Readiness to adopt the Smart Readiness Indicator scheme across Europe: A Multi-criteria Decision Analysis Approach

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***Abstract*—Facing the challenges of climate change, energy poverty, and energy crisis, humanity is increasingly focusing on the transition to green and fossil fuel-free alternatives, showcasing the commitment to sustainable development. Consequently, devising new methods for decarbonizing the energy system has become crucial to satisfy the energy demands of industries, businesses, transportation, and residential sectors. Towards this direction, a profound comprehension of the situation and, as a result, the implementation of a series of actions to overhaul the regulatory framework, advance technological innovations, stimulate economic development, and encourage collective social efforts emerges. The aim of this study is to assess the readiness for adopting the Smart Readiness Indicator (SRI) scheme in several European countries. This Indicator, introduced by the European Union, seeks to enhance the energy efficiency of buildings, adapt operations to the occupants' needs, and respond to signals from the electricity grid. Our analysis employs a multicriteria framework to evaluate a country's preparedness for the SRI scheme, relying on social, political, economic, and technological dimensions, and incorporates a comprehensive set of twelve evaluation criteria. The methodology is based on a combination of the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Twenty European countries are ranked, and areas for growth are identified, highlighting potential intervention gaps in the policy-making front.**

Keywords— Smart Readiness Indicator, Smart Homes, Energy Efficiency, Decarbonization, Climate Change, Multi-criteria Decision Analysis

I. Introduction

Buildings account for 40% of the total energy consumption worldwide [1]. Many tools have emerged lately aiming to reduce the consumption caused by buildings, including automation and control tools [2], AI models including comfort aspects [3], optimization techniques to exploit self-consumption [4], as well as forecasting algorithms for energy consumption [5]. The Smart Readiness Indicator (SRI) was introduced in 2017, following an initial technical study by the European Commission aimed at defining the SRI and formulating a methodology for its calculation. The momentum for implementing the SRI significantly increased with the 2018 recast of the Energy Performance of Buildings Directive (EPBD) [6] which officially established the SRI as an optional EU system for assessing the smart readiness of buildings [7]. Further regulations [8], [9] and technical studies [10] laid the groundwork for the formal SRI testing phase at national level, with support from the SRI support platform. This platform, acting as the official intermediary for Member States, offers technical guidance and assistance on the implementation of the SRI. The indicator evaluates a building's capability to optimize its energy efficiency and overall performance, adapt to signals from the grid (energy flexibility), and meet the needs of occupants [11], focusing on the electromechanical infrastructure rather than the building envelope.

This study aims to evaluate the level of SRI implementation in various European countries and identify potential actions to enhance its adoption. Additionally, it seeks to provide policymakers with insights into the indicator's maturity, aiding in strategic decision-making.

II. Background

The SRI scheme represents a transformative opportunity to digitize and modernize the EU's building stock, providing essential insights into the technological readiness of buildings for stakeholders involved in renovations, including owners, tenants, property managers, technology providers, designers, engineers, and policymakers [12]. These technologies impact several aspects of a building, such as energy efficiency, energy consumption, flexibility, and air and water quality, demonstrating significant reductions in energy use and CO_2 emissions, as well as overall improvements in quality of life.

The foundation of the SRI is built upon three primary pillars, which are the main drivers behind its development : a) responding to tenant needs, b) interacting with energy networks, and c) enhancing energy efficiency and operation.

The SRI's methodology is based on a compilation of 54 "smart-ready services" that increase a building's intelligence,

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categorized by the functionalities they offer. Examples include controlling heating and cooling systems, airflow, window shades, etc. These services are assessed against seven "impact criteria," aligned with the SRI's core goals, which can be further classified into three "key functionalities." It is worth noting that certain services may not apply universally to all criteria, and some services may be mutually exclusive.

To integrate various sectors and impact categories into a cohesive methodological framework, a Multi-Criteria Analysis method was proposed and developed as the official methodology for calculating the SRI.

Despite its potential, the SRI is still in its infancy, with only 11 countries formally adopting the framework: Austria, Croatia, Czech Republic, Denmark, Finland, France, Slovenia, Spain, Cyprus, Belgium, Germany [13].

III. Challenges and Objectives in SRI Adoption

The SRI scheme scrutinizes aspects related to categorizing buildings by their intelligence level. A key goal is to amplify energy savings through the integration of energy efficiency measures alongside smart building renovations.

The scheme aims to define buildings' future cross-sectoral role within the energy infrastructure, fostering synergies with the energy sector and other complementary fields, such as Information and Communication Technologies (ICT) [15]. Furthermore, SRI aims to raise awareness of the advantages of smart buildings, encouraging the adoption of innovative smart systems and advanced construction materials [16]. This initiative is expected to drive energy-efficient investments forward, facilitating the integration of nearly zero energy buildings (NZEBs) and positive energy buildings (PEBs) into the existing building stock.

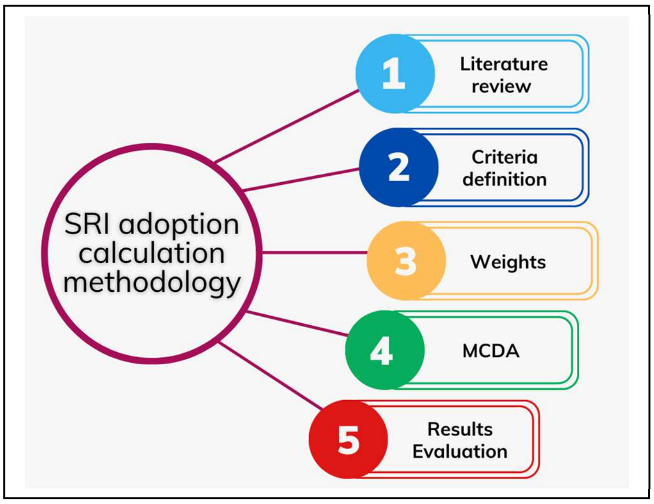

Fig. 1. Overview of SRI adoption readiness assessment methodology.

Despite its potential benefits, the development and adoption of the SRI have not been without challenges. Technical complexities, stakeholder engagement issues, and the need for robust data sources have posed significant hurdles. Comparisons with similar global initiatives highlight the unique characteristics of the SRI within the context of international smart building assessment frameworks. Understanding these challenges and global comparisons enriches the discussion surrounding the SRI's evolution and relevance.

In addition to the Smart Readiness Indicator (SRI), various methodologies have been developed to evaluate and promote smartness and energy efficiency in buildings. These methodologies offer complementary perspectives and approaches to assessing building performance and sustainability. Markoska et al [17] proposed a methodology that integrates real-time performance testing with the Smart Readiness Indicator to assess building smartness. By leveraging metadata schemas and real-time monitoring, this approach enhances building operation and sustainability. Sharifi [18] explored the typology and structure of smart city assessment tools and indicators, shedding light on diverse approaches and commonalities among tools aimed at evaluating smart city performance. These insights are relevant to building-specific assessments and can inform the development and refinement of methodologies such as the SRI. Saad et al. [19] discussed the Smart SME Technology Readiness Assessment, which offers insights into assessing technology readiness in industrial settings.

This study introduces and addresses a multi-criteria analysis challenge, aiming to assess the readiness of European countries to adopt the Smart Readiness Indicator scheme. Based on four pillars—social, political, economic, and technological—and incorporating twelve evaluation criteria, the research assesses and ranks twenty countries with varying profiles and levels of commitment to sustainable development. The outcomes seek to shift the interest in identifying areas for improvement and assist relevant entities in formulating suitable policies to foster a more sustainable society and economy.

IV. Methodology

A. *Multicriteria Decision Analysis (MCDA)*

The MCDA methods utilized in this study include the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The AHP, developed in 1980 by Saaty, explores how to ascertain the relative significance of a set of activities within a multicriteria problem [20]. This method enables the inclusion of judgments about qualitative criteria alongside quantitative ones [21] and is based on three crucial principles: first, structuring the problem at hand; second, making relative comparisons between alternatives and criteria; and third, synthesizing priorities to make the optimal decision.

The TOPSIS method, pioneered by Hwang and Yoon as an alternative to the ELECTRE family of methods, is a trade-off synthesis approach. It recommends selecting actions that minimize the geometric distance from the positive ideal solution and maximize the distance from the negative ideal solution [22]. This method involves constructing and normalizing a decision table (alternatives x criteria), calculating a weighted decision table, identifying positive and negative ideal solutions, and concluding with a ranking. TOPSIS is distinguished by its coherent logic, considering both ideal and counter-ideal solutions, and facilitating the evaluation of numerous alternatives against multiple criteria through a systematic, programmable computational process.

B. *Criteria to assess readiness per country*

Twelve evaluation criteria were identified: (1) social, (2) political, (3) economic, and (4) technological.

Social criteria:

- Climate change at the center of Global Challenges

- Personal action against climate change
- Personal action to improve home energy efficiency
- Employment in Renewable Energy Sources sector

Political criteria:

- Regulatory Indicators for Sustainable Energy (RISE)
- Number of energy communities

Economic citeria:

- Ease of doing business
- Financial System Stability

Technological:

- SRI implementation and number of building calculation publications
- Infrastructure
- Energy Transition Index
- Digital Economy and Society index

These criteria are predominantly quantitative, offering clear numerical evaluations, except for the qualitative "SRI implementation and number of building calculation publications". Some criteria, like "Employment in the RES sector" and the "Number of energy communities", have been normalized based on each country's population to ensure objective comparisons, using data from the United Nations database in 2021, normalized per million population [24], [25].

At the social sector, "Climate change at the center of Global Challenges" focuses on European societal acceptance of climate change between hunger, poverty, armed conflicts, climate change, the economic situation of the country and others [26]. For "Personal action against climate change" respondents were given a list of 15 actions and asked what they had personally done to combat climate change in the past 6 months like reducing water waste, recycling, reducing the consumption of disposable items, buying electronic devices with low energy consumption, installing devices at home that controls and reduces energy consumption etc. [26]. "Personal action to improve home energy efficiency" consists of whether they have taken at least one measure like thermal insulation, changing doors, windows, or the heating system to improve the energy efficiency of the house they live in during the last 5 years [27]. The goals of the fourth social criterion "Employment in RES sector" are to monitor and analyze the development of renewable energy sectors in the EU, evaluate RES progress compared to the European Commission's 2020 targets and disseminate the research results to European journalists and energy players [28].

In the political criteria, "RISE" have more than 30 indicators covering 140 countries, that assess policy and regulatory support providing a benchmark for policy development for each of sustainable energy pillar such as access to electricity, access to clean cooking, energy efficiency and renewable energy [29]. "Energy communities" are cooperatives, social enterprises, associations or other types of non-profit legal entities that contribute to the sustainable energy transition through investments in renewable energy production and participation in energy markets. A higher number of energy communities indicates a more intensive energy transition [30].

In the economic domain, "Ease of doing business" from the Doing Business study, records changes in legislation in 12 business sectors for 190 economies and analyzes regulations that encourage efficiency and support the freedom to do business. It serves as a tool for designing regulatory policies by comparing progress and stimulating policy debate [31]. "Financial System Stability", which is part of the Global Competitiveness Index 4.0, analyzes the strength of the banks, the percentage of loans that are late to be repaid to the total loans, the credit area, which expresses the measurement of the economy of a country in relation to its productivity and the ratio of its funds to total risk-weighted assets. Those ensure reduced corruption and trust in the financial system [32].

Technologically, "SRI implementation and number of building calculation publications" has qualitative characteristics of High, Moderate and Low implementation. At High use of SRI are the countries in Test Phase of the scheme. At Moderate use are countries that are in public reports of SRI calculations and also countries that received funding from European mechanisms like LIFE CET. In Low use, belong countries that there is no instance of public application reports. These characteristics will be quantified by setting High to "3", Moderate to "2" and Low to "1" in the application scale of the scheme. "Infrastructure" consists of technology, science, health and environment and education for 64 economies, so it has a significant role in economic development [33]. "The Energy Transition Index" measures 120 countries on the performance of their energy system, as well as their readiness to transition to a secure, sustainable, affordable and reliable energy future [34]. Lastly, the "Digital Economy and Society Index" is mainly based on data from 2021 and monitors the progress made in the EU Member States in the digital sector. During the COVID-19 pandemic, Member States advanced their digitization efforts, but are still struggling to fill gaps in digital skills, the digital transformation of SMEs and the deployment of advanced 5G networks [35].

The decision matrix with the criteria, the countries and the data for each country is presented in the TABLE I.

V. Anticipated Findings

The assessment of the rankings involves twenty countries, each with different profiles and levels of progress towards sustainable development. This research is designed to pinpoint areas requiring enhancement and to assist relevant entities in formulating policies conducive to a more sustainable society and economy.

In the multicriteria model, four distinct cases of weightings were explored:

1. Weightings with emphasis on the criteria
2. Weightings with emphasis on the pillars (social, political, economic, technological)
3. Weightings with the mean of the previous two cases (criteria-pillars)
4. Weightings that were calculated by the Analytical Hierarchy Process (AHP) method

The weightings in the first 3 weight systems were assigned in a simplistic way. Minimum weighting was designated with the number 1, moderate with the number 2, and maximum with the number 3.

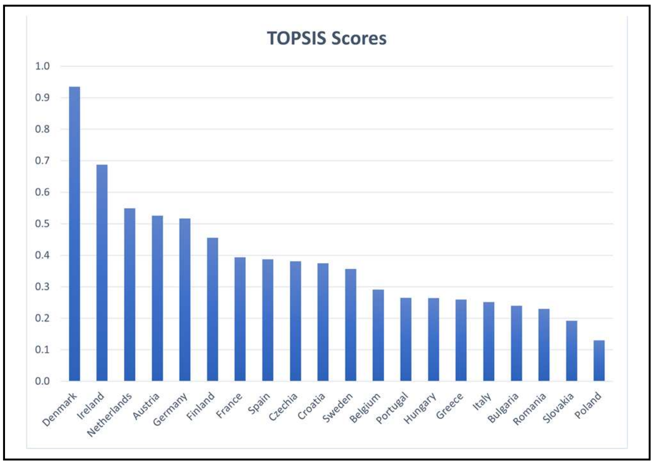

Fig. 2. TOPSIS scores in evaluating readiness of EU member states to adopt SRI scheme.

The most accurate and reliable approach is the last one, utilizing the Analytic Hierarchy Process. The findings of this study are expected to illuminate the specific areas where the evaluated countries fall short. This insight will then enable policymakers to implement targeted strategies for enhancement.

TABLE II. presents the pairwise comparison of the AHP assessment and the weightings that derived. The Consistency Ratio (CR) was found 4.2% which is acceptable. The scores that emerged after using TOPSIS Multicriteria method are shown in Fig. 2.

VI. Conclusions and Implications

The research and the subsequent application of the multicriteria analysis have revealed that the adoption of the SRI is still in its nascent stages. The TOPSIS scores can be divided into regions as shown in Fig. 3. Notably, Denmark and Ireland have demonstrated significant advancement in the implementation of the scheme, positioning them as leaders in readiness for future applications, largely due to their extensive participation in pilot projects. Denmark, in particular, has shown exceptional performance, ranking in the top 5 across all evaluated criteria, thereby securing the highest position in the overall ranking by a considerable margin. Meanwhile, Ireland has achieved the 2nd place, excelling especially in political criteria, where its high score underscores the importance of weighting in the analysis.

The scores can be analyzed into the categories they are in:

1. In the 1st region the score ranges between 0.55 – 1, involving two countries. Denmark as previously mentioned scores highly in all criteria. Ireland scores high in the key categories but the main criterion that brought it to 2nd place is “P2-Number of Energy Communities” where it has a big lead over the next country.
2. In the 2nd region the score ranges between 0.4 - 0.55, involving four countries. These are the Netherlands, Austria, Germany and Finland. They have very good scores in criterion “T1-SRI implementation and number of calculation publications in buildings” and similar scores in the P2 criterion. This puts them near the middle of the rankings.
3. In the 3rd region the score ranges between 0.29 – 0.4, where 6 countries are ranked. These maintain a medium to low score in all criteria. A notable example is Sweden which, despite its position in the P2 criterion where it surpasses the 2nd category groups, in the basic criteria “P1-Regulatory indicators for sustainable energy-RISE” and T1 lags behind and is below average.
4. In the 4th region the score ranges between 0 – 0.29, where eight countries are ranked. These countries are ranked lowest in almost all criteria with few exceptions for specific criteria that rank above average.

This research offers a thorough evaluation of options, taking into account a variety of factors simultaneously. For decision-makers, this means the ability to balance considerations such as cost, feasibility, environmental impact, and social implications, thus providing a nuanced understanding of the available choices. Moreover, the structured approach of multicriteria analysis minimizes personal biases, promoting objective decision-making. By clearly defining criteria, this method enhances transparency in decision-making processes, ensuring that choices are grounded in logical analysis rather than subjective preferences.

Looking forward, a comprehensive vision for the continuation of this study involves extending the assessment framework to include a broader array of countries. Establishing this evaluation as an annual benchmark could significantly assist analysts and policymakers in tracking advancements and identifying specific areas where countries lag, necessitating targeted improvements.

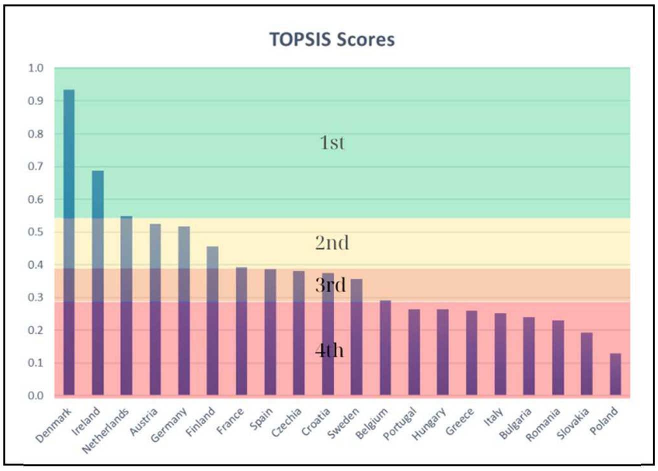

Fig. 3. TOPSIS scores divided in 4 classes.

The SRI scheme is instrumental in advancing the classification of buildings by their intelligence level and lays the groundwork for the establishment of building certification systems predicated on this innovative scheme. To enhance energy savings, it is essential to integrate energy efficiency measures with smart building renovations. Nonetheless, the transition to smart buildings necessitates a thorough economic and technical analysis regarding investment costs to ensure the attainment of desired levels of intelligence and energy efficiency with reasonable payback periods.

Future research should focus on expanding the involvement of a diverse group of stakeholders, such as building owners, tenants, technology providers, policymakers, and sustainability experts, in both the development and evaluation of the SRI system. This approach would facilitate ongoing dialogue and feedback, ensuring the indicator's relevance and its ability to meet the varying needs of stakeholders. Additionally, the implementation of pilot programs is crucial for testing and refining the SRI scheme in practical scenarios, enabling adjustments based on real-world experiences.

An essential direction for future research is the enhancement of the SRI's design to ensure its flexibility and adaptability across a wide range of building types, sizes, and uses. Acknowledging the diversity of buildings across different regions and sectors is vital for the universal applicability of the index. Moreover, the development and dissemination of case studies that demonstrate the successful application of the SRI could underscore its effectiveness and stimulate broader adoption. Finally, its combination with protocols like IPMVP for assessing the impact of energy efficiency actions could be a field of future research [36].

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APPENDIX

TABLE I. DECISION MATRIX

Countries	Criteria										
	S1	*S2*	*S3*	*S4*	*P1*	*P2*	*E1*	*E2*	*T1*	*T2*	*T3*	*T4*
Austria	18	63	29	3385	88	43.04	78.7	94.4	3	76.10	69.3	7
Belgium	20	61	48	1223	87	9.13	75.0	88.9	2	78.83	59.2	11
Bulgaria	6	35	41	3064	83	0.15	72.0	85.5	2	29.22	57.2	19
Croatia	12	60	37	4064	77	4.68	73.6	86.8	3	41.00	62.0	14
Czechia	9	47	47	2864	83	3.33	76.3	93.6	3	66.99	58.6	13
Denmark	35	76	47	9292	92	108.13	85.3	93.6	3	92.71	76.1	2
Finland	25	81	44	6413	86	14.99	80.2	98.3	3	87.60	72.8	1
France	16	69	37	2600	86	5.32	76.8	92.8	3	74.50	70.6	8
Germany	22	76	33	3079	92	58.12	79.7	90.6	2	77.12	67.5	9
Greece	12	62	25	2547	83	16.08	68.4	59.1	2	47.95	60.9	18
Hungary	11	61	38	3656	89	0.10	73.4	91.3	2	49.57	64.3	15
Ireland	24	68	39	1203	89	109.29	79.6	83.8	2	73.25	59.3	5
Italy	14	52	25	3479	87	3.34	72.9	80.1	2	58.81	60.6	12
Netherlands	35	72	62	4531	87	56.39	76.1	94.5	2	86.19	68.8	3
Poland	7	39	27	3375	70	2.14	76.4	91.2	1	48.46	59.7	17
Portugal	11	68	15	4878	89	1.07	76.5	78.0	2	58.34	65.8	10
Romania	6	29	33	1723	85	0.05	73.3	88.4	2	35.84	56.8	20
Slovakia	8	72	48	2662	88	4.22	75.6	94.2	1	43.42	58.8	16
Spain	17	76	33	2611	88	4.95	77.9	89.0	3	64.91	65.0	6
Sweden	41	81	41	6267	79	31.43	82.0	93.4	1	86.71	78.5	4

TABLE II. PAIRWISE COMPARISON OF CRITERIA IN AHP METHOD.

Criterion	S1	S2	S3	S4	P1	P2	E1	E2	T1	T2	T3	T4
S1-Climate change at the center of Global Challenges	1.00	0.50	0.25	0.33	0.14	0.20	0.33	0.17	0.14	0.20	0.17	0.33
S2-Personal action against climate change	2.00	1.00	0.50	0.50	0.20	0.25	0.50	0.20	0.20	0.33	0.20	0.50
S3-Personal action to improve home energy efficiency	4.00	2.00	1.00	2.00	0.33	0.50	1.00	0.33	0.25	1.00	0.33	3.00
S4-Employment in Renewable Energy Sources sector	3.00	2.00	0.50	1.00	0.25	0.33	1.00	0.33	0.25	2.00	0.33	1.00
P1-Regulatory Indicators for Sustainable Energy - RISE	7.00	5.00	3.00	4.00	1.00	2.00	3.00	3.00	1.00	3.00	2.00	5.00
P2-Number of energy communities	5.00	4.00	2.00	3.00	0.50	1.00	2.00	2.00	0.33	2.00	1.00	3.00
E1-Ease of doing business	3.00	2.00	1.00	1.00	0.33	0.50	1.00	0.50	0.33	2.00	0.33	3.00
E2-Financial System Stability	6.00	5.00	3.00	3.00	0.33	0.50	2.00	1.00	0.25	3.00	0.25	4.00
T1-SRI implementation and number of building calculation publications	7.00	5.00	4.00	4.00	1.00	3.00	3.00	4.00	1.00	3.00	1.00	6.00
T2-Infrastructure	5.00	3.00	1.00	0.50	0.33	0.50	0.50	0.33	0.33	1.00	0.25	3.00
T3-Energy Transition Index	6.00	5.00	3.00	3.00	0.50	1.00	3.00	4.00	1.00	4.00	1.00	5.00
T4-Digital Economy and Society Index	3.00	2.00	0.33	1.00	0.20	0.33	0.33	0.25	0.17	0.33	0.20	1.00
Criteria weights based on AHP	**0.017**	**0.026**	**0.057**	**0.046**	**0.175**	**0.104**	**0.058**	**0.097**	**0.183**	**0.054**	**0.151**	**0.032**