capital expenditures (CAPEX): The purchase of fixed assets, e.g. plant and machinery, for the purpose of increasing future production; the sum of money spent on fixed assets.

Circular Economy: An economic model focused on eliminating waste and maximizing resource reuse by keeping materials and energy in continuous circulation.

Citizen Energy Community (CEC): The Clean Energy Package (CEP) defines a CEC as a legal entity that: (a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises; (b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and (c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders.

CityGML: City Geography Mark-up Language. A common information model for the representation of 3D urban objects. The format defines classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantic and appearance properties.

Clean Energy Package (CEP): The Clean Energy Package or Clean energy for all Europeans package (CEP) is an EU rulebook adopted in 2019. It expects to bring considerable benefits for consumers, the environment, and for the economy through new directives which must be converted into EU countries' national law within 1-2 years.

Consiglio Nazionale delle Ricerche (CNR): Research institute.

Coefficient of Performance (COP): Ratio of the available useful heat produced by a system compared to the energy that must be fed into the system.

Combined Heat and Power (CHP): The consecutive generation of useful thermal and electric energy from the same fuel source.

Community Trading: Community Trading refers to energy exchanges that take place between multiple members of a community.

Compartmentalization: As a security engineering concept, means that the person or application requesting data will only be able to access the one needed to complete their task. As a result, exposure potential will be limited, or even in the case of a data breach, the damage could be minimized.

Contingency plan: Actions designed for use only if certain events occur.

CSS3 styling: Is a style sheet language used for describing the presentation of a document written in a markup language such as HTML or XML (including XML dialects such as SVG, MathML or XHTML).

Data controller: The natural or legal person, public authority, agency or other body which, alone, or jointly with others, determines the purposes and means of processing personal data.

Data distortion: Will ensure that an untrusted party releases company data (or pattern extracted from data); this party won't learn any of the company's sensitive information or reidentify company users. It is achieved through controlled data distortion/modification preserving specific characteristics (defined as utilities) of the data, e.g., statical properties.

Data processor: The natural or legal person, public authority, agency, or other body which processes personal data on behalf of the controller. Technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation.

Data terminal equipment (DTE): Part of a data station that serves as a data source, a data sink, or both.

Decarbonization: The process of reducing carbon dioxide (CO_2) emissions, particularly by transitioning to renewable energy sources, enhancing energy efficiency, and minimizing reliance on fossil fuels.

Decentralized Generations (DG): System involving small amounts of generation located on a utility's distribution system for the purpose of meeting local (substation level) peak loads and/or displacing the need to build additional (or upgrade) local distribution lines.

Demand Response Management (DRM): Schemes to manage energy for residential buildings in a smart grid.

Differential scanning calorimetry (DSC): Technique that records the difference in energy inputs into a substance and a reference material, as a function of temperature, while the substance and reference material are subjected to the same controlled temperature programme.

Digital Twins: Virtual representation using data, data analytics and machine learning to help stimulation models that can be updated and changed (real-time) as their physical equivalents change.

Disaster recovery (DR): Activities (planning, testing etc.) to protect an organization from the effects of significant negative events (e.g. cyberattack, natural disaster), which helps restoring operations and accesses, and getting back data quickly.

Distributed Energy Resources (DERs): Variety of small, modular power-generating technologies that can be combined with energy management and storage systems and used to improve the operation of the electricity delivery system, whether or not those technologies are connected to an electricity grid.

Distributed Energy Site (DES): Is a term which encompasses a diverse array of generation, storage and energy monitoring and control solutions. DES can be tailored to very specific requirements and users' applications including cost reductions, energy efficiency, security of supply and carbon reduction.

Distributed Multi-Generation (DMG): Is electrical generation and storage performed by a variety of small, grid-connected or distribution system-connected devices referred to as distributed energy resources (DER).

Distribution system operators (DSOs): Natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

District Heating and Cooling (DHC): Thermal energy delivered to a building from an outside source is known as district heating and cooling, which can range in size from small systems serving two or three buildings to networks serving entire cities. District heating and cooling is widely used in developed countries throughout the world and offers numerous advantages over individual building apparatus, including greater safety and reliability, reduced emissions, and greater fuel flexibility, particularly in using alternative fuels such as biomass or waste.

District Heating Network DHN (2nd generation): The second generation of district appeared in the 1930s, the main characteristics of this generation are the following: Were coal, waste and oil fuelled; Used pressurized hot water as heat carrier with temperatures above 100°C; Were built around a centralized production unit; Introduced Combined Heat and Power (CHP) to save primary energy use.

District Heating Network DHN (3rd generation): The third generation in district heating was developed in the 1970s after the two-oil crisis the led to oil shortage. This generation rapidly spread all around the world, the main characteristics of this generation are: Prefabricated and pre-insulated pipes; Operation temperatures below 100°C; Used coal, biomass and waste as energy sources, and some systems used geothermal energy and solar energy.

District Heating Network DHN (4th generation): The fourth generation in district heating is currently developed, they are a way to address climate change as: They integrate high shares of variable renewable energy; They supply low temperature district heating for space heating and domestic hot water (below 70°C); They distribute heat with low grid losses; They recycle heat from low temperature renewable energy sources.

District Heating Network DHN (5th generation): The fifth generation of district heating distributes heat at near ambient ground temperatures, minimizing grid losses and thus, insulation needs. The main design characteristics are: Bi-directional exchange of thermal energy: supply of heat means receiving cold and vice versa; Thermal storage at large and small scale, appropriately places, are integrated with the thermal system to balance the demand for heat and cold; Demand driven algorithm-based control that optimizes the exergy flows using real-time data and monitoring.

District Heating and Cooling Network (DHCN): Heating networks produce and transport heat in the form of hot water or steam for heating or domestic water use (hot water). Cooling networks produce and distribute cooling energy through a chilled water network to cool buildings.

Data Management Plan (DMP): Describes the types of data that will be generated or gathered during the project.

Domestic hot water (DHW): Hot water used in sinks, showers and baths for domestic purposes including drinking, cooking, sanitation and personal hygiene, but not including the hot water in heating systems.

Dynamic Host Configuration Protocol (DHCP): Is a network management protocol used on Internet Protocol (IP) networks for automatically assigning IP addresses and other communication parameters to devices connected to the network using a client–server architecture. The technology eliminates the need for individually configuring network devices manually, and consists of two network components, a centrally installed network DHCP server and client instances of the protocol stack on each computer or device. When connected to the network, and periodically thereafter, a client requests a set of parameters from the server using DHCP.

Edge Computing: A distributed computing model where data processing occurs closer to the source of data generation, enabling faster and more efficient real-time operations.

Electric vehicles (EV): Vehicle with a powertrain containing at least one electric motor or electric motor-generator.

Electrical Grid: Integrated system of electricity distribution, usually covering a large area.

Energy-as-a-Service (EaaS): A business model in which energy-related services, such as supply, maintenance, and optimization, are offered on a subscription or pay-per-use basis.

Energy Communities: Groups or collectives of individuals or organizations that collaboratively manage the production, storage, and consumption of energy, typically focusing on renewable energy sources.

Energy efficiency (EE): The ratio of output of performance, service, goods or energy, to input of energy.

Energy Efficiency Ratio (EER): Declared capacity for cooling or rated cooling or refrigeration capacity, expressed in kW, divided by the rated power input, expressed in kW.

Energy Storage Capacity (ESC): Energy capacity is the total amount of energy the battery system can store.

Energy Storage Density (ESD): Is the amount of energy stored in a given system or region of space per unit volume.

European Green Deal: A European Union policy framework aimed at achieving climate neutrality by 2050 through measures such as reducing greenhouse gas emissions and promoting renewable energy and circular economy principles.

Exergoeconomic optimization tool: The exergoeconomic optimization tool will be developed within the HYPERGRYD project. The tool will be based on QGIS and Python to optimize operation, components and design to reach a cost-effective use and to increase the decentralized share of RES and P2H. The tool will cover economic and thermal modelling of the DH grids and consider variable tariffs for consumers and producers.

Exploitable Results (ER): The manufacture of contract products or the application of the contract processes or the assignment or licensing of intellectual property rights or the communication of know-how required for such manufacture or application.

FAIR data: Set of guiding principles to make data Findable, Accessible, Interoperable and Reusable.

Fit for 55: An EU legislative initiative aiming to reduce greenhouse gas emissions by 55% by 2030, supporting the broader goals of the European Green Deal.

Genetic Algorithms: Search algorithm based on the mechanics of natural selection and natural genetics.

Geographic Information System (GIS): Computer system that analyses and displays geographically referenced information.

Global warming potential (GWP): Factor which describes the radiative forcing impact of one mass-based unit of a given greenhouse gas relative to an equivalent unit of carbon dioxide over a given period of time.

Graphical user Interface (GUI): Form of user interface that allows users to interact with electronic devices through graphical icons and visual indicators such as secondary notation, instead of text-based user interfaces, typed command labels or text navigation.

Greenhouse gas (GHG) emissions: Is a network management protocol used on Internet Protocol (IP) networks for automatically assigning IP addresses and other communication parameters to devices connected to the network using a client–server architecture.

Hardware-in-the-loop (HIL): Form of real-time simulation used in the development and testing of complex process systems which differs from real-time simulation by the addition of a real component, such as an electronic control unit, in the loop.

Heat Pump (HP): Machine, device or installation that transfers heat from natural surroundings such as air, water or ground to buildings or industrial applications by reversing the natural flow of heat such that it flows from a lower to a higher temperature.

Heat Roadmap Europe (HRE): This has been the focus of the Heat Roadmap Europe (HRE) study series since 2012. In the latest edition, HRE4 built evidence supporting the decarbonization of the heating and cooling sector in Europe and developed roadmaps for redesigning this sector by combining the knowledge of local waste heat conditions and potential savings with an energy system analysis.

High power generation: The term 'high power' refers to electricity generation working at more than 50 kW.

Hybrid Energy Grid: An energy system that integrates multiple energy carriers, such as electricity, heat, and gas, to improve resource utilization and flexibility.

IFC Model Specification (Industry Foundation Classes data model standard): Are an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector.

Information and communication technologies tools (ICT): ICT includes a wide variety of technologies, including computers and software learning tools, networking systems and protocols, hand-held digital devices, digital cameras and camcorders, and other technologies, including those not yet developed, for accessing, managing, creating, and communicating information.

Information Delivery Manuals (IDM): An be used to identify discrete processes that are undertaken during the lifecycle of a built asset, and to detail the information required to carry them out.

Integrated Design & Delivery Solutions (IDDS): Use collaborative work processes and enhanced skills, with integrated data, information, and knowledge management to minimize structural and process in efficiencies and to enhance the value delivered during design, build, and operation, and across projects.

Internal Combustion Engine (ICE): Engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber.

Internet of Things (IoT): Products and services that are connected to a network and can be controlled at a distance, for example via a voice assistant or mobile device

Interoperability: The ability of different systems, devices, or technologies to work together seamlessly, enabling efficient data exchange and operation.

Key Enabling Technology (KET): Enabling technology [IATE:1756394] which is expected to play a key role in the shift to a low-carbon, knowledge-based economy, deemed to be a precondition for ensuring welfare, prosperity and security.

Key Exploitable Results (KER): A Key Exploitable Result (KER) is an identified main interesting result which has been selected and prioritised due to its high potential to be "exploited".

Key Performance Indicator (KPI): Quantifiable and pre-defined measure that is used to gauge or compare performance, with the aim of achieving strategic and operational goals.

Kinetic energy recovery system (KERS): Is a type of regenerative braking system which has different approaches to store and reuse the lost energy.

LandXML: A non-proprietary XML-based format containing civil engineering and survey measurement data commonly used in the land development and transportation industries. Since autumn 2012, the maintenance and development have been shared by OGC and building SMART.

Level of Detail (LoD): Is the overall state of your information model at a particular point in its design process. This includes not only graphical objects, but also the data associated with the objects.

Level of Information (LoI): The level of information need is defined to enable the right level of information to be provided to satisfy the information related purposes at each information exchange. It is important to avoid the delivery of too little information, which increases risk, and the delivery of too much information, which is wasteful. The level of information need is a broad concept which represents the framework for how the "richness" of each information deliverable is going to be defined. There are many different ways to express the level of information need, including the richness of geometrical details and the richness of datasets.

Levelized Cost of Energy (LCOE): A calculation of the cost of generating electricity at the point of connection to a load or electricity grid.

Life Cycle Cost analysis (LCC): Method for assessing the total cost of facility ownership, which takes into account all costs of acquiring, owning, and disposing of a construction or construction system.

Life Cycle environmental Impact Assessment: E-LCA evaluates environmental performance throughout the life cycle of a product or from performing a service. The extraction and consumption of resources (including energy), as well as releases to air, water, and soil, are quantified throughout all stages.

Life Cycle Inventory (LCI): Combined set of exchanges of elementary, waste and product flows in a LCI dataset.

Lithium Ferro phosphate (LFP): Inorganic compound with the formula Life PO. It is a grey, red-grey, brown or black solid that is insoluble in water. The material has attracted attention as a component of lithium iron phosphate batteries, a type of Li-ion battery. This battery chemistry is targeted for use in power tools, electric vehicles, solar energy installations and more recently large grid-scale energy storage.

Live-in Lab (LiL): User-centred, open innovation ecosystem based on a systematic user co-creation approach integrating research and innovation processes in real life communities and settings.

Local Energy Community (LEC): An association, a cooperative, a partnership, a non-profit organisation or other legal entity which is effectively controlled by local shareholders or members, generally value rather than profit-driven, involved in distributed generation and in performing activities of a distribution system operator, supplier or aggregator at local level, including across borders.

Local energy markets (LEMs): Is a transparent market accessible for all appropriately metered assets – independent of size – within a Positive Energy Block (PEB) or District (PED), which could involve local production or local consumption. It is the basis for an Energy Community.

Loss of Load Expectation (LOLE): Measure of how long, on average, the available generation capacity is likely to fall short of the load demand.

Loss of Load Probability (LOPL): Expected annual fraction of a condition of insufficient generation available for the load.

Lower Heating Value (LHV): Number of heat units measured as being liberated when a mass unit of fuel is burned in oxygen saturated with water vapour in a bomb under standardised conditions, the residual materials being taken as gaseous oxygen, carbon dioxide, sulphur dioxide and nitrogen, water as water vapour and ash.

Machine learning techniques (MLT): Machine learning (ML) techniques enable systems to learn from experience. ML refers to a system's ability to acquire and integrate knowledge through large-scale observations and to improve and extend itself by learning new knowledge rather than by being programmed with that knowledge.

Measurement & Verification (M&V) professionals: Is an accreditation from the Efficiency Valuation Organization (EVO) and the Association of Energy Engineers (AEE) awarded to qualified professionals in the growing field of Measurement & Verification (M&V) within the energy industry. Its aim is to acknowledge good practice and raise overall professional standards within the M&V field worldwide.

Medium-High power generation: The term 'medium-high power' refers to electricity generation working between 10 and 50 kW.

Mitigation Measure: Measure that implies a reduction in the probability and/or impact of an adverse.

Model View Definition (MVD): As IFC schema subsets to describe data exchange for a specific use or workflow. These filtered IFC views basically allow you to simplify the data exchange process and to avoid sharing useless or redundant information while following standardized procedures.

Modular Technologies: Technological components designed for flexibility and scalability, enabling incremental deployment and adaptation based on specific needs.

Monitoring: Will allow individual actions to be traced with user IDs to sensitive changes.

Multi-Energy Carrier System: An integrated energy system that combines different types of energy carriers, such as electricity, gas, and heat, for optimized distribution and use.

Multi-Energy System (MES): Whereby electricity, heat, cooling, fuels, transport, and so on optimally interact with each other at various levels (for instance, within a district, city or region) represent an important opportunity to increase technical, economic and environmental performance relative to "classical" energy systems whose sectors are treated "separately" or "independently".

Net-Zero Emissions: A state where the amount of greenhouse gas emissions released into the atmosphere is balanced by the removal of emissions, resulting in no net increase.

Ochsner Wärmepumen GMB (OCHS): Company.

Only Saving Necessary Data: Temporary information needed to execute requests that are not important for further use, shouldn't be saved in the Cloud Storage.

Open Access (OA): The act of making peer-reviewed scientific publications accessible to anyone free of charge.

Open Research Data Pilot (ORDP): The ORD aims to improve and maximise access to, and re-use of research data generated by Horizon 2020 projects and takes into account the need to balance openness and protection of scientific information, commercialisation and Intellectual Property Rights (IPR), privacy concerns, security as well as data management and preservation questions. The ORD pilot applies primarily to the data needed to validate the results presented in scientific publications. Other data can also be provided by the beneficiaries on a voluntary basis, as stated in their Data Management Plans. Costs associated with open access to research data, can be claimed as eligible costs of any Horizon 2020 grant.

Operational (O): Parameter.

Operational expenditures (OPEX): Expenses incurred during regular business, such as general and administrative expenses, research and development, and the cost of goods sold.

Operations & Maintenance (O&M) Phase: The period of time in the software life cycle during which a software product is employed in its operational environment, monitored for satisfactory performance, and modified as necessary to correct problems or to respond to changing requirements.

Organic Rankine Cycle (ORC): Cycle containing condensable fluorinated greenhouse gas converting heat from a heat source into power for the generation of electric or mechanical energy.

Peer-to-Peer Trading (P2P): Peer-to-Peer Trading (P2P) is defined by IRENA as a business model based on an interconnected platform, serving as an online marketplace where consumers and producers "meet" to trade electricity directly, without the need for an intermediary. It allows participants to exchange their surplus energy with other participants in the community. The model grants participants enhanced access to locally produced and cleaner energy, often at a favourable rate.

Phase Change Material (PCM) heat exchanger: Is a substance which releases/absorbs sufficient energy at phase transition to provide useful heat or cooling. Generally, the transition will be from one of the first two fundamental states of matter – solid and liquid – to the other. The phase transition may also be between non-classical states of matter, such as the conformity of crystals, where the material goes from conforming to one crystalline structure to conforming to another, which may be a higher or lower energy state.

Phase-Change Material (PCM): When heat is added to or removed from materials, phase change can occur in a variety of ways such as melting, evaporation, change of crystal-bound water content, etc., where total energy change is given by the change of enthalpy.

Photovoltaic (PV): Capable of generating a voltage as a result of exposure to visible or other radiation.

Platform as a Service (PaaS): Is a cloud computing model where a third-party provider delivers hardware and software tools to users over the internet. Usually, these tools are needed for application development. A PaaS provider hosts the hardware and software on its own infrastructure. As a result, PaaS frees developers from having to install in-house hardware and software to develop or run a new application.

Power to heat (P2H): Defines the conversion of electrical energy into heat. The purpose of such systems is to utilize excess electricity generated by renewable energy sources which would otherwise curtailed. Power-to-Heat systems are hybrid systems and when there is an excess of energy the heat production can result from electric energy otherwise the traditional heating system will be used. In order to increase flexibility power-to-heat systems are often coupled with heat accumulators.

Predictive Maintenance: A maintenance approach that uses data analysis and forecasting to identify potential equipment failures before they occur, ensuring proactive interventions.

Primary Energy Consumption (PEC): Direct use at the source, or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process.

Primary Energy Factor (PEF): Ratio between primary energy and the final energy consumed by the end user.

Probability and impact matrix: A common way to determine whether a risk is considered low, moderate or high by combining the two dimensions of a risk: its probability of occurrence and its impact on objectives if it occurs.

Programmable Logic Controller (PLC): Digital computer or microcomputer used for automation of electromechanical processes (such as control of machinery on factory assembly lines or lighting fixtures).

Project Datasets: The sets of facts, information, and statistics in the technical work packages that lead to the information reported in project deliverables or scientific publications.

Project Information: Deliverables, dissemination materials, communication materials, stakeholder information or other content produced by the project for which the project's consortium has decided to apply both data management principles (FAIR) and Open Access principles (free and available to anyone). This information is voluntarily included in the Data Management Plan.

Prosumer: Are generally defined as electricity consumers that produce part of their electricity needs from their own power plant and use the distribution network to inject excess production and to withdraw electricity when self-production is not sufficient to meet own needs.

QGIS: QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, printing, and analysis of geospatial data.

RANOTOR Utvecklings AB (RANO): Company.

Regular Rotation of Security Keys and Certificates: As security keys are the root of the security infrastructure, a handling procedure should be in place to ensure that a single actor won't compromise the system.

Renewable Energy Community (REC): The Clean Energy Package (CEP) defines a REC as a legal entity: (a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; (b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities; (c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.

Renewable Energy Sources (RES): Renewable sources of energy (wind power, solar power, hydroelectric power, ocean energy, geothermal energy, biomass and biofuels) are alternatives to fossil fuels that contribute to reducing greenhouse gas emissions, diversifying energy supply and reducing dependence on unreliable and volatile fossil fuel markets, in particular oil and gas.

Renovation Wave: A European Union initiative focused on improving energy efficiency and sustainability through the large-scale renovation of existing buildings and infrastructure.

Return on investment (ROI): Financial metric used to evaluate the performance of an investment, where the gain of the investor is expressed as a percentage of the original investment.

Risk: An uncertain event or condition that, if it occurs, has an effect on at least one project objective.

Risk Analysis: Process of prioritizing risks for further analysis or action by assessing and combining their probability of occurrence and impact.

Risk identification: The process of determining which risks may affect the project and documenting characteristics.

Scalability: The ability of a system or technology to adapt to increased demand or expanded operations without compromising performance or efficiency.

Scenario Analysis Interface for Energy Systems (SAInt): The Scenario Analysis Interface for Energy Systems (SAInt) is a planning software to model coupled energy networks & markets, including electricity and gas. SAInt advances energy planning by allowing users to model coupled energy networks to quantify their interdependencies and synergies and plan their integration and coordination. SAInt's users can run physical simulations and optimization models to quantify the trade-offs between costs and reliability and study the intersection of markets and physical systems.

Security measures: Security and cybersecurity measures must be adopted for the system, not only for data protection but also for information security.

Self-sufficiency (SS): "Self-supply" is more correct than "self-sufficiency". The "taux d'auto-approvisionnement" of a country in a product may be more than 100%. Hence, it is more logical to translate the term as "self-supply ratio" rather than "self-sufficiency ratio" since "sufficiency" cannot be more than 100%.

Service Oriented Architecture (SOA): Style of software design where services are provided to the other components by application components, through a communication protocol over a network.

Smart Energy Districts (SED): Those districts (or networks) where thermal and electric grid are coupled, according to the 4th and 5th generation DHC models, and renewable energy sources are soundly integrated with the grids through the use of smart hardware and software solutions.

Smart Energy Trading: The use of digital platforms and technologies to optimize energy transactions, enabling efficient, transparent, and real-time trading.

Smart Hybrid Grids (SHG): Hybrid smart grid that produces electricity from various sources Photovoltaic (PV), hydro and thermal power with a delivery system that satisfies energy optimization of the energy costs in real-time (ECRT).

Social life cycle assessment (S-LCA): A powerful technique to assess and report about these impacts and benefits of product life cycle from the extraction of the natural resources to the final disposal.

Solar thermal (ST): Energy produced using direct heat from the sun, concentrating it to produce heat at useful temperatures; solar thermal devices do everything from heating swimming pools to creating steam for electricity generation.

Sorption Storage (SOR): Sorption heat storage belongs to the class of thermochemical storage and relies on a physical reaction which involves the application or deletion of heat energy to occur. Different types of sorbents are used, zeolites (aluminosilicates) being the most common and most researched sorbents for sorption heat storage.

Sorption thermal energy storage (STES): Sorption thermal energy storage is a promising technology for effectively utilizing renewable energy, industrial waste heat and off-peak electricity owing to its remarkable advantages of a high energy storage density and achievable long-term energy preservation with negligible heat loss.

Stakeholder Engagement: The process of involving individuals, groups, or organizations affected by or interested in a project to foster collaboration, gather input, and ensure mutual benefits.

State of Charge (SoC): Available capacity remaining in a battery, expressed as a percentage of the rated capacity.

Steam Buffer (SB): A steam buffer shall, as the name indicates, accomplish a levelling between power input in the shape of the steam arriving from the steam generator and the power output to the steam engine, which will make it possible to use intermittent and stochastic energy sources like solar energy in stationary plants, and above all make it possible to obtain considerably higher peak power outputs for short periods than the power that corresponds to the steam generator capacity.

Steam turbine CHP systems: Steam turbines normally generate electricity as a byproduct of heat (steam) generation. A steam turbine uses a separate heat source and does not directly convert fuel to electric energy. The energy is transferred from the boiler to the turbine through high pressure steam that in turn powers the turbine and generator. This separation of functions enables steam turbines to operate with an enormous variety of fuels, varying from clean natural gas to solid waste, including all types of coal, wood, wood waste, and agricultural byproducts.

Supervisory Control and Data Acquisition (SCADA): A generic name for a computerized system that is capable of gathering and processing data and applying operational controls over long distances. Typical uses include power transmission and distribution and pipeline systems. SCADA was designed for the unique communication challenges (e.g., delays, data integrity) posed by the various media that must be used, such as phone lines, microwave, and satellite. Usually shared rather than dedicated.

Sustainability: The practice of meeting present needs without compromising the ability of future generations to meet their own, encompassing environmental, social, and economic dimensions.

Technology Readiness Levels (TRL): Set of management metrics used to assess the maturity of a particular technology and to allow consistent comparison of the maturity of different types of technology in a given system, application and operational environment.

The Least Privilege Principle: Strong guidance for maintaining confidentiality, ensuring only the bare minimum access permission required to complete a task is guaranteed for the user; moreover, if users are granted access permits, exploitation opportunities should be minimized.

Thermal Energy Storage (TES): Technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation.

Thermal Grid: Centralized thermal generation systems, a system of networks that transport thermal fluids, enable the demand for heating and domestic hot water in homes and other buildings to be met.

Thermochemical Storage: Storage system using any process which transforms an initial set of chemical reagents into a different product set of chemicals involving the application or deletion of heat energy.

Thermochemical Storage Systems (TCMS): Thermochemical energy storage is a new technology which provides the advantage of high storage densities and minor thermal losses. This makes the technology attractive for low-temperature long-term storage as well as for high-temperature storage.

Thermogravimetric analysis (TGA): Type of testing that is performed on samples to determine changes in weight in relation to change in temperature.

Unit of Measure (UoM): Value of a quantity chosen by convention as a reference for measuring quantities of the same kind.

Use case (UC): Description of how users will perform tasks on a computer system.

Vanadium Redox Flow Battery (VRFB): Is a type of rechargeable flow battery. It employs vanadium ions as charge carriers. The battery uses vanadium's ability to exist in a solution in four different oxidation states to make a battery with a single electroactive element instead of two. For several reasons, including their relative bulkiness, vanadium batteries are typically used for grid energy storage, i.e., attached to power plants/electrical grids.

Variable energy resources (VREs): Refers to any generation resource whose output is not perfectly controllable by a transmission system operator, and whose output is dependent on a fuel resource that cannot be directly stored or stockpiled and whose availability is difficult to predict. Wind and solar power generation are the primary VERs, since the sun does not shine all the time (even during the day, clouds and dust can interfere with solar power generation in surprising ways) and the wind does not blow all the time. In some cases, hydroelectricity without storage (so-called “run of river” hydro) could be considered a VER since its output is dependent on streamflow at any given moment.

Zero-Emission Buildings (ZEBs): Buildings that achieve net-zero carbon emissions, typically by generating as much renewable energy as they consume and maximizing energy efficiency.