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Energy Transition Reality Check: Are Municipalities Meeting the Mark?

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***Abstract* – In order to meet regional and national climate neutrality goals, decentralisation has placed the energy sector under local government governance, pushing municipalities to take a more active role in energy planning and sector decarbonisation. This study attempted to assess the extent to which municipal efforts have been successful in the adaptation of low-carbon energy systems, and what is the current state of municipal initiatives concerning regional energy transitions. A composite index was constructed, incorporating nine indicators grouped into three main dimensions of sustainable municipal energy transition: energy efficiency, energy decarbonization, and smart energy system deployment. Five municipalities of the Baltic Sea Region were analyzed, and their energy transitions were assessed: the Gulbene municipality (Latvia), Tukums municipality (Latvia), Taurage municipality (Lithuania), Tomelilla municipality (Sweden), and Wejherowo municipality (Poland). Using a benchmarking approach, the main challenges and opportunities of energy transition in the selected municipalities were identified, which could be used as signals in developing concrete municipal sustainability action plans.**

***Keywords* – Benchmarking; composite index; energy efficiency; energy transition; energy policy; energy sustainability; municipality.**

Nomenclature

ETI	Composite municipal energy transition index
I_N^+	Positive impact normalized indicator
I_N^-	Negative impact normalized indicator
I_{act}	Actual value of an indicator for the specific municipality
I_{max}	Maximum value of an indicator across all municipalities
I_{min}	Minimum value of an indicator across all municipalities
I_D	Sub-index of a dimension
w	Determined weight of an indicator
n_I	Number of indicators in a dimension
n_D	Number of dimensions

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1. INTRODUCTION

The EU's ambitious path towards becoming the world's first climate-neutral continent by 2050 [1] has shifted the energy sector towards the adoption of new solutions on how energy is produced, supplied, consumed, and, more importantly, managed [2]. As the energy transition pushes towards national energy system decentralization and highlights the importance of the local energy generation framework [3], municipalities are regarded as the primary drivers and change agents of the EU's path to climate neutrality [7]. Decentralization has brought the energy sector under local government management, pushing for more active involvement in energy planning and sector decarbonization to reach national and global climate neutrality targets [4]. Improving energy efficiency and fostering renewable energy resource (RES) adaptation are local matters, and local authorities should provide the right conditions for it, considering the region's specifics, such as geographical conditions and special planning [5], [6]. Sperling *et al.* argued that the new role of municipalities would be to act as strategic energy planners, actively participating in the development of national energy policy and flexibly exploring, for example, new legal or economic incentives [10]. Other studies highlight the role of municipalities in energy transition by arguing that municipalities can reduce costs by independently generating electricity from RES. To achieve this, they should establish a transparent energy transition strategy that encourages the participation of stakeholders from all sectors and collaborates closely with them to execute the necessary changes [7]–[9]. Regional development in the context of the energy transition is multi-level and the identified inhibiting or facilitating factors need to be analysed as a whole, as they are interlinked [10]. The Covenant of Mayors initiative, which includes the development of Sustainable Energy and Climate Action Plans (SECAPs) in municipalities, is at the core of this transformative journey, steering municipalities across the EU to commit to ambitious climate and energy goals [11]. Although there has been a growing interest in analysing municipal energy systems over the last decade [12], there is still a lack of comprehensive tools that could effectively help to identify specific areas for increasing the sustainability of the municipal energy system [13].

Prior research employed different approaches to analyse municipal energy systems and explore potential future development scenarios. Hammerschmid *et al.* presented a municipal energy modelling tool based on massive data sets on Austrian municipalities to analyse the most optimal energy transition strategies in terms of regional economic and environmental impacts towards climate neutrality [14]. Although the tool offers great insights into the municipal energy system, it might be difficult to replicate because of the significant data limitations of municipalities in different countries. Azevedo & Leal used decomposition analysis to assess the contribution of local actions to climate change mitigation by looking at the aggregate change in the local energy system under the individual influence of multiple drivers of change, including externalities [15]. Moreover, Vringer *et al.* developed an operational model with an approach specifically designed to assess the impact of municipal performance, exclusively to assess the link between governance capacity and energy transition policy outcomes [28]. Stennikov *et al.* proposed multiple-criteria decision analysis to assess the state of municipal district heating (DH) system and rank different regions with respect to their DH efficiency [17]. Kleinebrahm *et al.* developed a municipal energy system optimization model to investigate energy transition scenarios in main sectors of municipal economy such as households, industry, services and transport. The authors argue that decision-making tools for municipal energy system analysis are crucial nowadays due to rapidly changing political frameworks [18]. Li *et al.* developed a long-range energy alternative planning (LEAP) model to characterize and describe energy flow and balance between supply and demand of municipal energy system [19]. Fischer *et al.* used the simulation tool EnergyPLAN to carry out a techno-economic analysis of the electricity and heating sectors of the energy systems of Nordic municipalities. The authors argue that a significant carbon reduction in the municipal energy systems could be achieved without increasing costs [20]. Drewello presented an analytical framework – a three-level model – that focuses on the determinants of success of the local energy transition and summarises the complex interrelationships of this process. The basic aspects that were identified as indicators for a potentially successful energy transition were: active citizens, local networking, the ability to adapt the local transmission grid and the deployment of long-term storage technologies [21]. Literature review shows that there is limited research on comprehensive evaluation framework for energy transition evaluation and comparison between the municipalities. Establishing a systematic approach to assess and compare the progress made by municipalities in their transition to low-carbon energy systems is crucial. Different indicators associated with municipal energy transition efforts would enable the identification of specific areas that require improvement in achieving the goal of sustainable energy transition.

This study introduced a novel methodology for municipal energy transition evaluation. This study uses a composite index approach to benchmark sustainable municipal energy transition potential in five municipalities of the Baltic Sea Region: Gulbene municipality (Latvia), Tukums municipality (Latvia), Taurage municipality (Lithuania), Tomelilla municipality (Sweden), and Wejherowo municipality (Poland). This study analyses nine indicators that characterise the transition of municipal energy systems towards more sustainable energy production, supply and consumption. The results provide valuable insights into specific improvement opportunities for each of the analysed municipalities and policy.

2. METHODOLOGY

This study applied a multilevel assessment metric to analyze and compare the energy system sustainability of five different municipalities in the Baltic Sea region – Gulbene, Tukums, Taurage, Tomelilla, and Wejherowo municipalities. This study developed and demonstrated an integrated method for evaluating sustainable energy transition in municipal energy systems. A composite index integrating nine indicators grouped in three key dimensions characterizing the existing levels of municipal energy system decarbonization and efficiency was constructed. The index approach was further used to benchmark the current energy transition efforts of municipalities. Figure 1 illustrates the general framework of the study approach.

The composite index method is widely recognized in the field of sustainability research owing to its numerous advantages [22]. First, it allows for the combination of numerous indicators with diverse units of measurement into one integrated assessment metric. Second, it allows to obtain benchmarks for improved energy monitoring and management. Third, the results are comprehensive and easily interpretative, which is extremely important for communication with policymakers and decisionmakers [23].

Five main steps were taken to construct a composite municipal energy transition index (ETI). The first step involved data collection, processing, and selection of relevant indicators. Municipality energy managers and other representatives provided data for each municipality. Based on the data availability and municipal energy system characteristics analysis, a total of nine indicators were selected for the analysis and grouped in three main dimensions – energy efficiency, energy decarbonization and smart energy systems, as outlined in Table 1.

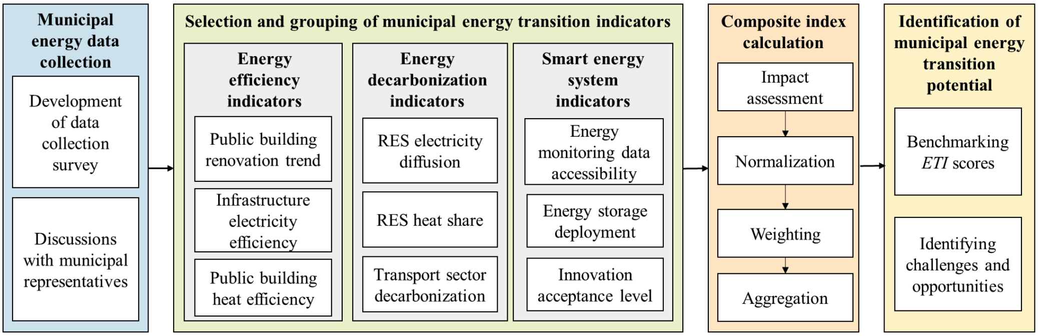

Fig. 1. General framework of the study approach.

All the selected data were data from year 2022 which at the time of the study were the latest available data.

There were two main approaches in data collection for selected indicators – quantitative and qualitative assessment approaches. For quantitative indicators i_1 – i_6 actual municipal data was used. However, due to data limitations, an evaluation scale was introduced for the indicators i_5 and i_6. The renewable energy source (RES) heat share indicator (i_5) includes both the renewable energy produced in district heating and the sources used in local heating supply sources of municipal buildings. Due to data limitations, only approximate figures could be obtained for each municipality; therefore, an evaluation scale was introduced, as shown in Table 1. Data limitations occurred in certain missing fuel-consumption-specific figures, where minor approximations had to be taken. Similarly, an evaluation scale was introduced for the transport decarbonization indicator (i_6). This includes fuel consumption in private and public municipal transport. Owing to data limitations on the specific fuel consumption and concrete distances travelled, approximations were made. However, sensitivity analysis revealed that the evaluation scale does not significantly impact the overall outcome or results of the composite index.

Moreover, for qualitative indicators i_7 – i_9 an assessment approach using a five-point scale was introduced, as outlined in Table 2. Qualitative indicators were assessed based on the information received from the municipal representatives through private one-to-one discussions and municipal energy data provided.

Second, each indicator was assessed according to its impact on the energy transition. Two main categories were determined: positive and negative impact indicators. An indicator is considered to have a positive impact if its increasing value results in increased sustainability. However, the indicator is negative if its increasing value diminishes the sustainability level. Third, both positive and negative impact indicators are normalized using the min-max normalization technique, according to Eqs. (1) and (2) which were retrieved from [24]. For indicators with evaluation scale (i_5 - i_9), in the normalization minimum value was equal to 1 and maximum value equal to 5, according to predefined scales in Table 1 and Table 2.

TABLE 1. SELECTED COMPOSITE MUNICIPAL ENERGY TRANSITION INDEX (ETI) INDICATORS AND VALUES

Indicator	**Explanation**	**Unit of measure**	**Impact**	**Gulbene municipality**	**Tukums municipality**	**Taurage municipality**	**Tomelilla municipality**	**Wejherowo municipality**
Energy efficiency dimension								
Public building renovation trend (i_1)	Proportion of municipal buildings renovated from total heating area of buildings	%	+	51.9	34	21.28	63	67
Infrastructure electricity consumption efficiency (i_2)	Municipal electricity consumption per inhabitants	kWh/inhabitant	–	167.4	147.5	100.6	206.4	172.3
Public building heat consumption efficiency (i_3)	Average heat consumption of municipal buildings	kWh/m^2	–	106.8	132.8	133.6	126.0	92.7
Energy decarbonization dimension								
RES power installation diffusion (i_4)	Installed municipal RES power plants per inhabitants	MW/inhabitant	+	0.47	0.21	1.50	2.60	0
RES heat share (i_5)	Share of produced heat energy from renewable energy resources	Evaluation scale: 5p: 95 %–100 % 4p: 85 %–95 % 3p: 50 %–84 % 2p: 10 %–49 % 1p: 1%–9 %	+	95 %–100 % (5)	85 %–95 % (4)	85 %–95 % (4)	95 %–100 % (5)	1 %–9 % (1)
Transport decarbonization (i_6)	Share of electrical and alternative fuel transportation in municipal transport system	Evaluation scale: 5p: 40 %–100 % 4p: 30 %–39 % 3p: 20 %–29 % 2p: 10 %–19 % 1p: 1 %–9 %	+	1 %–9 % (1)	1 %–9 % (1)	10 %–19 % (2)	20 %–29 % (4)	10 %–19 % (2)
Smart energy system dimension								
Digitalization and energy monitoring data accessibility (i_7)	Level of data quality and complexity of energy data collection	5-point scale, with 5-the highest, 1– the lowest	+	4	3	3	2	3
Energy storage deployment (i_8)	Existing RES storage technologies installed	5-point scale, with 5-the highest, 1- the lowest	+	2	1	1	1	1
Innovation acceptance level (i_9)	Considerations of innovation adaptation such as hydrogen, and its derivatives	5-point scale, with 5 – the highest, 1– the lowest	+	2	2	2	3	4

TABLE 2. ASSESSMENT SCALE OF THE QUALITATIVE INDICATORS OF THE ETI

Indicator	Explanation	Evaluation scale
Digitalization and energy data accessibility (i_7)	Level of data quality and complexity of energy data collection	5p: High-quality data, easily accessible through digital monitoring systems 4p: Well-maintained systems with access to data with manageable complexity 3p: Data accessibility is adequate with some complexity in data collection 2p: Limited data accessibility, with complexity in collection 1p: Minimal accessibility, with highly complicated data collection
Energy storage deployment (i_8)	Existing RES storage technologies installed	5p: High installation of renewable energy storage technologies 4p: Significant deployment of renewable energy storage technologies 3p: Moderate installation of renewable energy storage technologies 2p: Low implementation of renewable energy storage technologies 1p: Very minimal or no deployment of renewable energy storage technologies
Innovation acceptance level (i_9)	Future considerations of innovation adaptation such as hydrogen, and its derivatives	5p: Strong acceptance and strategies for integrating hydrogen and its derivatives 4p: Positive perception and determined strategies for adopting these innovations 3p: Consideration given to incorporating hydrogen and its derivatives into future 2p: Some hesitancy or limited planning for the integration of these innovations 1p: Minimal acceptance and low consideration for use of these innovations

$$I_{\mathrm{N}}^{+} = \frac{I_{\mathrm{act}} - I_{\min}}{I_{\max} - I_{\min}}\,, \tag{1}$$

$$I_{\mathrm{N}}^{-} = 1 - \frac{I_{\mathrm{act}} - I_{\min}}{I_{\max} - I_{\min}}\,, \tag{2}$$

where

I_{N}^{+} positive impact normalized indicator;
I_{N}^{-} negative impact normalized indicator;
I_{act} actual value of an indicator for the specific municipality;
$I_{\max}$ maximum value of an indicator across all municipalities;
$I_{\min}$ minimum value of an indicator across all the municipalities.

Fourth, after normalization, equal weights were applied. This study considers all indicators to be equally important determinants of sustainable energy transitions in municipalities. Finally, the weighted indicators are aggregated into a respective dimension sub-index according to Eq. (3). Following this, ETI is computed as shown in Eq. (4) by combining the values of each sub-index with its corresponding weight. Aggregation is performed in line with [25].

$$I_{\mathrm{D}} = \sum w \times I_{\mathrm{N}}^{+} + \sum w \times I_{\mathrm{N}}^{-}\ ;\ w = \frac{1}{n_{\mathrm{I}}}\,, \tag{3}$$

$$ETI = \sum w \times I_{\mathrm{D}} \ ; \ w = \frac{1}{n_{\mathrm{D}}} \ , \tag{4}$$

where

I_{D} sub-index of a dimension;

w determined weight;

I_{N}^{+} normalized positive impact indicator;

I_{N}^{-} normalized negative impact indicators;

n_{I} number of indicators in a dimension;

n_{D} total number of dimensions.

For each dimension sub-index and ETI benchmarks were calculated as weighted average value of municipal scores.

3. RESULTS

The results were grouped and described according to the values achieved in each dimension sub-index. The aggregated ETI results and benchmarks are then discussed.

3.1. Energy Efficiency Dimension Sub-Index Results

Figure 2 illustrates the energy efficiency dimension sub-index results. Three main indicators described the energy efficiency dimension of selected municipalities – public building renovation trend (proportion of municipal buildings renovated from total heating area of buildings, %), infrastructure electricity consumption efficiency (municipal electricity consumption per inhabitants, kWh/inhabitant), public building heat consumption efficiency (average heat consumption of municipal buildings, kWh/m^2).

The values of the energy efficiency dimension sub-index range from 0.77, the highest (for Wejherowo municipality) to 0.28, the lowest (for Tukums municipality), with an average benchmark value of 0.46. Three municipalities showed results below the benchmark: Tukums (0.28), Taurage (0.33), and Tomelilla (0.37). The main cornerstone of the Tukums municipality is the low share of public building renovation and building heat consumption efficiency. Similarly, the Taurage municipality had the lowest share of renovated public buildings and the highest average heat consumption of public buildings. However, the Taurage municipality had the lowest municipal electricity consumption per inhabitant, indicating a higher power consumption efficiency compared to other municipalities. In contrast, the lowest power consumption efficiency was observed in Tomelilla municipality. Although the overall share of renovated public buildings in Tomelilla municipality was considerably high (63 %), the overall average heat consumption of municipal buildings was the third highest (126 kWh/m^2). This could be potentially explained by the colder climate. Although the Wejherowo municipality had the highest municipal building renovation share and lowest average heat consumption, its main challenge is the considerably high electricity consumption of the municipal infrastructure. This could potentially be explained by inefficient public street lighting in the municipal region, indicating opportunities for the replacement of public street lighting. Similarly, the electricity consumption per inhabitant of the Gulbene municipality could be improved. Municipal infrastructure includes municipal buildings and equipment, public street lighting, water supply, sewerage, and other.

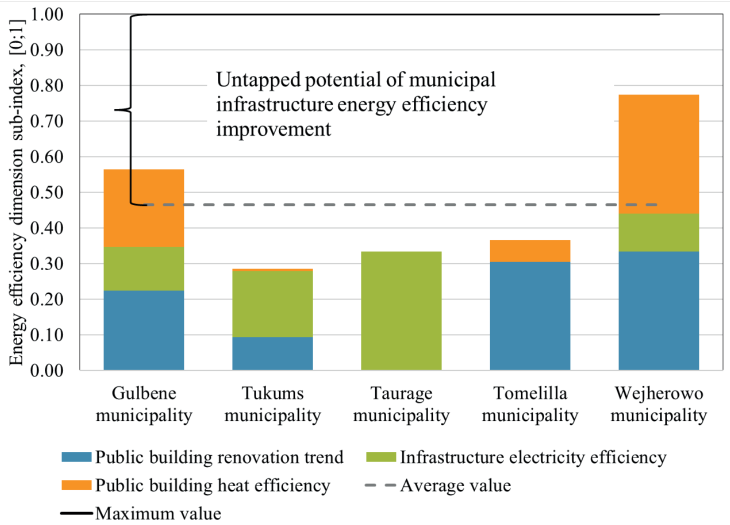

Fig. 2. Energy efficiency dimension sub-index results.

3.2. Energy Decarbonization Dimension Sub-Index Results

Figure 3 illustrates the energy decarbonization dimension sub-index results. Three main indicators describe the energy decarbonization dimension of selected municipalities: RES power installation diffusion (installed municipal RES power plants per inhabitants, MW/inhabitants), RES heat share (share of produced heat energy from renewable energy resources, %), and transport decarbonization (share of electrical and alternative fuel transportation in the municipal transport system, %). Energy decarbonization dimension sub-index values indicated the highest range in the achieved results for the municipalities, with highest value of 0.92 (for Tomelilla municipality) and lowest of 0.08 (for Wejherowo municipality). Three municipalities scored below the average benchmark value of 0.44: Wejherowo municipality (0.08), Tukums municipality (0.28), and Gulbene municipality (0.39).

The Tomelilla municipality indicated the highest level of decarbonization in the power, heat, and transport sectors, and therefore reached the highest energy decarbonization sub-index score. There are 35.9 MW installed RES power plants in the municipal region with 29 MW wind turbines and 6.9 MW solar PVs. The heat production in both regions' district heating and individual heating of municipal buildings is entirely based on biomass (wood pellets and chips) and electricity (heat pumps). Moreover, Tomelilla municipality stands out with a high share of transport sector decarbonization. Besides diesel and petrol, municipal transport consumes considerably high amounts of biogas (27.5 thousand kg), HVO (36.8 thousand litres), and electricity (2.5 MWh) for transportation needs. Moreover, according to Tomelilla municipal representatives, the local public transport company entirely uses RME (biodiesel) for their bus fleet, and the public transport fleet is entirely based on renewable energy.

Decarbonization of the transport sector is the main challenge for all municipalities. Besides the Tomelilla municipality, noticeable transport decarbonization efforts are observed in the Taurage and Wejherowo municipalities. In the Taurage municipality, there has been a significant increase in the electricity consumption of municipal private transport (146 MWh in 2022) and public transport (16 electrical buses with a total consumption of 146 MWh in

2022). Similarly, the Wejherowo municipality consumed 230 MWh of electricity to meet public transport needs. Moreover, the Wejherowo municipality considers the purchase of hydrogen buses that can be used for public transport fleets in the future. However, regarding renewable energy deployment for heat and power generation, the Wejherowo municipality showed the poorest results. According to municipality representatives and municipal energy data, no RES power plants are installed in the municipality. Power is produced by the natural gas CHP. In the municipal region, there are only small photovoltaic installations (micro-installations) with a capacity of 4-5 kW, which are individual sources installed in private buildings (mainly single-family residential houses). The heat in district heating in the Wejherowo municipality is produced entirely by fossil fuels, such as coal and natural gas. Furthermore, the results of the energy decarbonization sub-index show that Wejherowo, Tukums and Gulbene municipalities significantly lag behind in installation of RES power plants such as solar PVs and wind turbines in the municipal region. Although both Latvian municipalities possess a considerably high share of RES in heat generation, which is mostly based on biomass utilization, significantly lower amounts of RES power plant installation were observed in the municipalities compared to the other Baltic Sea Region municipalities selected for the analysis.

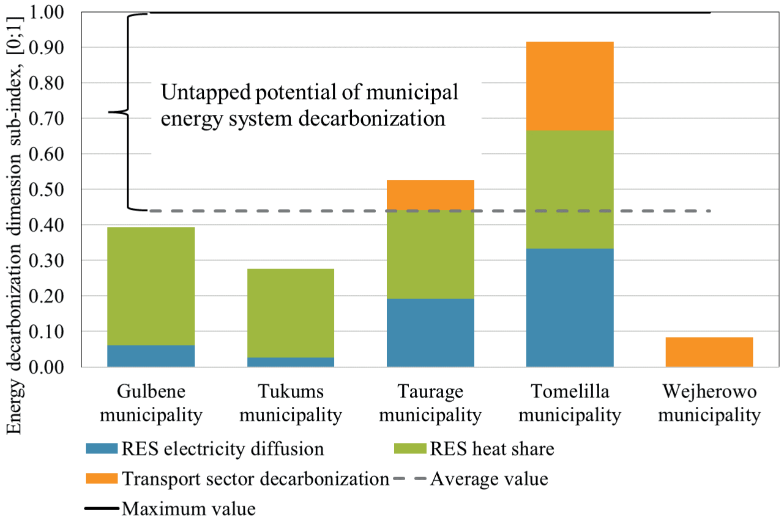

Fig. 3. Energy decarbonization dimension sub-index results.

3.3. Smart Energy System Dimension Sub-Index Results

Figure 4 illustrates the smart energy system dimension sub-index results. Three main qualitative assessment indicators describe the smart energy system dimension of selected municipalities: digitalization and energy monitoring data accessibility (level of data quality and complexity of energy data collection), energy storage deployment (existing RES storage technologies installed), innovation acceptance level (considerations of innovation adaptation such as hydrogen, and its derivatives). The smart energy system dimension sub-index results, with an average benchmark score of 0.32, were significantly lower than in other dimensions, representing higher untapped potential. The values ranged from 0.42 the highest for Gulbene and Wejherowo municipality and lowest with 0.25 for Tukums, Taurage and Tomelilla municipalities.

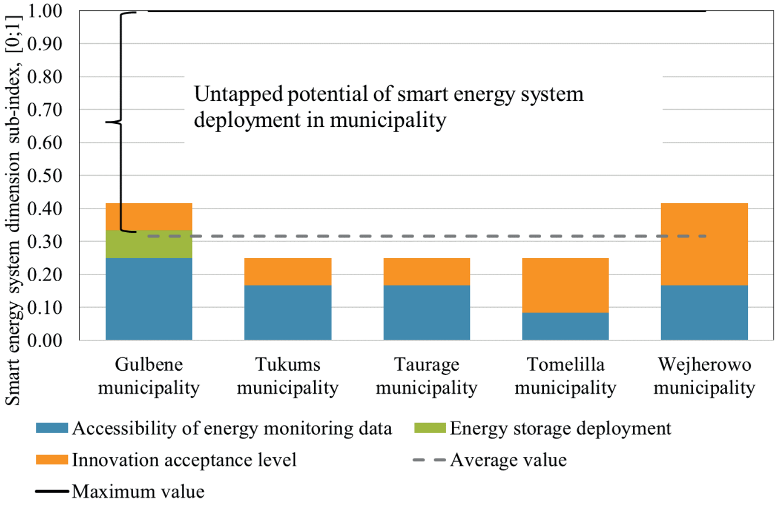

Fig. 4. Smart energy system dimension sub-index results.

The Gulbene municipality stood out as the only municipality that has installed renewable energy storage technologies. There is one small battery system with a total capacity of 9 kWh installed on Gulbene's municipal building, in combination with PV panels. There are also small units of thermal energy storages in individual boiler houses. The Gulbene municipality also demonstrated considerably good data quality and solutions for necessary data acquisition. Regarding innovation acceptance in terms of possible hydrogen, biomethane, and synthetic fuel integration, Gulbene municipality was reluctant. According to the municipal representatives, the Gulbene municipality does not plan to implement hydrogen systems currently because there is no further infrastructure to use hydrogen in the Gulbene region, and it is still expensive and unexplored.

A similar reluctance was also observed by the representatives of Tukums and Taurage municipalities, which do not plan specific actions with regard to hydrogen research and possible integration in municipal infrastructure. However, more positive attitudes and concrete considerations were expressed by the Tomelilla and Wejherowo municipalities with regard to innovation deployment, such as hydrogen and its derivative integration into municipal energy systems. Tomelilla is interested in exploring the long-term potential of hydrogen in the municipality. Most concrete actions were demonstrated by the Wejherowo municipality, where municipal public transport company plans to switch urban transport to buses powered by hydrogen fuel (the first hydrogen bus has already been tested practically in the city for a period of two weeks in December 2023). By 2035, it is planned to purchase 27 zero-emission buses powered by hydrogen fuel. To become completely independent from external hydrogen supplies, investment in the construction of its own hydrogen production and refuelling station in the municipality is also planned.

This study marked that data collection and quality issue is still one of the major challenges and cornerstones of municipalities, which is also reflected in the values of the digitalization and energy monitoring data accessibility indicator (i_7). According to observations, there is no single digital energy monitoring system that covers all economic sectors implemented in municipalities. All selected municipalities encountered significant challenges in data collection. A lack of data monitored directly by the municipality has been observed in several forms. First, data on electricity consumption and production are available only to the national system operator with no direct access to the municipality without special requests, which often involves unnecessary bureaucratic procedures. This issue was observed in the Gulbene, Tukums, and Wejherowo municipalities. Second, district heating and public transport companies are reluctant to provide data that often result in inconsistent and incomplete heat consumption assessments of all sectors of the municipal region. Third, some data are monitored by national authorities and are classified, meaning that municipalities do not have access to these data. This was most prominently observed in the Tomelilla municipality. No direct control over energy data significantly hinders municipal efforts in energy transition.

3.4. Municipal Energy Transition Index (ETI) Results

Table 3 outlines the aggregated results of the ETI and benchmarking values for all three sub-dimensions. Figure 5 illustrates the aggregated results for municipal energy transition index (ETI) of the selected municipalities. The index results illustrate the contribution of each dimension – energy efficiency, energy decarbonization, and smart energy systems. The results show which of the dimensions for a specific municipality is of particular challenge at the moment, and which is the strongest compared to other municipalities, see Table 3.

The aggregated results of the municipal energy transition index (ETI) range from 0.27 the lowest (for Tukums municipality) to highest of 0.51 (for Tomelilla municipality). The average ETI score equals 0.41 where two municipalities scored below the benchmark – Tukums (0.27) and Taurage (0.37) municipalities. Gulbene municipality (0.42) and Wejherowo municipality (0.42) scored above the average benchmark value. However, all municipalities show major untapped potential for sustainable municipal energy transition given that the maximum index value is equal to 1.

TABLE 3. BENCHMARKING RESULTS OF THE COMPOSITE MUNICIPAL ENERGY TRANSITION INDEX (ETI)

	Avg	**Gulbene municipality**	**Tukums municipality**	**Taurage municipality**	**Tomelilla municipality**	**Wejherowo municipality**
Public building renovation trend		0.22	0.09	0.00	0.30	0.33
Infrastructure electricity efficiency		0.12	0.19	0.33	0.00	0.11
Public building heat efficiency		0.22	0.01	0.00	0.06	0.33
Energy efficiency sub-index	**0.46**	**0.56**	**0.28**	**0.33**	**0.37**	**0.77**
RES electricity diffusion		0.06	0.03	0.19	0.33	0.00
RES heat share		0.33	0.25	0.25	0.33	0.00
Transport sector decarbonization		0.00	0.00	0.08	0.17	0.08
Decarbonization sub-index	**0.44**	**0.39**	**0.28**	**0.53**	**0.92**	**0.08**
Accessibility of energy data		0.25	0.17	0.17	0.08	0.17
Energy storage deployment		0.08	0.00	0.00	0.00	0.00
Innovation acceptance level		0.08	0.08	0.08	0.17	0.25
Smart energy sub-index	**0.32**	**0.42**	**0.25**	**0.25**	**0.25**	**0.42**
Municipal energy transition index	**0.41**	**0.46**	**0.27**	**0.37**	**0.51**	**0.42**

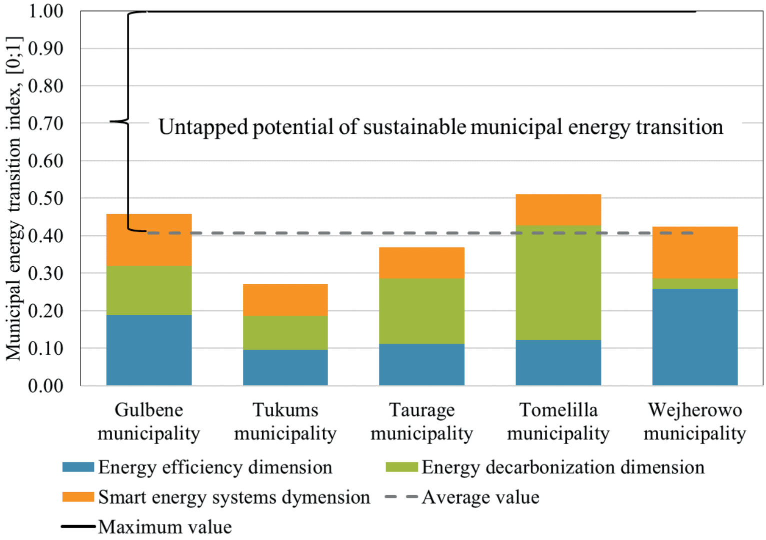

Fig. 5. Municipal energy transition index (ETI) results.

The aggregated results reveal that for Gulbene municipality key strengths are 100 % renewable heat generation system and experience in energy storage technology deployment, i.e., installation of the first battery storage system. However, challenges persist, such as slow progress in transport decarbonization, limited deployment of renewable energy sources (RES) power plants like solar panels and wind turbines, and comparatively high electricity consumption in municipal infrastructure. For Gulbene municipality the identified opportunities and untapped potentials lie in include enhancing energy efficiency further, increasing the installation of RES power plants, electrifying the heat sector through the integration of heat pumps and energy storage systems, and advancing transport sector decarbonization efforts.

For Tukums municipality key strengths lie in the good efforts of heat sector decarbonization and successfully established energy management system. However, the key weaknesses are the low public building renovation rate and the unused potential of RES power plant installation (solar PV and wind power). Key opportunities for Tukums municipality energy transition would be the acceleration of higher RES deployment in power production and transport decarbonization, improvements in infrastructure, and building energy efficiency.

Favorable conditions for wind energy installations, which have led to a greater number of renewable energy source power installations than in other municipalities, and minimal electricity consumption of municipal infrastructure are two of Taurage municipality's greatest strengths. Low rates of public building renovation and transportation decarbonization progress are significant obstacles. Key opportunities for the Taurage municipality include the potential to produce hydrogen and synthetic fuel from surplus wind energy, improving the energy efficiency of public buildings and decarbonizing transport.

The strengths of the Tomelilla municipality are its 100 percent renewable heat generation system, its substantial use of biofuels in the transportation sector, its positive trend in the installation of RES power plants, and its positive trend in the renovation of public buildings. The public building's substantial electricity consumption and the complex nature of energy management and monitoring constitute major weaknesses. Key opportunities include the electrification of the heat sector, the inclusion of storage systems to increase self-sufficiency, and the substantial potential for hydrogen production from excess renewable energy.

For the Wejherowo municipality, the main strengths are the good trend in the renovation rate of public buildings, the considerably low average heat consumption of public buildings and the good efforts in the decarbonisation of public transport. The main weaknesses are the heat generation based entirely on fossil fuels, the lack of municipal measures in the installation of RES power plants (PV panels, wind turbines) and the inefficient electricity consumption of public street lighting. The main opportunities are the utilisation of the untapped RE electricity potential and possible hydrogen production, the massive possibilities of decarbonising and electrifying the heat sector and improving the efficiency of public street lighting.

3.5. Discussion on Policy Implications Based on Results

Study findings reveal a gap in existing policies and approaches used at both at national and regional levels which are consistent with the findings from the prior research. A number of policy initiatives have been promoted and implemented at both EU and national level, but the problem is often implementation rather than development. Policy measures to help stakeholders promote the energy transition include information campaigns, scientific and technological cooperation, tax and production incentives, infrastructure investment, training courses and simplification of administrative procedures [26]. Martínez *et al.* analysed the approach of twenty-eight municipalities in the Netherlands to transition to sustainable heating systems. They concluded that the lack of binding policies to phase out natural gas and the low availability of alternative heating systems should be addressed, while the establishment of centralised support mechanisms and building renovation should be promoted to facilitate this transition in municipalities [27]. Satrovic *et al.* highlights necessity of policies such as funding support, cooperation, monitoring, capacity building and knowledge sharing as key to regional sustainable development [14]. Traill & Cumbers found that municipalities need both financial, political and knowledge gap mitigation support to implement energy transition related change strategies. Sustainable financial and political support are key things that enable municipalities to implement novel solutions and fully invest in the energy transition [29]. Research argues that it is an illusion that energy transition will automatically reduce energy bills and cut emissions. The benefits depend on how energy policies are implemented and enforced [12].

4. CONCLUSION

In this study, developed composite municipal energy transition index which incorporated nine different indicators grouped into three main dimensions – energy efficiency, energy decarbonization, and smart energy systems. Five different municipalities were analysed and compared with the index and sub-index benchmarks of each dimension.

The results highlight various challenges of the municipal energy transition. Transport decarbonization major issue for the majority of municipalities with a low share of renewable energy. The results show that there is significant untapped potential for the installation of RE power plants in all municipalities, taking into account that surplus electricity could be combined with integrated energy storage solutions or through the production of hydrogen. The majority of municipalities are still reluctant when it comes to innovations such as the use of hydrogen and its derivatives. There is still a great deal of uncertainty that affects municipalities' confidence in decision-making regarding the potential use of hydrogen. Low energy efficiency is still a major issue in some municipalities. The renovation rate of municipal buildings and heat consumption could be significantly improved by actively investing in energy efficiency measures.

The method presented is highly dependent on the availability of data. The study has shown that the monitoring and collection of energy data in municipalities is still a major problem that should be given special attention at national level. Barriers to the availability and accessibility of data should be removed at national level. The municipal energy system cannot be assessed and planned if the existing situation cannot be properly evaluated on the basis of reliable data. The results of this study will be integrated into a system dynamics model to analyse the dynamic relationship between the factors and their impact on the local energy transition.

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