Digitalization and Adaptation, from a Regional Perspective – a Hungarian Case Study

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Abstract: Currently, digital transition and innovation are significant dimensions of transition processes and development policies. These are becoming increasingly important as more diverse and complex social, economic and environmental problems and challenges emerge. The achievement of digital transition and the promotion of sustainable development are crucial elements of the European development policy. Digital transformation can bring new challenges and many new opportunities and solutions for individual stakeholders, companies, sectors, and regions. However, little is known about the interrelations between mobility, sustainability, digitalization and climate change, especially from a regional perspective. This research aims to explore ways to make the interrelations between sustainability, climate change and digitalization more tangible, measurable and traceable. To investigate this question, (i) the spatial interpretation of the interrelations between mobility, sustainability, digitalization and climate change was formulated, (ii) an indicator-based database was developed, and (iii) a methodology for assessing the digitalization and adaptation by the regional level was formulated. The analysis exploring the correlations between digitalization and adaptation was carried out in 2021 and focused on the level of districts (LAU 1 level in Hungary). Based on the digitalization and adaptation parameters, the Spatial Digitalization Index and the Spatial Adaptation Index were conceptualized. The dynamic regression analysis proved that digitalization is increasing at the LAU 1 in Hungary, and digitalization can support and strengthen adaptation to an increasing degree in different sectors such as transportation enhancing sustainability. The findings highlight the important role of different stakeholders and the challenge-based regional or local planning perspectives.

Keywords: digitalization; sustainability; adaptation; climate change; mobility

1 Introduction

Research on the interrelations between sustainable regional development where mobility plays important role and climate change promotes holistic approaches and integrated solutions owing to their inter-, multi- and transdisciplinary

characteristics. Consequently, technical-technological and socio-economic aspects and natural-environmental factors have come to the forefront of studies. The results of analyses on connections and interrelations between sustainability and adaptation bridge a gap both at the regional and the sectoral level (transportation for instance), and they improve the plannability of relevant development processes, their implementation and general livability.

One of the most significant and complex global challenges of our time, is climate change, and our knowledge about its possible effects and consequences is widening daily [1]. In addition to international agreements and treaties, a growing number of professionals from the scientific, political and social circles draw our attention to the various preparatory and preventive measures that could mitigate the effects of this phenomenon. Climate change is also gaining focus in spatial and regional development. The arising challenges may be regarded as potentials for the European regions concerning employment and innovative capacities.

The future phenomena and effects of climate change are difficult to predict with high certainty [2] [3]. Thus, challenges concerning ecological, social, economic and transportation systems and their resilience and willingness to adapt are expected to be even more significant [4]. Preparation for and adaptation to the expected effects of climate change are not isolated tasks, but they constitute a plannable process that requires cooperation at the social, political, regional and sectorial levels. The primary aim of preparation is to increase the resilience to various expected effects and to enhance the sustainability of regions and characteristic sectors. This is achieved by shifting the focus from preventive measures and control to the ability to live together with the constantly changing and occasionally dangerous environment. Adaptation to climate change can be very versatile, and the different methods require different preparatory measures, tools and methods especially considering regional characteristics [5] [6]. Socio-economic processes take place in a given area and in a given time, which – when speaking about the practical implementation of sustainability – are complemented by the fact that these processes are embedded in the natural environment, i.e., the biosphere. The adaptation to and preparation for unavoidable effects are closely related to the concept of sustainability. Consequently, the compilation and realization of spatial and sectoral, local, regional and national economic strategies, irrespective of being sustainability, climate or adaptation strategies, can all help avoid expected effects and mitigate potential damage [7-10]. Concerning regional livability, research today tends to focus on measurability in addition to theoretical explanations. Therefore, it is shown how, primarily socio-economic processes and interventions lead to the deterioration of environmental quality; thus, the effects of these processes and climate change are revealed, together with the potential effects on the practical realization of sustainability and their effect on mobility and daily life [11-13]. In relation to cognitive mobility altogether five key areas can be identified [14] including cognitive sustainability, that can contribute to and foster the understanding of mobility and economic process-related interactions [15] [16].

From this perspective, it is worth examining whether digitalization and adaptation from a regional perspective can turn into an effective tool to promote sustainability. Societies have always had to respond to climate variability and extreme weather events. Climate has always existed, it exists, and it will exist. However, the expected effects of climate change and possible solutions for these challenges differ, and they influence the motivation for turning to sustainability to a variable degree. As the connections between sustainability and climate change prove, climate change itself is one of the most significant hindering factors on the way to sustainability. The present study discusses the possible local interpretations of the connections between present-day global processes, with a special focus on the triplet of sustainability–climate change–digitalization. Concerning the steps towards sustainable regional development, the investigations presented here aim to explore how the connections between adaptation and digital transformation can be realized at the local level.

1.1 Sustainable Regional Development and Adaptation

The effects of climate change can be directly experienced already today, and this trend will not change. Consequently, expected impacts will affect everyone from the most vulnerable social groups, sectors and regions to the most resilient ones [2], [3]. The European Union is preparing for the expected effects, especially for the growing frequency and intensity of extreme weather events, primarily interpreted at the local level. At this level, decision-makers should prepare to handle such problems, in which the subsidiarity principle also plays a role. When setting up mitigatory, preparatory, and adaptive measures, programs and strategies designed in harmony with the precautionary principle, it is also a challenge to determine the extent of intervention by those concerned, for which the experiences gained in the past years or decades should be used as guidelines. Today, it focuses on how the following questions may be answered [17] [18]: What changes are expected in a given region or sector? Will the planned level of intervention prove to be satisfactory in fighting off the expected challenges?

Sustainability and climate change are in a circular relationship, which is reflected in several research results [19-21]. The expected direction and characteristics of development can fundamentally influence the climate change process; however, climate change also affects the chances of moving towards sustainability, both from a mitigatory and adaptive perspective. Focusing on sustainable regional development, adaptation to climate change and sustainability have gained more focus, together with analyzing synergic effects among climate-friendly solutions, tools, methodologies and policies. The research area is a European inland territory located in the Carpathian basin. The examined Central European country is Hungary, where the ratio of rural areas is still beyond the EU average [22], which results in higher exposure and vulnerability. A related UN document implied Hungary, as one of the most vulnerable countries in Europe, considering the

possible effect of climate change on biodiversity [23]. The possible impacts of climate change on the environment are crucial especially when fostering digital transformation and sustainable transition on regional or local level and its cross-fertilization effect on mobility and transport. In Hungary, several research reports and studies have published prognoses on the expected effects of climate change [23] [24]. Such prognoses are becoming more accurate over time regarding the extent of the effect and the probability and risks of its occurrence. Preparation for and prevention of expected effects and the mitigation of the connected risks are the fundamental interest of all those concerned due to the facilitation of resilience and the fact that this resilience is profitable [25] [26]. According to the available knowledge and research results, climate change affects Hungary to an extreme degree, both on the global and the European scale; but the different parts of the country are to be affected differently. These impacts may strengthen existing socio-economic differences, and regional differentiation might also be enhanced, leading to significant novel social inequalities [23] [27]. Climate change might influence every dimension of sustainability, and it fundamentally affects regional living conditions, incomes, health status etc., which are considered the cornerstones of sustainable regional development [8]. In order to preserve or enhance the standard of living and livability, it is advisable to offer incentives. The best measures are cost-effective and environment-friendly; as further positive externalities, they might also help to enhance living standards, the health status of local people (e.g., due to better air quality), might provide jobs for local professionals, and act as a driver for the local economy. In order to create a solid basis for the preparation and adaptation of local communities, it is indispensable to explore the needs and expectations for forming a general concept. In Hungary, one of the main hindering factors, for local ambitions, remains the lack of financial sources. The cost-effective adaptation to climate changes should focus on realizing local initiatives, i.e., local preparatory adaptive measures should be economically profitable and serve livability, conservation or sustainability.

The regional or local perspective is of utmost importance in analyzing connections between climate change and sustainability, with special emphasis on the following facts:

- Climate change is generally ignored in the practical implementation of sustainability measures.
- The exploration of how local sustainability-related initiatives and models are connected to regional strategies is typically missing from earlier studies.
- Reaching sustainability while considering climate change is impossible without exploring local economic activities and sectors and considering local living conditions and interests.
- The primary income-generating sector must be analyzed, focusing on climate change and local adaptive possibilities. Such analyses are lacking both at the domestic and the international levels.

- The role of digitalization in sustainable regional development considering the possible impacts of climate change.

While exploring the interconnections between the concepts of sustainability and adaptation, it was proven that endogenous factors play a key role in forming the main motivating forces in the transition towards sustainability. It was also stated that the subsidiarity principle plays a role in the practical realization of this transition. It can be stated that climate change strategies, mitigation and adaptation policies and political decisions have complex (economic, social and ecological) effects with respect to sustainable mobility. In the "normal" business operation of the market economy of today and the near future, decisions are passed respecting sustainability values only to a limited degree, although natural and environmental interests can only be taken into consideration successfully if they are in line with strategic political goals [17], [28-31]. The ability to adapt should not only be interpreted as resistance to outer effects (resilience), but the ability of the system to adapt flexibly to the changing conditions, especially local conditions, should also be included in this concept. Moreover, based on the above claims, the transition towards sustainability and the adaptation to global, regional and local challenges can be most effectively facilitated by the best practices of sustainable regional development [32] Available and future adaptive tools may be extremely versatile both within regions and sectors, depending on the stakeholders, the target group of adaptive measures, and the expected results. Several uncertainty factors should be considered when planning preparatory measures and adaptation strategies to climate change and its expected effects. Uncertainty may stem from various causes [33]:

- Available information – the lack of information or information asymmetry might be severe hindrances during the planning of adaptive measures and the management of challenges
- Limitations of predictions
- The impossibility of estimating the future effects of planned measures during the preparatory and adaptive processes
- The responses of the given society, and the uncertainty of predicting these responses

Adaptation means the reactions and processes of a system together with their outcomes, which aim to make the system ready to tackle changing circumstances more easily and effectively [35]. These include the mitigation of damage and reconstruction after present events, the preparation for and prevention of future events, and also the enhancement of resilience to various stress scenarios. In the adaptation process, the identification of two factors is of primary importance: (i) who wishes to adopt (e.g., the society, individuals, communities, institutions, sectors, regions, settlements); and (ii) what they wish to adapt to (e.g., warming, the increasing frequency and intensity of weather events, biodiversity loss), only after the identification of these two factors that is it worth examining the available skills, abilities, possibilities and the potential devices. Adaptation has many forms

depending on its duration, character or effects on those concerned or the pilot area. The adaptive capacity of a given region also depends on whether a given resource might be replaced by something else, and if yes, at what costs.

Environmental and socio-economic challenges of climate change can be regarded as primary threats to the realization of sustainability. The transition toward sustainability might also serve the mitigation of climate change. The circular relationship between sustainability and climate change is also related to the different development directions. Regional adaptive processes, actions and measures may not only serve the preparation for the expected effects of climate change or the mitigation of present damage, but by improving local living conditions, they might also facilitate the transition toward sustainability.

1.2 Spatial Aspects of Digitalization and Climate Innovation Initiatives

The achievement of digital transition and the promotion of sustainable development are crucial elements of the European development policy. Innovation processes play a key role in enhancing the economy's efficiency, greenness and competitiveness. The European Commission incentivizes the realization of sustainable sectoral and regional development, which the European Green Deal also supports. There is a need for further research how can digitalization foster sustainable transition and what extent. Most of the studies published on this topic focus on the environmental [35-37] or social dimension of sustainability [38-40], there are limited examples for multidimensional and interdisciplinary research [41-44] which have shown an increasing trend only in recent years in the scientific literature. At the end of February 2021, the new European Adaptation Strategy [45] was published. This document focuses on the achievement of resilience to the effects of climate change in the European Union, which is in line with the EU's green economy and sustainability ambitions. The most important goal in the strategy is to make the EU a society resilient to the effects of climate change by 2050, in which achieving climate innovations in non-urban areas might play a significant role. In order to find local solutions to global challenges, applying a systematic and holistic approach is indispensable, with special focus on subsidiarity and the precautionary principle.

Today, in both sectoral and regional analyses, it is advisable to focus not only on the mitigation of climate change and the adaptation to the expected effects, but also on the challenges and effects of the digital transition. New challenges require novel solutions: novel problems call for non-traditional, often creative, inter- or multi-disciplinary perspectives and solutions. The key to solving the problems related to climate change lies, among other things, in the promotion of creative and innovative solutions and in implementing related proposals effectively. While technical and technological innovations may significantly contribute to the solution of social challenges, they may also bring about social externalities, which should be

considered both in the design phase and during implementation. Beyond problem-based planning the challenge-based planning can play a pivotal role from regional development perspective due to digitalization. The interrelations between sustainability, digitalization and innovation can be grouped into four categories, from a regional perspective:

1) SD: Digitalization processes and developments serving sustainability
2) SC: Sustainable and climate-oriented processes and developments
3) CD: Climate-oriented digitalization processes and developments
4) SCD: Climate-oriented digitalization processes and developments were serving sustainability

This research aims to explore ways to make the interrelations between sustainability, climate change and digitalization more tangible, measurable and traceable. Today it is widely accepted that intelligent and innovative solutions, digitalization are required to mitigate climate change, enabling us to offer adequate socio-economic, spatial and sectoral solutions for the complex challenges arising in the future [46-50]. The present national governments tend to regard climate change mitigation and adaptation more and more as a possibility rather than an obstacle to economic welfare [51]. The concept of innovation was introduced by Joseph Schumpeter, one of the founding fathers of modern economic theory, in his 1911 book entitled “The theory of economic development”. Compared to the five basic categories of innovation established by Schumpeter (i.e., new product, the introduction of new production technology or method, the discovery of a new market, a new resource on the input market, establishment of a new organization), today's innovation is a much broader concept [52]. Despite being widely researched, literature on the connection between innovation and answers to climate change is scarce. Currently, only two major organizations deal with climate innovation and the interpretation of the background concepts: the WWF and the EIT Climate-KIC (Knowledge and Innovation Community). Today Climate-KIC is one of the most significant innovation collaborations with both public and private goals in Europe, which focuses on climate innovation to mitigate climate change and adapt to it. There are other similar fields, such as sustainable innovation; however, climate innovation is a much narrower concept. Novel ideas related to climate innovation are typically connected to mitigatory activities, although they can also be adaptive actions [53]. The systematic approach followed by the EIT Climate-KIC [54] categorizes climate innovations according to whether they are incremental or disruptive. Moreover, it also differentiates different levels of change, from the level of products and processes to the level of changes in value systems. However, this approach lacks the recognition of spatial aspects, local circumstances and characteristics. As far as it can be seen, climate-oriented digitalization processes and developments serving sustainability (cf. SCD in Figure 2) are very often spatial climate innovation initiatives as well, at the same time. Climate innovation can also be interpreted as a unique kind of innovation – be it a technological solution, a

product, a process, a service etc. – which can mitigate the expected negative effects of climate change to some extent or can aid preparation for these changes [55]. The concept of climate innovation can be interpreted from several perspectives, including spatial and sectoral ones and emission reduction and adaptation viewpoints [56] [57].

In order to include the missing regional perspectives an indicator-based analysis was conducted to examine the spatial interdependencies between digital transition and climate change. Based on the introduction the research question is whether there is a correlation between digitalization and adaptation on regional level.

2 Methodology

For the statistical tests on digitalization, 22 parameters were identified from the available databases (Different databases of the Hungarian Central Statistical Office were used: TMER, TIMEA, TeIR) (Table 1). Various temporal and spatial distributions characterized parameters. In Hungary the LAU 1 (Local Administration Unit 1, previously NUTS 4 level) level is the so-called, district level ("járás" in Hungarian). The NUTS classification (nomenclature of territorial units for statistics) is a spatial hierarchical system of the European Union. The current Eurostat NUTS list, which is valid from 2021, contains 92 regions at NUTS 1 level, 242 regions for NUTS 2 level and 1166 regions in the NUTS 3 level.

One of the bottlenecks of the analysis was that district level data were not always available. Regarding the data on adaptation, 72 parameters were identified, with various spatial and temporal distributions (TMER, TIMEA, TeIR). Finally, the 2013-2018 period was considered for both district level digitalization and adaptation parameters. Concerning the district level digitalization data, the DESI index (Digital Economy and Society Index) served as a starting point, while for the collection of adaptation data, adaptation capacity models [58] [59] were considered as the methodological basis.

In the context of this research, it is necessary to assess Hungary's digitalization and climate change adaptive capacity on LAU 1 level. No such coherent database exists until now on this spatial level for Hungary. Author has established database. Let us formulate a methodology for assessing the digitalization and adaptive capacity on LAU 1 spatial level. The purpose of this technique is to merge two complex estimates.

Table 1
List of indicators

Name of indicator on LAU-1 level	Dimension	Start and end year
Internet access per capita	[pcs/1000 capita]	2013-2019
Number of official places with internet access per 1000 capita in public educational institutions	[pcs/1000 capita]	2001-2009
Number of internet access	[pcs]	2003-2010
Number of operating enterprises in the information and communication branch of the national economy	[pcs]	2008-2011
Number of operating enterprises per thousand inhabitants	[pcs]	2012-2018
Proportion of professional, scientific enterprises within the operating enterprises	[%]	2006-2018
Net income per capita,	[HUF/capita]	2006-2018
Unemployment rate	[%]	2006-2018
Population density, on 31 December	[capita/km^2]	2012-2019
Population	[capita]	2006-2018
Passenger cars	[pcs]	2006-2018
Average size of real estates	[m^2/real estate]	2006-2018
Forest covered area	[km^2]	2012-2018
Urban green spaces	[km^2]	2012-2018
Electricity consumption	[1000 kWh/capita]	2006-2018
Volume of gas supplied to households per capita,	[1000 m^3/capita]	2006-2018
Proportion of real estates connected to a public sewer network	[%]	2006-2018
Proportion of real estates connected to the public drinking water network	[%]	2006-2018
Amount of total municipal solid waste transported	[t]	2006-2018
Number of granted patents	[pcs]	2009-2016
Ratio of the extent of total protected natural areas to the area of settlements	[%]	2006-2018
Hospital beds per ten thousand capita	[pcs/10 000 capita]	2006-2018

Based on the above digitalization and adaptation parameters, the Spatial Digitalization Index and the Spatial Adaptation Index were conceptualized (Fig. 1):

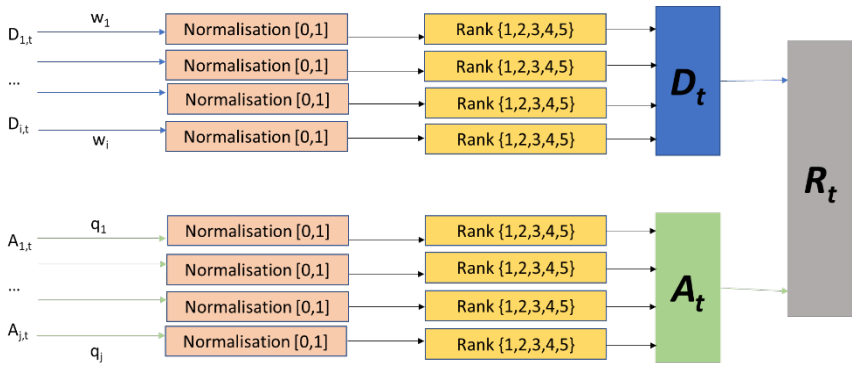


Figure 1
Conceptual framework of assessment

Firstly, the index components needed to be defined therefore correlation analysis was made to filter out the multicollinear parameters (1), (2):

$$r_{k,t;k+1,t} = \frac{\sum_{k=1}^{i}(D_{k,t}-\overline{D_t})(D_{k+1,t}-\overline{D_t})}{\sqrt{\sum_{k=1}^{i}(D_{k,t}-\overline{D_t})^2(D_{k+1,t}-\overline{D_t})^2}} \quad (1)$$

$$r_{l,t;l+1,t} = \frac{\sum_{l=1}^{j}(A_{l,t}-\overline{A_t})(A_{l+1,t}-\overline{A_t})}{\sqrt{\sum_{l=1}^{j}(A_{l,t}-\overline{A_t})^2(A_{l+1,t}-\overline{A_t})^2}} \quad (2)$$

Where,

$r_{k,t;k-1,t}$ – the correlation coefficient of the linear relationship between the variables k^{th} and $k+1^{th}$ at the year t

$D_{k,t}$ – the k^{th} values of the digitalization parameter variable in a sample at year t

$\overline{D_t}$ – the mean of the values of digitalization parameter variable

$D_{k\ 1,t}$ – the $k-1^{th}$ values of the digitalization parameter variable in a sample at year t

$A_{k,t}$ – the k^{th} values of the adoption parameter variable in a sample at year t

$\overline{A_t}$ – the mean of the values of adoption parameter variable

$A_{k\ 1,t}$ – the $k-1^{th}$ values of the adoption parameter variable in a sample at year t

Multicollinearity is a phenomenon in which one predictor variable in a multiple regression model can be linearly predicted from the others. In this situation, the coefficient estimates of the multiple regression may change erratically in response to small changes. Ordinary least squares method requires the absence of multicollinearity. The remaining parameters were normalized to the 0–1 scale (3) and (4):

$$\widehat{D_{i,t}} = \frac{D_{i,t}}{\max\{(D_{i,t})\}} \quad (3)$$

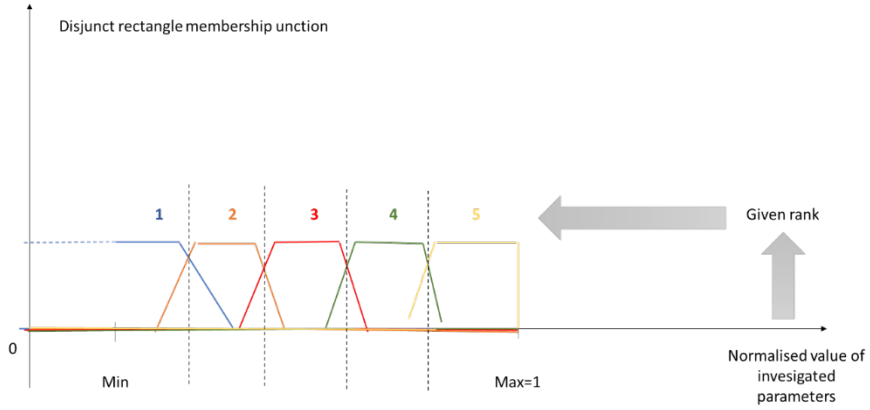
$$\widehat{A_{i,t}} = \frac{A_{i,t}}{\max\{(A_{i,t})} \tag{4}$$

Where,

$\max\{(D_{i,t})\}$ – maximum of D_i at year t

$\max\{(A_{i,t})\}$- maximum of A_i at year t

The filtered parameters had different weights. Using this normalized scale, each district was assigned a rank from 1 to 5 for each year. For that author fuzzified the problem and established a membership function to be able to automatize the assignment. The membership function was based on the maximum and minimum value of parameters and automatically calculated five steps =Figure 2):



Visualization of membership functions

For faster calculation core of membership function were maximized and boundary of membership function were minimized (Figure 3). The weights for each parameter for each of the two indices were determined by the SPSS program, applying principal component analysis to the normalized, time-independent data.

3 Results – Local Adaptation in the Digital Era

The Sixth Assessment Report on impacts, adaptation and vulnerability of the IPCC (Intergovernmental Panel on Climate Change) was published at the end of February 2022 [3]. In addition to a wide range of adaptation possibilities, various risks, adaptation types and major hindering factors are also presented. Digital solutions as means for enhancing the efficiency of adaptation appear in this report several times, irrespective of the area of adaptation or the topic of discussion. One of the major objectives of the new Adaptation Strategy of the EU (2021) is that by 2050, the

Union should become a society resilient to the expected effects of climate change, i.e., a society which is capable of providing intelligent, dynamic and systematic answers and can carry out the required steps [45]. The question is how to interpret this objective in the era of the digital transition. The effects of climate change arise in different forms in various areas. Thus, it may be crucial to identify and utilize the potentials at various spatial levels in regions with different conditions. This section explores how the correlations between digitalization and adaptation can be considered at the local level to harmonize regional development initiatives with the digital transition.

The premise of the analysis is that digitalization and adaptation are correlated: more digitally developed regions adapt to the expected effects of climate change more quickly. If a given region has no sufficient adaptive ability, it becomes vulnerable, resulting in reduced livability and a diminished sustainable regional development potential. It is a fundamental question whether initiatives related to digital transition might influence this process, and if yes, to what extent. The adaptive ability of a given region is related to the level of living standards and development. Both adaptation and digitalization are characterized by versatility concerning their types and measurability. From an ecological economics perspective, digitalization can be interpreted as a tool for closing socio-economic chains and, thus, as a factor contributing to the transition towards sustainability. Finally, the district level results were visualized on maps (QGIS): *Figure 3.* shows the average values of the Spatial Digitalization Index for each district in Hungary, while *Figure 4.* depicts the average district level values of the Spatial Adaptation Index.

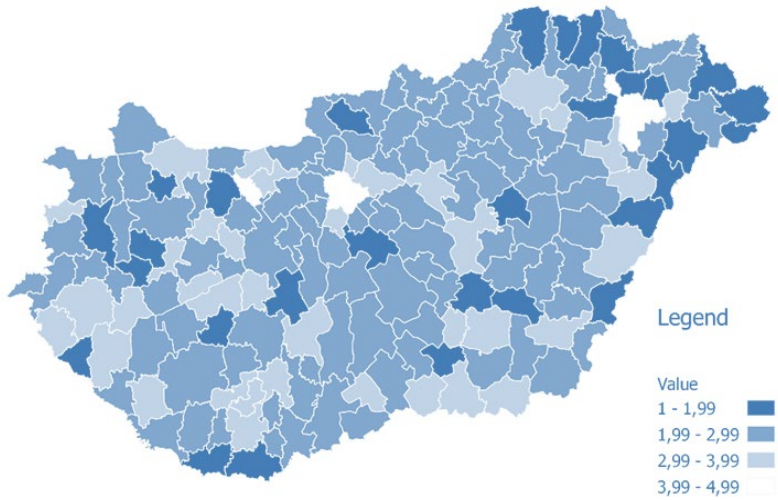


Figure 3
Visualization of digitalization parameters based on the average of 2013-2018

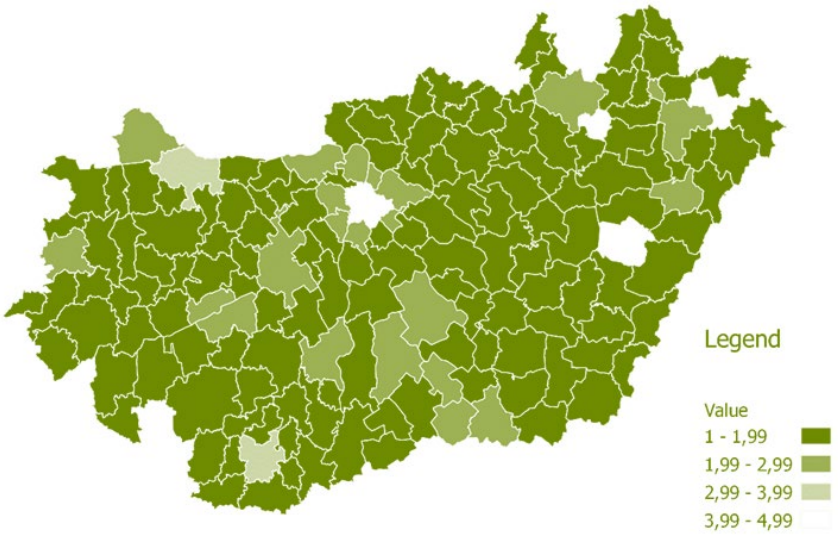


Figure 4
Visualization of adaptation parameters based on the average of 2013-2018

4 Analysis

The analysis exploring the correlations of digitalization and adaptation presented here was carried out in 2021 and focused on the level of districts (NUTS 3 level in Hungary). The dynamic regression analysis proves that digitalization is increasing at the district level in Hungary and digitalization can support and strengthen adaptation to an increasing degree:

$$\min\{\varepsilon_t\} \rightarrow A_t = \propto \cdot D_t + \varepsilon_t \quad (5)$$

where,

A_t is adoption rank at year *t*

D_t is digitalization rank at year *t*

α is slope of linear regression

ε_t is the error term in year *t*

In the examined period, the level of digitalization increased and helped adaptation; thus, the excess of support also grew owing to the higher level of digitalization over time (Figure 5):

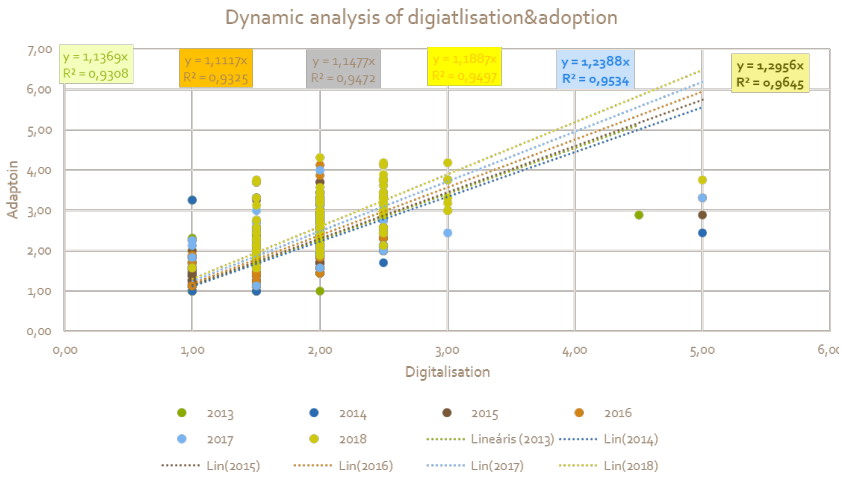


Figure 5
The change of the correlation between digitalization and adaptation of Hungarian districts between 2013 and 2018

The tests prove that the weight of certain digitalization and adaptation parameters is different. This analysis proves a correlation between the district-level values of the Digitalization Index and the Adaptation Index. Digitalization might play a role in the integrated approach to adaptation. The data prove that the level of the digital infrastructure of Hungarian districts is growing, which in turn aids the adaptation of districts to a higher extent, which can also contribute to the relevant region's transition to sustainability.

Sustainability is the development and a possibility at the same time, and development can be interpreted as an improvement in adaptation. From the perspective of regional development, it is crucial to determine the extent to which climate change affects endogenous and exogenous factors and how this can be interpreted in the era of digitalization.

The present study wishes to explore how the interpretation framework and spatial characteristics can be interpreted from a sustainability perspective, focusing on the challenges posed by climate change. Another research question is whether correlations can be found between digitalization and adaptation from a spatial perspective. Owing to the strong locality of the expected effects of climate change, local solutions will be required. The question is how innovative adaptation can be interpreted concerning sustainable regional development. Spatial aspects may influence the flexibility of adaptation to various degrees. The above analyses prove that the exploration of correlations between digital transition and adaptive capacity and the strengthening of potential synergic effects may contribute to enhancing livability at the local level and strengthening local sustainability.

Conclusions

Sustainability and climate change are connected in several ways and exist in a circular relationship. The direction of climate change may fundamentally be affected by the direction and characteristics of regional development. Additionally, the occurrence of the expected effects of climate change may modify the chances of moving towards sustainability even at the local level, both from a mitigatory or an adaptive perspective. Moreover, the achievement of digital transition and the promotion of sustainable development are central elements in European development policies.

This study interpreted the interrelations of sustainability and digitalization with a special focus on the phenomenon and concept of climate innovation. Regional climate innovation ambitions might facilitate the movement of the region towards sustainability. One reason for this is that various innovative digital solutions, which might serve as effective tools to handle the challenges related to climate change, may also contribute to the change of adaptive capacity. This is especially true for the potential of digital transition, which is also supported by the correlation explored in this study between the district-level Digitalization Index and Adaptation Index and by the mutual strengthening effect of processes related to digitalization and adaptation.

The major focus of this study was on adaptation, which can be interpreted as a new dimension of sustainable regional or local development. In sum, the study's results on connections between digitalization and adaptation at the regional level direct attention to the interrelations of the transition towards digitalization and sustainability in the era of climate change.

Taking into account the challenge-based planning options can be pivotal in regional sustainable development perspectives. This also highlights those aspects of sustainable regional development which might provide useful information for experts, designers, policymakers and local decision-makers.

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