Energy Research and Innovation Discourses, Applications, and Future Directions: A Review and Case Discussions from National and International Projects.

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ABSTRACT

The research investigates the trends and state of art on energy research and innovation by closely looking into energy-focused literature and mapping the review results and making a reflection using ongoing and completed projects of the case organization. For this, more than 20 national and EU-funded international projects of Smart Innovation Norway (SIN) were considered. Both the projects' mapping and the literature showed the trend toward community and citizens-oriented solutions. The solutions cover multifold dimensions including multivector, flexibility services, modular tools, active engagement of the community, social innovation, etc. In this regard, the content analysis of SIN's completed and ongoing projects seems to emphasize socio-economic values whereas most of the literature focused on technology advancement. E-LAND, which is one of the EU-funded projects that bring together society, business, and technology, is discussed as an example. E-LAND puts society (community and citizens) at the center and provides modular tools for energy communities. The research has implications for energy research, energy communities, businesses, policymakers, and academia in the context of creating synergy and developing an innovative solution that helps to accelerate the green transition.

Keywords: Research and innovation, energy community, citizens, energy technology, flexibility, energy efficiency, demand response, business model.

1 INTRODUCTION

The impacts of climate change have long been discussed and have recently become a crucial challenge for the globe more than ever before. Consequently, in responding to this challenge, various research and innovations are done to overcome and mitigate the risks associated with it. In general, the energy research areas seem diversified which covers the development of smart technological and digital solutions, new business models, impact assessment methods, energy communities, and citizen engagement.

Nevertheless, the energy research and innovation trajectory/trends seem less studied in a structured way. Looking at closely the state of art energy research and the general literature on the innovative solutions proposed, there is not one universal method and solution for all applications and it differs from one case to another and varies from one context to another context. Now, the question is to answer **'is there any focal point where all the smart energy research solutions and innovations come together for a better impact?**'

Indeed, it is understandable that each energy research has its own thematic goal with the overall objective of leveraging various new and better alternative technologies which enable efficient energy consumption and help with GHG emission reduction. But, how it can be sustainable and ensure these solutions are acceptable to the communities and citizens?

In this paper, energy-focused literature is reviewed to understand the energy research trajectory and mapped with practical reflections on completed and ongoing projects of the case organization (SIN).

2 METHODOLOGY AND CASE DESCRIPTION

2.1 Methodology

The research used a mixed strategy by looking at the selected key literature (Table 1) from the past decade and the alignment is mapped with the general trajectory of energy research and innovation in the case organization (SIN). Furthermore, a selected case is discussed from one of the ongoing projects which is in line with the trend of the research foci.

Title	Aligned Keywords	Literature	Search criteria & results
Energy research	(a) Technology	[1] [2] [3] [8]	Searched the publication year 2011-2021, a total number of articles found 72, published both in journals and other channels including books. Engine: Harzing's publish or perish
	(b) Business model	[13]	
	(c) Flexibility	[3] [11]	
	(d) Demand response,	[1] [3]	
	(e) ICT &integration	[1] [10]	
	(f) Storage	[1] [3]	
	(g) Societal (Community, citizens)	[4][5][6][10] [12] [13]	
	(h) Innovation	[1] [7]	
	(i) Efficiency	[3] [7] [9]	
	(j) Optimization	[1] [3] [7]	
	(k) Sustainability & policy	[1] [7] [9]	

Table 1. research methodology with search criteria.

2.2 Case Description

SIN is a research organization with five interconnected departments forming a unique innovation platform including Research, Smart Cities and Communities, Clusters, Venture, and Communication. SIN currently runs more than 18 EU-funded projects and equally the same amount of national projects funded by the Research Council of Norway (RCN), Innovation Norway, regional and municipalities, and SIVA, among others. The rationale to consider SIN as a case study is the consistent and growing success rate of research and innovation projects both on an international and national level. Research council Norway (RCN) recently reported SIN on of the top research institutes[1].

3 IDENTIFIED MAJOR ENERGY RESEARCH DOMAINS

Based on the content analysis of the literature, five research domains were identified (A-E)

A. Energy Technology development, digitalization/ICT, and integration.

The technology development covers both the hardware and software part of smart energy systems and their integrations to effectively manage all types of energy system operations (e.g. the grid) and get the intended functionalities. Indeed, these need all necessary digital and ICT infrastructure for seamless integrations of the developed energy technologies and services [3] [7].

B. Energy efficiency, optimization, modeling, and simulation

Different solutions and methods have been proposed by several scholars to realize and validate the effectiveness and efficiency of energy systems design and technology. These include developing and testing various optimization algorithms, modeling, and using various simulation techniques. These cover various application areas of energy sectors and operations. For example, improved grid and building energy efficiency using various tools and methods such as multi-vector simulations, energy system modeling, forecasting and scheduling algorithms, etc. [1].

C. Demand response and flexibility

One recently discussed topic in the energy research domain is the concept of demand response (DR) and flexibility. Despite various definitions of these concepts, DR and flexibility aim to transform passive consumers into prosumers. This is perfectly in line with the recently published JRC report "prosumersim and energy sustainability"[2]. [1] [11].

D. Business model, techno-economic, and sustainability assessment

One crucial area of energy research is developing a business model and assessing the economic viability of the technology developed. In this connection, various researchers proposed different methods and tools such as cost-benefit analysis (CBA), Levelized cost of energy (LCOE), life cycle assessment (LCA), etc. [7]

Sustainability seems a buzzword and repeatedly discussed in energy research and has been viewed from many perspectives. For example, some literature looked at it from environmental and GHG emissions while others viewed the business aspect of sustainability which assesses how to scale and sustain the proposed technology and services [13].

E. Energy Community and citizens

The state of art energy project research trends includes putting energy communities and citizens at the center. However, the previous studies focused on developing the technology and its effectiveness in the successful deployment and operations. The involvement of citizens, households, and energy communities has been understated in the literature for the past couple of decades, especially in the development phases of the technology. [5][6] [10].

4 TELESCOPIC VIEW OF ENERGY RESEARCH AND REFLECTIONS BASED ON SIN'S ONGOING AND COMPLETED PROJECTS

Some general overview of the SIN's project objectives and the respective alignment to the literature identified. This is based on the alignment of the methodology designed in table 1 and the project objectives listed below (Table 2).

	Name of the project	Short description	Aligned research
1	ACCEPT (H2020, 2021-2024)	ACCEPT aims to leverage emerging local energy governance structures and significant amassed know-how and point technological solutions in order to deliver a solution that is simultaneously operational, financially viable, and socially acceptable through the convergence of citizen engagement, business planning, and digital product development similar to a standard, commercial new product development methodology.	a, b , g, h
2	ChargeFlex (RCN, 2015-2017)	Seeks to develop software to enable a 25 % increase in EV-charging capacity in a local grid – through smart demand response management. This includes the development of prediction models for charging demand, capacity constraints and available flexibility Utilization of big data and real-time analytics technology Implementation of optimization models for flexible energy resources	a,c,d,j
3	CINELDI (RCN, 2016-2024)	CINELDI will ensure that we are building the smart energy system of the future. The project will contribute to designing a flexible, robust, and cost-effective electric distribution grid, and will facilitate renewable energy, electrification of transport, and more efficient use of energy.	a,c,i,
4	E-LAND (H2020, 2018-2022)	The E-LAND project targets to develop and demonstrate tools for energy systems to overcome the technical, business and societal challenges associated with the creation of low carbon, climate-resilient energy supply in challenging ecosystems of isolated, remote, or rural areas.	a, b,e,g, h, i,j,k
5	EMPOWER (H2020, 2015-2017)	H2020 Local Electricity retail Markets for Prosumer smart grid pOWER services The EMPOWER concept aims to encourage and enable the active participation of citizens that consume and produce energy in the electrical system. It is based on the insight that a	c,d,g,h, i,k

[1] https://www.forskningsradet.no/nyheter/2022/stor-norsk-suksess-i-europeisk-forsknings--og-innovasjonsprogram/

[2] https://publications.jrc.ec.europa.eu/repository/handle/JRC126571

		significant reduction of greenhouse gas emissions and an increase in energy efficiency require radical changes in the way we produce and consume energy.	
6	ENTRACK (H2020, 2020-2023)	The goal of EN-TRACK is to create a one-stop-shop platform with standardized data related to the energy efficiency performance of the public and private building stock. GECO contributes its expertise with user engagement and agile service development in order to maximise market adoption of the platform. We are leading the project communication and platform branding efforts and will support the establishment of a co-creation dialogue with financial institutions and building owners all over EU.	a,g,i,
7	FLEXGRID (H2020, 2019-2022)	A novel smart grid architecture that facilitates high RES penetration through innovative markets towards efficient interaction between advanced electricity grid management and intelligent stakeholders	a,b,k
8	FlexNett (RCN, 2015-2017)	Contributes to increased flexibility for future smart distribution networks in a cost-efficient-environmentally- friendly and reliable manner. This will be done by demonstrating and verifying flexibility at various levels in the power system – for the benefit of customers, TSOs, market stakeholders/aggregators, etc.	c, d, g, k
9	IELECTRIX (2019-2022)	Leaning upon four demonstrations managed by large DSOs in Austria, Germany, Hungary, and India, IELECTRIX aims to develop and demonstrate a set of solutions and tools for the optimization of local energy networks to support the development of decarbonized local energy communities with a high replication potential in Europe and in India since allowing additional renewables to generate and distribute electricity at lower costs than a traditional grid reinforcement.	a,g, j,i
10	INVADE (H2020, 2017-2019)	H2020 Smart system of renewable energy storage based on INtegrated EVs and bAtteries to empower mobile, Distributed and centralized Energy storage in the distribution grid. The INVADE project aims to deliver a Cloud-based flexibility management system integrated with EVs and batteries empowering energy storage at mobile, distributed and centralized levels to increase the share of renewables in the smart grid.	a, b,c, f, h
11	IoTSec (RCN, 2015-2020)	The initiative IoTSec, Security in Internet of Things for Smart Nett, was established in 2015 to contribute to a safe information system. The project's purpose is to build a national security center for SmartGrids and to educate cybersecurity specialists on the Master's and Ph.D. levels. The project will engage 15 professors, 15 Ph.D. candidates and 20 master's students. IoT Sec will gather the most important cybersecurity actors and will increase security and personal security after implementing SmartGrids in Norway.	a,e
12	Probono (H2020, 2022-2026)	PROBONO's ambition is to provide validated solutions for the design, construction, and operation of new and/or retrofitted zero-pollution and positive energy buildings as part of sustainable green neighborhood developments. The type of neighborhoods will be piloted across six EU states where the PROBONO living labs will be established.	a, b,h,k
13	RESOLVD (H2020, 2017-2020)	The project aimed to improve the efficiency and the hosting capacity of distribution networks, in a context of highly distributed renewable generation by introducing flexibility and control in the low voltage grid. The project used European Commission Joint Research Centre proposed methodology to perform a cost-benefit analysis. The methodology is suitable for Innovation cation projects and can be used in the project.	a,e,f, i,j
14	SCOTT (H2020 ECSEL JU, 2017-2020)	Creating trust in wireless solutions and increasing their social acceptance are major challenges to achieving the full potential of the Internet of Things (IoT). Therefore, SCOTT – Secure Connected Trustable Things, a pan-European effort with 57 key partners from 12 countries (EU and Brazil), will provide comprehensive cost-efficient solutions of wireless, end-to-end secure, trustworthy connectivity and interoperability (Technology Readiness Level 6-7) to bridge the last mile to market implementation. SCOTT will not just deal with ,things that are "connected", but with "trustable things that securely communicate", i.e. things interconnected by dependable wireless technology and valuing the end-users privacy rules.	a,e,g,
15	SENDER (H2020, 2020-2024)	SENDER's overall aim is to develop and test the next generation of energy service applications for demand-response, but also home-automation and -convenience. This includes engaging consumers/prosumers directly in a co-creation process with other actors from the energy domain	a,c,d,e,f,g
16	SENSEI (H2020, 2019-2022)	SENSEI will first elaborate P4P schemes to finance energy efficiency improvements and then integrate these P4P schemes with the preparation and implementation stages of the Energy Performance Contracting model. GECO Global leads the dissemination and communication activities as well as the engagement strategy to support stakeholders in rolling out the first P4P pilots in the EU.	e,i,g
17	Smartenergy Hvaler (RCN,2014-2016)	Norway´s premier demo lab for SmartGrid technology and consumer flexibility.	a,c
18	Smart Rural Grid (FP7, 2014-2016)	Smart ICT-enabled Rural Grid innovating resilient electricity distribution infrastructures, services and business models.	a,b,e
19	SYNERGY (2020-2023)	SYNERGY introduces a novel framework and references big data architecture that leverages data, primary or secondarily related to the electricity domain. Stakeholders are getting involved in novel sharing/trading models of data sources and intelligence, to gain better insights and shift individual decision-making at a collective intelligence level. SYNERGY attempts to unleash the data-driven innovation and collaboration potential across currently diversified and fragmented electricity actors.	a,e,g,
20	E-REGIO (ERA-Net-2017-2020)	E-REGIOs primary objective is to perform new trials in order to increase the level of understanding of local markets as well as to demonstrate and validate that local energy markets will be part of the solution towards a greener, more sustainable, and distributed energy supply. One of the main E-REGIO objectives is to integrate the AI methodology into the local market design and local flexibility trading. Deep learning reinforcement algorithms have already been developed for this purpose.	a,e,g,k

Table 2. SIN's projects map aligned to the literature.

Summarizing the SIN's projects trajectory, next to the technology, community and citizens-oriented solutions are getting attention in the efforts of accelerating the decarbonization of energy systems and facilitate the green transition (Figure 2).

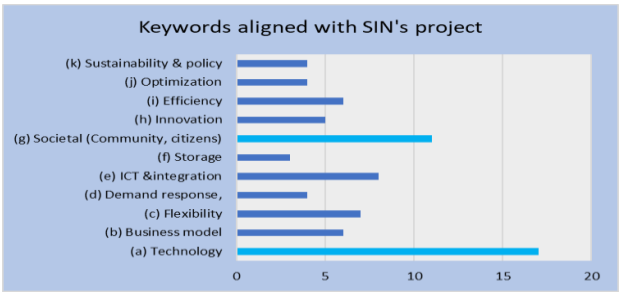

Figure 2. keyword alignment with SIN projects objectives

5 THE FUTURE DIRECTIONS OF ENERGY RESEARCH AND INNOVATIONS

The Case of the ELAND project: Energy solution converging toward community and citizens

E-LAND through its modular toolbox aimed to solve technological, societal, and business challenges on multi-vector energy Islands. The toolbox comprises different methodologies and tools to support the energy islands and isolated communities in their decarbonization processes and green transitions.

E-LAND put the society (communities and citizens) in the center and all the solutions and developed technology, modular tools, and business models work for them (see Figure 2).

One best practice in the E-LANAD project is the early engagement of the pilot communities to co-create the E-LAND toolbox for better adoption and utilization by the end-users. This kind of development towards citizen-centered energy research is clearly seen also in call topic requirements from the new Horizon Europe funding programme.

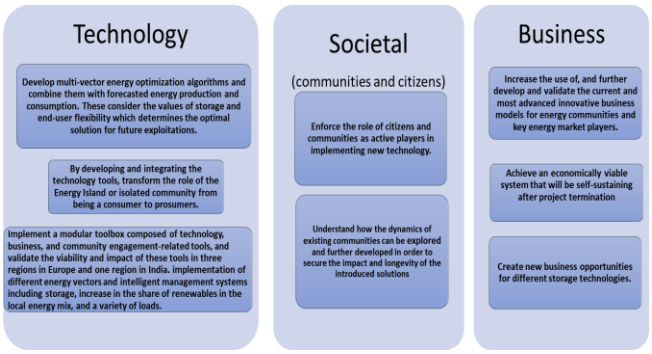

Figure 1. E-LAND's objective to overcome technological, societal, and business challenges.

6 CONCLUSION

Advanced energy research and innovation have contributed to the green transition and improved the well-being of society. In this connection, enormous research projects have documented positive results in many ways. Despite these positive achievements, the need for smart energy solutions is growing as there is still a huge gap to achieve net-zero greenhouse gas emissions.

After a thorough investigation of the energy research and innovation for the last decade, the paper identified and discussed five major research dimensions 1) Energy efficiency, optimization, modeling, and simulation, 2), Energy Technology development, digitalization/ICT, and integration 3), Demand response and flexibility, 4), Business model, techno-economic, and sustainability assessment, 5) Energy Community and citizens.

In line with the literature findings, the content analysis of the ongoing and completed projects of SIN showed that most of the research tends to focus on and has become emphasized communities and citizens-oriented solutions (e.g. the E-LAND) next to the technology development.

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