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***Abstract*— Demand response is important to integrate renewable energy sources into the energy system, and maintain frequency stability and security of supply. Demand-side management (DSM) is essential for energy consumers to participate in demand response. The adoption of DSM solutions relies on financial incentives, technology readiness, regulatory support, but also the adoption environment and conditions that vary in different regions. However, no available method facilitates this investigation process. This paper uses a case of residential DSM solutions in Denmark to introduce an ecosystem-based instrument that can systematically identify regional needs and evaluate potential DSM solutions. The case study shows several types of DSM appliances and services have been offered to residential consumers, covering certain parts of both implicit and explicit demand response. However, none of the existing DSM solutions has fully managed to target any identified opportunities. Furthermore, three aspects should be focused for promoting the adoption of the DSM solutions: 1) financial incentives for acquiring DSM-enabled technologies; 2) adoption of distributed energy resources; and 3) big data and AI enabled automatic load control.**

Keywords*—*demand side management, regional need, domain analysis, business ecosystem, CSTEP ecosystem analysis

I. INTRODUCTION

The modern electricity system, to a large extent, depends on fluctuating electricity production from various renewable energy sources [1]. This leads to either excess electricity production when renewable energy production is high or a lack of electricity when renewable energy production is low [2].

Demand response becomes increasingly important to integrate renewable energy sources into the energy system, maintain frequency stability and security of supply [3]. According to the Federal Energy Regulation Commission, demand response is defined as "being changes in the usage of electricity by consumers from normal consumption patterns in response to either change in prices or to incentive payments designed to induce lower electricity usage when high prices in the market" [4]. The demand response potential in Europe consists of a minimum hourly load reduction of 61 GW and a minimum hourly load increase of 68 GW [5].

There are three types of electricity consumers: industrial, commercial and residential consumers [6]. According to [5], the residential demand response potentials can come from the following appliances: freezers/ refrigerators, washing machines/ tumble dryers/ dishwashers, air conditioners, electric storage water, heat circulation pumps, and electric storage heaters. However, compared to the other two types, residential consumers are more passive in participating in demand response.

To motivate residential consumers to participate in demand response, demand-side management (DSM) is considered one of the more promising solutions. However, the adoption of DSM solutions relies on financial incentives, technology readiness, and regulatory support. Furthermore, these conditions vary in different regions. Therefore, the design of DSM solutions needs to consider and fulfil the regional needs. However, no method can facilitate this investigation process.

Therefore, this paper aims to introduce an instrument that can systematically identify regional needs and evaluate potential DSM solutions that fulfil local needs. This paper uses the residential DSM in Denmark - the consumption side of the Danish electricity system as a case study. There are four steps in the instrument, and introduced in each section of the paper:

Step 1- Business ecosystem mapping

Step 2- CSTEP ecosystem analysis

Step 3- Existing solution investigation

Step 4- Feasibility evaluation

II. METHODOLOGY

The regional-oriented design and evaluation of DSM are based on the methods:

- Business ecosystem architecture development [7]. It includes five stages, and at each stage, certain activities are conducted with certain methods as shown in TABLE I.
- CSTEP ecosystem analysis and evaluation method [8]. This method includes five critical business ecosystems dimensions called CSTEP, and each CSTEP dimension includes two or more sub-dimensions as shown in TABLE II.
- Ecosystem-driven business opportunity identification method [9]. It is a systematic approach for analyzing and evaluating business opportunities based on the CSTEP ecosystem analysis and evaluation method.
- Solution analysis and evaluation method [10]. This method combines the scoping review method and the CSTEP five-dimensional three-scale evaluation (shown in TABLE III) in Ecosystem-driven business opportunity identification method [9] to investigate, evaluate, and select solutions.

TABLE I. THE FIVE-STAGE BUSINESS ECOSYSTEM ARCHITECTURE DESIGN APPROACH WITH A DETAILED EXPLANATION [7]

Stage	Purpose	Input/methods
Boundary identification of a business ecosystem	Define the business ecosystem boundary with two dimensions of the targeted domain and the cultural/geographic boundary	Market research
Identification of actors and their roles in the business ecosystem	Identify actors and their roles	The output from Stage 1; Market research
Identification of actors' value propositions	Identify value propositions for each role and identify the potential interactions between roles	The output from Stage 2; Market research
Identification of interaction between actors	Identify the types and content of the interaction between roles	The output from Stage 3; Market research; Assumptions
Verification of business ecosystem architecture design	Design minimum viable ecosystem and ecosystem roadmap Visualize the developed business ecosystem architecture Check completeness	The output from Stage 3 and Stage 4 (business model); Research aims/focuses

TABLE II. DEFINITIONS OF CSTEP FIVE DIMENSIONS [8]

Dimension	Sub-dimension	Explanation
Climate, environmental and geographic situation	Climate	The general weather (including seasons) conditions that are usually found in a particular place;
	Environment	The conditions that people live, work or spend time in and the way that they influence how they feel, behave or work;
	Geographic situation	The natural features of a place, such as mountains and rivers
Societal culture, demographic environment	Societal culture	The way of life or work, especially the general customs and beliefs, of a society or an organization;
	Demographic environment	The demography of an area is the number and characteristics of the people who live in an area, in relation to their age, sex, if they are married or not, etc.
Technology readiness	Infrastructure	The basic systems and services, such as transport and power supplies, that a place uses in order to work effectively.
	Technology development capacity	The set of capacities to plan for technology transfer and development to achieve regional and national goals [11]
	Technology maturity	Refer to the Technology Readiness Levels (TRL) for assessing the maturity level of a particular technology [12]
	Technological skills	The knowledge and expertise needed to accomplish complex actions, tasks and processes relating to computational and physical technology
Economy and finance	Economy	Economy related to market trade, industry
	Finance	Cost of labour, material, maintenance, and service Revenue from sales, income, compensation, Return-on-Investment
Policies and regulation	Polices	the activities of the government, members of law-making organizations, or people who try to influence the way a country is governed;
	Regulation	An official rule or the act of controlling something

TABLE III. CSTEP FIVE-DIMENSIONAL THREE-SCALE EVALUATION [9]

CSTEP dimension	Criteria
Climate and environmental benefit	1: no significant climate or environmental benefit 2: there is climate or environmental benefit, but remain unclear 3: there are significant and clear climate or environmental benefit
Social awareness and feasibility	Social awareness and feasibility mainly refer to the increasing awareness of certain social norms and convenience (from full/semi-manual labour involvement to fully automatic): 1: no significant increasing awareness or convenience 2: might have increasing awareness or convenience, but remain unclear

	3: there is significant and clear increasing awareness or convenience
Technology readiness level	The evaluation also corresponds to the Technology Readiness level 1: may be reached within a long-term period (TRL 1-2) 2: may be reached within a medium period (TRL 3-6 3: can be realized within a short-term period. (TRL 7-9)
Economic feasibility	1: long-term return-on-investment, or no financial significant benefit but large investment/cost 2: medium-term return-on-investment 3: short-term return-on-investment, or significant financial benefit and low investment
Political and regulatory feasibility	1: policy agenda is under discussion, and the related regulations remain unclear 2: political agenda is there, and the regulation will be ready after a certain period 3: the regulations are ready or will be ready in a short-term period

III. Case Study and Results

A. *Business ecosystem investigation*

Based on the business ecosystem architecture development [7], the targeted energy ecosystem of the energy distribution network in Denmark is mapped as shown in Fig. 1.

The transmission system operator (TSO) is included because the TSO, Energinet, in Denmark is responsible for the DataHub. Since 2013, Denmark has implemented DataHub, a centralized IT system that handles all consumption and billing data for the Danish electricity market.

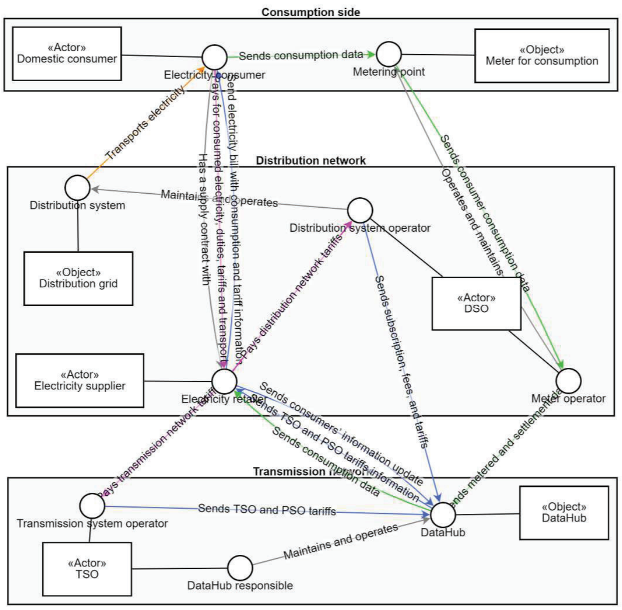

Fig. 1. The electricity distribution network ecosystem in Denmark

B. *CSTEP ecosystem analysis*

The current and future ecosystem conditions are investigated based on the CSTEP ecosystem analysis and evaluation method [8], and shown in TABLE IV.

The analysis for the dimension of climate, environmental and geographic situation shows that Denmark has a significant amount of oil and gas reserves. The renewable energy resources in Denmark are wind, solar, biofuels and waste incineration. Renewable energy resources account for 60% of the total electricity generation in Denmark [13]. According to the Energy Agreement by the Danish Parliament in 2018 [14], the conventional energy reserves will be decreased and renewable energy resources are expected to increase significantly in the future.

The total electricity consumption in Denmark is 112,148 TJ in 2016 [13], corresponding to the electricity consumption of 5,422 kWh per capita which is above the global average electricity demand of 3,127 kWh per capita (2014) [15]. Similar to the global trend, the Danish electricity consumption is expected to increase due to the increasing electrification.

The population of higher education in Denmark is 39.2%, which is higher than the OECD average [16]. The level of education among the Danish population is steadily increasing. According to [17], the number of people with Ph.D. has increased by 170% and master degrees have increased by 80% from 2006 to 2018.

The electricity network in Denmark is one of the most advanced electricity networks in the world with the highest security of supply in Europe, corresponding to 99.99% [18]. The Danish electricity transmission lines interconnect with Germany, Norway and Sweden. New interconnections, e.g., to the Netherlands (COBRAcable), England (Viking Link), and Germany (Kriegers Flak and Vestkystforbindelsen) are currently under construction or in the project pipeline. Smart meters are mandatory in Denmark which is the foundation of DSM implementation. Furthermore, there is increasing number of energy related data have been collected, stored and utilized.

The Danish electricity price is higher compared to the rest of European countries, this is due to high taxes and tariffs. The market price is only about 14% of the price the consumer actually pays, the remaining 86% are VAT, tariffs and other taxes [19]. The electricity price structure is expected to change significantly in the future. The authorities have agreed to investigate the opportunities for implementing variable electricity tariffs and providing incentives towards energy efficiency investments, but mainly for industries.

Denmark's electricity market has been liberalised and unbundled Since 2003 [20]. hourly billing is possible for all residential consumers From 2022. A market player needs to be pre-qualified by Energinet to operate in the market, and the ancillary service market is mainly designed for generation not consumption. Both primary and secondary reserves require symmetrical bids, which is difficult for smaller energy consumers to participate in demand response.

The Danish Government's long-term goal is to make Denmark a low-emission society, e.g., the 2030 goal of being fossil free in the electricity and heat sector, the 2050 goal of an entire fossil-free energy society. The electricity market is expected to allow smaller consumers and producers to participate in the near future.

TABLE IV. The Current and Future Ecosystem Conditions and the Opportunities

Dimension	Current ecosystem condition	Future ecosystem condition	Opportunity
Climate, environmental and geographic situation	A significant amount of oil and gas reserves Renewable energy resources account for 60% of the total electricity generation in Denmark	Decreased conventional energy reserves Increased renewable energy resources	DSM is needed to respond to the fluctuating electricity production to ensure grid stability
Societal culture, demographic environment	Electricity consumption is decreasing	Electricity consumption will increase due to increasing electrification The adoption of DSM solution will grow and be faster	The adoption of DSM solutions will be increased and be easier
Technology readiness	Smart meter DataHub	More data will be collected and utilized More intelligent solutions will be developed	Data driven and AI (Artificial Intelligence) embedded DSM solutions will be possible to provide better results
Economy and finance	High electricity prices due to taxes	Hourly electricity prices with variable electricity tariffs	Consumers will be more alert towards electricity price signals and CO2 emission signals
Policies and regulation	Liberalized and unbundled electricity market Hourly electricity prices as an option	Fossil free The electricity market is open to smaller consumers' and producers' participation	Smaller prosumers will have more incentives to participate in the demand response programs

C. DSM solution investigation

Demand response programs are divided into incentive-based or explicit methods [21]. The implicit demand response methods include, e.g., Real-Time Pricing (RTP), Time-of-Use rates (ToU) and Critical Peak Pricing (CPP) [10]. The explicit demand response mechanisms include, such as remotely direct load control [22] and ancillary service [23].

In Denmark, an implicit demand response method, ToU, is popularly used by distribution system operators (DSOs). For instance, the Danish DSO, Trefor, charges higher DSO tariffs during the hours of 17.00-21.00 in the winter due to high electricity demand for lighting and heating purposes as shown in TABLE V. However, according to [10], RTP and CPP are not feasible due to the Danish distribution tariff legislation.

TABLE V. TREFOR'S TARIFF MODELS

Period hours	Tariff	
	Winter [Ore/kWh]	Summer [Ore/kWh]
0-6	11.62	11.62
6-17	11.62	11.62
17-21 (17-20)	(35.97)	11.62
21-24 (20-24)	(11.62)	11.62
Average	14.66	11.62

The explicit demand response mechanisms have not yet been fully implemented in Denmark. For instance, Grundfoss' Circulation pumps ("Alpha 3" range of pumps) have internet-connect ability that can be remotely controlled. A pilot project [24] aggregates the flexibility of 315 kW heat pump capacity and offers it to the regulatory electricity market. Another pilot project [23] aggregates 10 kW of electrical vehicle (EV) capacity and trades it in the Frequency Containment Reserves (FCR) market. However, the operations are at the grid level, not directly on the consumption side.

In the market, there are some remotely controllable household appliances. For instance, a white appliance retailer, IoTeksperten, sells IoT-enabled and controllable refrigerators/freezers, dryers, dishwashers and washing machines, but consumers need to manually control the devices based on their preferences.

Some international companies offer DSM solutions. For instance, Enel X (https://corporate.enelx.com) which primarily operates in Italy, participates in DR programs by flexible adjustments of loads, and develops DSM systems using the DEN.OSTM platform to manage loads and on-site assets. Another company, Eaton (https://www.eaton.com/), offers software, hardware and service to provide a complete portfolio of DR alternatives for residential, commercial, and large industrial consumers. Their solutions mainly focus on the commercial sector and only provide DSM solutions in North America. Voltalis (https://www.voltalis.com/) provide DSM solutions for consumers, but only operates in France.

D. Feasibility evaluation

To investigate whether and how much the existing DSM solutions can match the identified opportunities in the Section of CSTEP ecosystem analysis, the feasibility evaluation is conducted.

- **Opportunity 1**. DSM is needed to respond to the fluctuating electricity production for ensuring grid stability

Most of the existing DSM solutions aim to aggregate the electricity loads, and the aggregated loads are mainly offered to the electricity markets. However, grid stability was not mentioned. The aggregated loads can easily be offered to DSOs for grid balancing. DSOs have foreseen the grid overload challenges due to the increasing number of distributed energy resources and electrification. Therefore, DSM solutions for grid balancing will be soon needed.

- **Opportunity 2**. The adoption of DSM solutions will increase and be faster

The adoption of DSM solutions will increase and be faster due to consumers' increase in technology skills and environmental awareness. In the market, there are IoT, or internet based remote-controllable appliances and consumers can use mobile applications to remote control these appliances. However, consumers need to manually control the devices based on their preferences. This inconvenience might demotivate consumers and manually based control only can participate in implicit demand response.

- **Opportunity 3**. Data-driven and AI-embedded DSM solutions will be possible to provide better results

Many ongoing pilot projects and DSM solutions in the market have embedded big data and AI in the solutions. However, the implementation of big data and AI-embedded DSM solutions are still rare due to the low maturity level. Furthermore, privacy and security are still big concerns, especially due to General Data Protection Regulation (GDPR) (EU) 2016/679.

GDPR is a regulation on data protection and privacy for all individuals within the European Union. Due to GDPR, the data collection and use for training AI are challenging for many technology providers if their DSM solutions target residential consumers.

- **Opportunity 4**. Consumers will be more alert towards electricity price signals and CO2 emission signals

Currently in Denmark more and more residential consumers have chosen hourly electricity prices and many mobile applications provide hourly electricity price information. Meanwhile, residential consumers are aware of the electricity price signals due to high energy prices.

Although some DSM solutions have considered hourly electricity prices, RTP and CPP are not feasible due to the legislation. Meanwhile, although more residential consumers have been aware of CO2 footprint, e.g., recycling, but electricity production-related CO2 emission signals are not considered. Furthermore, no existing DSM solutions have offered this service.

- **Opportunity 5**. Smaller prosumers will have more incentives to participate in the demand response programs

Currently, some residential consumers who have EVs can participate in demand response programs (e.g., ancillary services) via their EV charging service providers. However, in general, there are no available DSM solutions targeting residential prosumers who have photovoltaics, batteries, or heat pumps.

IV. DISCUSSION

Based on the investigation, this paper finds that several types of DSM appliances and services have been offered to residential consumers. More solutions in the market start to include hourly electricity prices, but not variable electricity tariffs or CO2 emissions. Several DR-enabled household devices and appliances are available in Denmark, but no DSM services. Furthermore, DSM-enabled technologies require consumers to actively react towards the signals, e.g., electricity prices or CO2 emissions signals. However, electricity consumers are relatively passive due to various reasons.

To promote the adoption of the DSM solutions, this paper recommends the following three aspects considered in the demand response implementation:

- Financial incentives for acquiring DSM enabled technologies

Due to long Return-on-Investment period, financial incentives (e.g., loans or compensation) to consumers might encourage the adoption of DSM enabled technologies. The implementation of the financial incentives depends on the governmental agencies, or related authorities, such as TSO or DSOs.

For instance, the Danish energy agency has several support schemes for energy performance improvement. However, for residential energy consumers, only building renovation is supported; and subsidies for digital solutions for improving energy improvements in municipal and regional buildings are provided. Therefore, there is no financial support for demand response or energy flexibility enabled technologies or solutions.

- Distributed energy resources (DERs) adoption

The current trend shows that even more DERs, e.g., Electric Vehicles, heat pumps, and batteries, will be been installed on the demand side. DSM solutions can optimize the performance of the consumers' energy profiles, which would benefit both consumers and DSOs. Therefore, the DERs adoption on the demand side will encourage the DSM adoption. However, the cost of DERs with an intelligent control system is still high for residential consumers.

- Big data and AI enabled automatic load control

Controlling consumers' appliances based on the electricity price signal, CO2 emissions signals, and consumers' preferences can reduce electricity costs and CO2 emissions. Furthermore, the flexible load can be aggregated to participate in the regulation market as a virtual power plant.

Automatic load control relies on the implementation of at least hourly electricity billing contracts and would benefit from the implementation of variable electricity tariffs. Furthermore, it highly depends on the quality of data which usually from multiple sources and AI algorithms.

Data acquisition of real-time, high-resolution, multiple-sources big data is not easy. Especially different energy loads require different types and resolutions of data. Furthermore, AI algorithms have been implemented in many domains, e.g., social media, AI algorithms for automatic load control at the demand side are not popularly implemented. Adopting AI-enabled load control also depends on customers' preferences and tolerance towards faults and errors.

V. CONCLUSION

This paper introduces an ecosystem-based instrument for opportunity identification and feasibility evaluation. The instrument includes four steps as shown in TABLE VI. The case of residential DSM solutions in Denmark shows that there is no significant technological barrier for the DSM development, although the automatic load control requires big data and AI algorithms which have been developed and improved fast.

Several types of DSM appliances and services have been offered to residential consumers, and cover certain parts of both implicit and explicit demand response. However, none of the existing DSM solutions has managed to fully target any of the identified opportunities. Therefore, there is still room for innovative DSM solutions that can address the identified opportunities in the targeted energy ecosystem.

Three aspects should be focused for promoting adoption of the DSM solutions: financial incentives for acquiring DSM enabled technologies; adoption of distributed energy resources; and big data and AI enabled automatic load control.

TABLE VI. THE ECOSYSTEM-BASED INSTRUMENT FOR OPPORTUNITY IDENTIFICATION AND FEASIBILITY EVALUATION

Step	Activities
Step 1- business ecosystem mapping	• Identify the main elements of the targeted energy ecoystem • Map the targeted energy ecosystem
Step 2- CSTEP ecosystem analysis	• Investigate current and future situation of the energy ecosystem • Investigate the opportunities (the significant differences between the current and future situation)
Step 3- Existing solution investigation	• Investigates existing solutions in the ecosystem
Step 4- Feasibility evaluation	• Evaluate the solutions based on the identified opportunities

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