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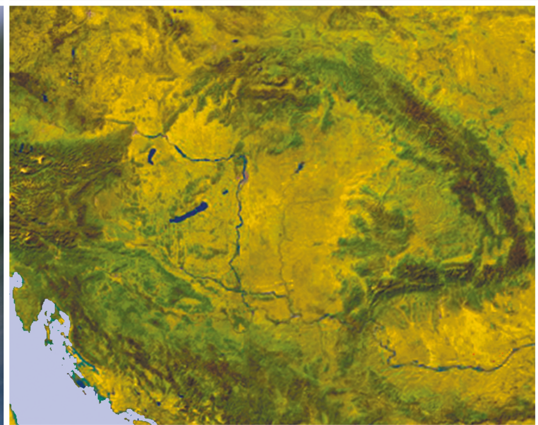

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Industry 4.0 in economic geographical approach

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The evolutionary and disruptive potential of Industrie 4.0

Johannes WINTER[1]

Abstract

Despite all the hype, digitalization is not a new trend. The third industrial revolution started as early as the beginning of the 1970s and has continued to this day. It is shaped using electronics and information technologies (IT) in the economy and progressive standardization and automation of business processes. While exponential growth is typical for the IT sector, this is rarely the case for the classic industries. For a long time, the change was barely perceivable, which led many players to denounce these developments as uninteresting, losing interest at an early stage. But then, as the process picks up breakneck speeds, it often becomes impossible to jump on board or keep up. When automation driven by electronics and IT established itself in production, it led to dramatic changes in value chains and employment structures. Through standardization and automation, business processes became more efficient, quicker, and transparent. When the dot-com speculative bubble burst in 2000, vending machines that ordered supplies independently were already in operation. In the search for the business model of the Information Age, electronic marketplaces became popular pioneers for dynamic business networks and real-time business. Many of today's well-known technology firms – such as Google, Netflix, or the predecessors of Facebook – were already active on the market in a similar form. In recent years a second wave of digital transformation is experienced and with it, a fourth industrial revolution. The necessary information and communication technologies have now become so cost-effective that they can be used in widespread areas. As a result, many of the dot-com promises have been realized today. The aim of this paper is to intensify the Industrie 4.0 debate in economic geography by showing the evolutionary and disruptive potential of Industrie 4.0.

Keywords: Industrie 4.0, fourth industrial revolution, digitalization, Internet of Things, economic geography, Europe.

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Introduction: the second wave of digitalization

When it comes to the second wave of digitalization, mobile connected devices such as smartphones are a vital part. But first: Why do we call it the second wave, what makes the difference between the wave of digitalization today and digitalization in the early years of this millennium when the dot.com-bubble burst?

The ideas and concepts that are depicted here aren't that new, especially the concept of "everything as a service" and the even greater personalization of services and products. One aspect of this servitization and personalization is the idea that instead of buying off-the-shelf products and services we use web- and cloud-based services and we go online to buy bundles of products and services – and these bundles are individually tailored to the needs and preferences of their users. These are so-called smart services. One example of how these ideas are implemented today is "mobility as a service": In order to get from A to B, people may use an app on the smartphone combining different means of transport, like car-sharing or public transportation or they choose if they would like to take the quickest or the cheapest connection.

So, what is different today? In short: the technologies that are needed to implement the ideas like "everything as a service" can now be deployed on a large scale at very low costs (Daugherty, P. and Wilson, H.J.

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2018). Nearly all objects, like cars and trains, machines on a factory shopfloor or household appliances can be connected to the Internet and can be equipped with sensors in order to generate, collect and exchange data. Their sensors provide us with a huge amount of real-world data at nearly no costs. This data in turn can be used to gain valuable information using data analytics and machine learning. And it can be used to develop and train autonomous systems – which will become more and more common in the course of next years.

The term "autonomous systems" can be applied not only to robots in the conventional sense but also to manufacturing systems, vehicles, buildings and software systems: for example, a system for the energy management in the smart home that adapts to the user's individual patterns of energy consumption. A system can be described as autonomous if it is capable of independently achieving a predefined goal in accordance with the demands of the current situation without recourse either to human control or detailed programming. Of course, Artificial Intelligence (AI) and machine learning (ML) play a great role in developing such systems (Acatech, 2017). This second wave of digitalization has far-reaching consequences for the economy and established business models.

So far, there has been little existing systematic research in economic geography on the topic of Industrie 4.0, which is surprising, since it can be assumed that the digital transformation of the economy could also have a regional impact. Current Industrie 4.0 research in economic geography refers to regional disparities and transformative industrial policy (Bailey, D. and De Propris, L. 2019), national and regional comparative advantages in key enabling technologies (Ciffolilli, A. and Muscio, A. 2018), the impact on existing clusters (Götz, M. and Jankowska, B. 2017), Industry 4.0 in factory economies (Szalavetz, A. 2017), socio-economic effects of smart manufacturing (Fuchs, M. 2020), and location decision and upgrading in automotive industry (Haider, M. 2020; Molnár, E. *et al.* 2020) as well as the potential of EU regions to contribute to Industry 4.0 (Balland, P.A. *et al.* 2019). So far, there is a lack of a common and uniform understanding in economic geography of what Industrie 4.0 is and what spatial impact the fourth industrial revolution can have. The main purpose of this paper is to develop a common understanding of the importance and impact of Industrie 4.0 at different geographical levels, based on the conceptual and empirical considerations of the National Academy of Science and Engineering (Acatech, 2013), which introduced the term Industry 4.0 in 2013.

This contribution is empirically based, relying on primary data collected through 160 qualitative guided interviews with executives and experts from China, Germany, Japan, Korea, United Kingdom and the US conducted between September 2015 and December 2018. The in-depth interviews were transcribed and analysed using 'Qualitative Content Analysis' (Glaeser, E. and Laudel, G. 2004). (The study forms part of a research project carried out at "acatech" funded by the German Ministry of Economic Affairs and Energy.)

The study consists of six major parts. The second part demonstrates the evolutionary path of the fourth industrial revolution. The third part tries to reply to what Europe has to do in order to join to the fourth industrial revolution, while the fourth part describes the major features of a data driven economy. In the future the research fields of economic geography research will also transform, and this is introduced in the fifth part. Finally, some conclusions and outlook follow.

The fourth industrial revolution – an evolutionary path

Like in many other regions of Europe, in Western Europe industrialization began with the introduction of mechanical manufacturing in the early 19th century, when machines such as the mechanical loom revolutionized the way goods were made. The first industrial revolution was followed by a second one at the turn of the 20th century, which involved electrically-powered mass production of goods, labour division and the rise of multinational enterprises. This was in turn superseded by the third industrial revolution during the 1970s, which employed electronics and information technology to achieve increased automation of manufacturing processes. Machines took over not only a substantial proportion of manual labour but also some parts of non-manuals' work (Kagermann, H. *et al*. 2010) (*Figure 1*).

Based on the findings of an empirical survey in six industrialized countries, the study analyses both the opportunities and challenges of Industrie 4.0 for the economy. First, the question arises as to what is new about the concept of Industrie 4.0? The introduction of the Internet of Things and Services (IoT) into the manufacturing world, which is referred to as Industrie 4.0, is about to introduce a completely new approach to production. Embedded manufacturing systems within factories are vertically networked with business processes and horizontally connected to value networks that can be managed in real time: from the moment of a customer's order right through to outbound logistics.

Together with industrial partners, researchers mainly from the economic sciences and engineering sciences are developing prototypes of such future smart factories (Schuh, G. *et al.* 2017; Tolio, T. *et al.* 2019). Smart factories allow individual customer requirements to be met and mean that even individual items can be manufactured profitably. Dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexible to disruptions and failures on behalf of suppliers. Transparency is provided over the manufacturing process, facilitating optimized decision-making.

Industrie 4.0 – what are their achievements to this day?

The first three industrial revolutions came about as a result of mechanization, electricity and IT. Now, the introduction of the combination of the internet and services in the manu-

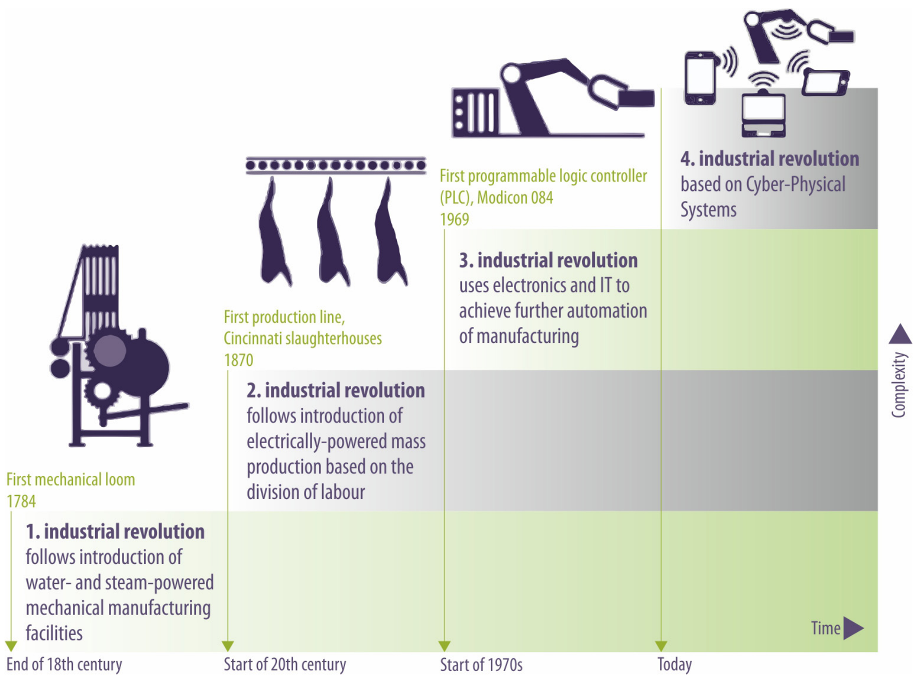

Fig. 1. Industrial revolutions during the history. *Source:* Forschungsunion and acatech, 2013.

facturing environment is ushering in a fourth industrial revolution. In the future, businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of Cyber-Physical Systems (CPS). Europe with its strong industrial core is thus uniquely positioned to tap into the potential of a new type of industrialization: Industrie 4.0.

A revolution always battles with the "old" world (Winter, J. 2010). Industrie 4.0 is extending the analogue and physical world to a digital environment. In this context, revolution means that system boundaries are expanded – not only physically but also virtually. From now on smart factories are built and connected to the smart supply chain. With the help of digital twins – e.g. of the product or even the production systems – the system can be mapped in a virtual world. These changes offer new opportunities to increase the productivity and emerge new business models (Schuh, G. *et al.* 2017). That implies organizational and individual competences required by a digitized world being expanded. This is the reason why agile working methods should be adopted (Cooper, R.G. and Friis Sommer, A. 2020).

Industrie 4.0 – what does it take to go a step forward?

Professionals from science and industry become more and more familiar with the concept of Industrie 4.0. Since 2015, the German initiative 'Plattform Industrie 4.0' brings together companies, trade unions, associations, science and politics to join forces. We see more and more Industrie 4.0 use cases, projects, demonstration centres and competence centres emerging all-around in Europe. But many people still underestimate just how radically and how rapidly we will need to change. Recent studies suggest that Industrie 4.0 may have the same dramatic effects on the geography of knowledge and innovation in Europe as the previous three industrial revolutions (Kagermann, H. and Winter., J. 2018; Balland, P.A. *et al.* 2019), especially when developing new data-driven business models and disruptive innovation. When it comes to the broader public, more and more people are probably at least aware of the buzzword Industrie 4.0. The topic has finally made it to mainstream media. But still, most people will start to understand and to enjoy Industrie 4.0 not until they really experience its benefits first hand – for example, in terms of better / cheaper / more customized products and services. Or as workers in a smart factory: machines will take over more and more physically wearing and monotonous tasks; workers will be able to work more flexibly and with more individual choice and responsibility. Intelligent assistance systems will help employees to perform their tasks and support lifelong learning.

The smart factory

The ideal smart factory employs a completely new approach to production: machines and products, production equipment and employees are digitally connected with each other. The production system is highly digitized and makes it possible to track its status and productivity. Smart products are uniquely identifiable, may always be located and know their own history, current status and alternative routes to achieving their target state. The embedded manufacturing systems are vertically networked with business processes within factories and enterprises and horizontally connected to dispersed value networks that can be managed in real time – from the moment an order is placed right through to outbound logistics (Xu, L.D. and Duan, L. 2019). In the manufacturing environment, so called Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently. This facilitates fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management (*Figure 2).*

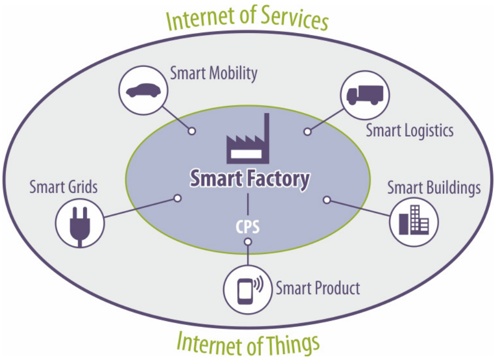

Fig. 2. Smart factories as part of the Internet of Things and Services. *Source*: Acatech, 2013.

The digital twin of the factory

According to recent studies (Park, K.T. *et al.* 2020), in future roughly every object will have a digital twin with which enterprises can do many things in virtual space. By means of cyber-physical systems, the real and virtual world is further merging. For instance, much better simulations of products and production processes will be possible, meaning that less energy and resources must be expended in trial runs. The results of this study suggest that there is also an increasing connectedness within manufacturing and along value chains. This leads to a higher degree of automation, improved manufacturing quality, faster innovation cycles, and lower consumption of resources (Kagermann, H. and Winter, J. 2017). Since all physical objects can be interconnected via the internet, we can, for example, make just-in-time logistics even better and prevent machine failures through predictive maintenance. Both prevent idle periods in production, thus saving resources.

Following the logic of the Internet of Things (IoT), assets, machines and components can exchange information continuously. Therefore, production- and logistic processes become integrated and, therefore, can be controlled and coordinated in real time and from spatial distance (Muscio, A. and Ciffolilli, A. (2020). A necessary precondition is the standardization and modularization of several single process steps and the programming of virtually adaptable models of such modules. Therefore, operating processes can be planned, coordinated and controlled. Moreover, the interconnection enables the continuous exchange of data that are necessary to adjust processes automatically and according to a specific situation. Here, the application of CPS allows a decentralization of the process control. It can be transferred to components that process ambient data by using embedded systems. In the next step, precise control commands can be derived. This increases the flexibility in production.

Industrie 4.0 and the future of work

The digital transformation will enable companies to react faster and more precisely to changing customer needs and new market conditions. It is already well understood that a fast implementation of data-based business models and a high level of flexibility, adaptability, and willingness to change among organizations and its employees are crucial for success in the face of global competition. As Boschma, R. (2017) showed, a region has a higher probability to develop innovative goods when these are related to existing goods and value chains in a region. This means that there is a risk that regional disparities will be exacerbated by technological change – with effects on the regional labour market. This is the reason why key factors in the successful introduction of innovative processes and products include the acceptance of new technologies by employees and the design of attractive forms of work. At the same time, the higher degree of flexibility, in turn, opens the opportunity for workers to also achieve a higher level of work-life-balance and to safeguard their long-term employability by personalized re- and up-skilling measures. In this context, the ability of workers to learn (and retrain) throughout the span of their careers is key to ensuring their future employability (lifelong learning) (McAfee, A. and Brynjolfsson, E. 2017). Companies share the responsibility by providing the corresponding education and training, and their employees obviously benefit from these measures.

Some company leaders are already dreaming of relocating value that was lost in the past two decades to East European and Asian countries (Fuchs, M. and Winter, J. 2008; Winter, J. 2008), where labour costs were significantly lower than back home. In the world of smart production however, a countries' competitive advantage is rather determined of sophisticated country infrastructures, innovation and know-how than from cost benefits of mass production. However, Industrie 4.0 may have the same dramatic effects on the geography of knowledge and innovation in Europe as the previous industrial revolutions (Balland, P.A. *et al.* 2019). Contrary to some fears about automated factories being orphan places (Frey, C. and Osborne, M. 2013), the fourth industrial revolution will provide new and often better job opportunities for skilled human workers.

In this perspective, a skilled labour force is crucial in order to introduce the entirely new production approach. The European and national ability to manage complex industrial processes in multi-stakeholder networks becomes a key factor for success. Another asset is the country's specialization in research, development and production of innovative manufacturing technologies. Universities, research institutes and companies are constantly developing innovative solutions for enhanced manufacturing. That is why STEM (Science, Technology, Engineering and Math) education becomes still more important. Hybrid skills become more and more important: future engineers need additional mechatronics and software skills. Managers need business skills as well as technical skills (e.g. data science). And: soft skills also play an important role in a connected economy/society (e.g., collaboration, conflict management, foreign language skills). As mentioned earlier, cyber physical systems consist of networks of small computers, equipped with sensors and actuators. Such embedded systems are integrated in materials, products, devices and machine parts and connected via the Internet. This constitutes the so-called Internet of Things (IoT), where the boundaries between the physical and digital world become more and more blurred. Moreover, there are tighter interactions between human users and their connected personal devices that lead to an Internet where human users become more central than ever. This means people are not seen only as end users of services and applications but become active elements of the so-called Internet of People (IoP).

What Europe can do to join the fourth industrial revolution

There is still disagreement in the literature about the extent to which Industry 4.0 can reduce regional disparities or, in certain circumstances, increase them. According to Muro, M. *et al.* (2019), there are differences across metropolitan regions in the US regarding their exposure to automation-driven task replacement. On the other hand, Barzotto, M. and De Propris, L. (2019) argue that regions that have been left behind will find their way back if they specialize in smart processes, products and services that they can market globally. Muscio, A. and Ciffolilli, A. (2020) show that EU researches and SME funding play an important role in technology integration and increased competitiveness. For most of the experts we surveyed, Industrie 4.0 offers great potential for European regions. This is because the deployment of Industrie 4.0 solutions is seen as one means of promoting the reshoring of manufacturing capacity mainly from East Asia. According to our empirical findings, a higher degree of digitization and automation and the resulting productivity gains are keys to the regional competitiveness of industry in Europe.

Germany, for example, developed in 2013 a 'digital journey' and strategy to lead companies of each size to a high degree of digitization and to save their competitiveness. Networking platforms are founded to guarantee the exchange of the knowledge between companies, science, policymakers and trade unions. Enterprises share their best practices of Industrie 4.0 and help other companies on their evolutional way to the fourth industrial revolution. Politics support their development with public funding and focused research projects. Moreover, companies are offered different programs to gain knowledge regarding Industrie 4.0 and its implementation funded by the government, unions and trade associations. Thus, Industrie 4.0 is all about networking and exchanging knowledge and experiences with all parts of the economy.

Moreover, especially for European countries, it is important that digital technologies are adopted by businesses in order to grow labour productivity and to benefit from the potentials of online commerce. Europe would benefit from an Industry 4.0 scheme to develop specific digitization plans for the industry. It is important to think about investment in developing a strong Europe-wide ecosystem of digital innovation hubs. In several regions digital manufacturing platforms have already been developed to help digitize the manufacturing process. Europe could also benefit from creating the right conditions for private investments to improve the digital infrastructure. However, Europe must overcome shortages in IT-skills of the citizens. According to the Digital Economy and Society Index (DESI), about 20 per cent of the European population has never used internet. That also limits the possibilities offered by the digital economy and society.

As our expert survey shows, data become more and more important and independent economic goods, have a value and are base of innovative and profitable business models. Once they have left factory, smart products are still connected via the internet and exchange massive volumes of data during their use. These big data are refined into smart data, which can then be used to control, maintain or enhance and improve smart products and services. They generate the knowledge that forms the basis of new business models.

The consolidation and refinement via real-time analytics and artificial intelligence is usually done in data-rich digital platforms, which will soon be the predominant marketplace. Quite a few companies have already connected smart products to the Internet and have started collecting and evaluating data. Ideally those platforms should combine device management with easy connectivity, data storage systems and an app store open for customized data-driven services provided by an open digital ecosystem. The quality of the digital innovation ecosystem and how fast it can be established will be crucial for a successful implementation of new data-driven business models. In addition, several challenges must be answered regarding financing, reliability, data security, Intellectual Property Rights (IPR)-protection, and finally standardization *(Figure 3).*

When it comes to the concept of Industrie 4.0, there is an area of tension between the ubiquitous access to production and personal data in order to create value on the one side and the protection of privacy on the other side. Wherever companies or organizations running Industrie 4.0 applications use data that is directly or indirectly tied to a specific person, they will be subject to the General Data Protection Regulation (GDPR). The GDPR aims at harmonizing the regulatory frame-

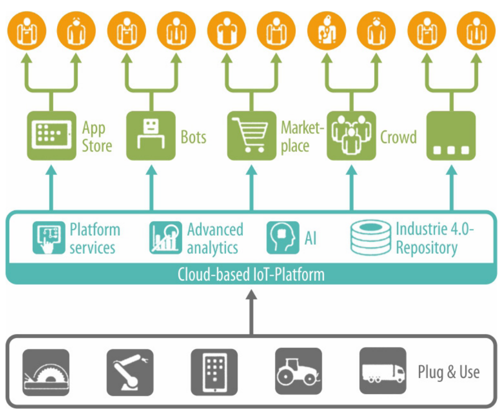

Fig. 3. Dimensions of Industrie 4.0. *Source*: Schuh, G. *et al.* 2017.

work regarding the usage of personal data in the European member states. The GDPR does not only affect European companies or organizations. It affects every business that handles or processes personal data of European citizens. According the GDPR, personal data must be processed in a lawful and transparent manner. This refers to specific purposes for collecting, storing and processing the data. Organizations must ensure that personal data is stored for no longer than necessary for the purposes for which it was collected. In addition, they are obliged to install appropriate technical and organizational safeguards that ensure the security of the personal data.

Towards a data driven economy

In the opinion of most of the experts we interviewed, we see a shift from product-driven to data-driven business models in all European core industries. Today, around 30 billion products around the world are connected to the Internet. Once they have left the factory, products are connected via the Internet. These products are data-driven, and they will be refined with digital services, so called smart services.

How are smart services created?

Smart services need data about the products, their use and consumers, and from other sources like traffic data or weather. These product-service-bundles must be able to extract valuable information from it via data analytics or machine learning. This is shown by the example of 'mobility as a service'. In order to implement this data-driven business model, a wide range of data is required: data of the locations of the users, cars or means of public transportation, movement data, weather data, information about restaurants at the destination etc. are required. And of course, mobile devices play a central role in gathering this information and data about how a certain service is used. In other words: it can be assumed that there is a shift towards data-driven innovations.

Smart services are created in dynamic digital ecosystems that evolve around digital platforms without geographical limitations. Why is that? According to our empirical findings, trustworthy partners are necessary to build up networks and to create innovative smart services. These partners often come from geographical proximity or at least existing business networks. Proximity is therefore a factor that should not be underestimated – especially in the digital age, which seems to be borderless. It should be added that many companies don't have all the know-how to implement such data-driven smart services on their own. For example, companies need help from a start-up that is cutting edge in data analytics in order to get the information you require out of the vast amount of data. So, there must be a kind of digital business or innovation ecosystem. In my view, four different groups of the actors involved in the digital ecosystem can be distinguished (*Table 1*).

In the case of a smartphone, a tech giant such as Google or Samsung is the platform sponsor (design of the Android operating system) and acts as a platform provider (operation of the Android operating system and the app store). Application developers are those who make their apps available in the app store, the end users are the smartphone customers. Platform sponsor and platform operator can be the same company, but don't have to be.

Digital platforms consist of two parts:

– First: A "core" that is stable and changes only slowly – in our example the app store itself. This core defines technical and economic "rules of the game" such as interfaces and processes.
– Second: A "periphery" with a high development speed and heterogeneity. These are the app developers. They do not necessarily enter business relationships with each other but are often independent participants of the same platform. Due to virtual collaboration, spatial proximity

*Table 1. The structure of a digital innovation ecosystem**

Group	Role
01 End users	The end users are the actual customers of the platform and use it for their own purposes – be it the smart phone user or an industrial company that runs its business with the help of such a platform.
02 Application developers	The application developers create programs and services based on the technological platform.
03 Platform providers	The platform providers deliver the technical infrastructure of the platform. In the IT sector, this is a package of hardware and operating system based on which programs and services can be developed.
04 Platform sponsors	The platform sponsors are the actual "leaders" of the platform as such, as they determine the design of the platform and own the intellectual property of the platform.

*Edited by the author.

hardly plays a role in digital platform relationships (Moore, J.F. 1993; Kagermann, H. and Winter, J. 2017).

In platform logic, the consumer interacts with both the platform operator and the providers in the platform's periphery, the app developers. In order to be able to use the offers on a platform, the consumer enters a relationship with the platform. He logs in and user-related data is collected. On the platform, the consumer meets the providers: he buys, consumes and uses the offers on the platform. Over time, profile information is supplemented by information that arises from using the applications on the platform (Silvestri, S. and Gulati, R. 2015; Cusumano, M. *et al.* 2019) (*Figure 4*).

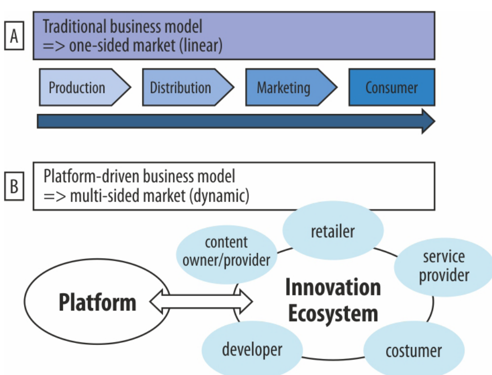

Fig. 4. From one-sided to multi-sided markets. *Source*: Tiwana, A. 2013, Winter, J. 2018.

Digital platforms as a future field of economic geography research

What are the special characteristics of platforms when it comes to competition in the digital era of manufacturing at a global and regional level? The empirically derived answer is that service platforms create new virtual control points instead of geographical or physical control mechanisms. Not only do they provide the rules, standards and processes according to which the different players in the digital ecosystems get connected and do business. They also serve as a central interface to the customers at a global level. Digital platforms are discussed in the economics literature under the concept of multi-sided markets (Evans, P. and Gawer, A. 2016). Case studies of geographical marketplaces are abundant in economic geography literature (Nocke, V. *et al.* 2007). The concept of virtual marketplaces and multi-sided platforms are not yet widely used in the economic geography research and should be taken more into account when assessing a globalized industry that is increasingly networked via software platforms. Multi-sided markets have special characteristics and can unfold certain dynamics that may in certain cases call for action from the regulatory authorities. All involved actors in the multi-sided market depend on each other and on the platform: creating APPs for the app store wouldn't be attractive if no one was using android as an operating system. That's why network effects emerge: the benefits of one side depend on the participation and desired transactions of the other side and vice versa.

Due to the network effects and economies of scale, competitors may face significant market entry barriers (Rysman, M. 2009). And since many digital platforms in the B2C-sector initially focus on the fast growth of their user base rather than sales growth, the growth of the platform into a very powerful position in the market or a quasi-monopoly may take place without major takeovers. That's why regulatory instruments that rely on turnover thresholds may be too slow in these cases. So, what are the benefits and risks for customers and consumers in digital platforms, and are there spatial effects?

Risk of data monopolies

If a digital platform takes on the role of a quasi-monopoly the opportunities for consumers as well as for other actors in the ecosystem to find substitutes for the dominant platform such as virtual or geographical marketplaces are often limited. This leads to so called lock-in effects. Here, interoperability and portability obligations may be a means of restoring competition between different platforms and avoiding lock-in effects. However, such obligations, especially in early market phases, can make differentiation and competition between the platforms more difficult.

In the General Data Protection Regulation, the European Union (European Union, 2019) established a right to data portability. Its aim is to strengthen data protection, consumer protection and the competition for privacy-friendly technologies. Ultimately, it is intended to strengthen the control over the personal data. The EU had in mind cases in which, for example, a user of a social network, a music portal or certain mobile apps wants to change the provider. If the legal requirements are fulfilled, the persons concerned have the right to receive their personal data in a suitable format (e.g., via a USB stick, a CD, the private cloud or a barcode), to transmit their personal data to another provider. But it is not yet sufficiently clarified what is meant by personal data "provided" by the data subject. It includes personal data that relate to activity of the consumer or result from the observation of an individual's behaviour. But there is also data resulting from subsequent analysis of that behaviour: data that has been created as part of the data processing, e.g., by a personalization of certain services, for example personalization of recommendation systems. According to the Article 29 working group, which serves as an advisory body on the GDPR, these kinds processed data are not covered by the right to data portability.

Lock-in effects vs. increased number of options and comparability

Platforms can reduce information asymmetries – for example when consumers exchange ratings and assessments of services and products. Consumers can easily obtain information about services and products. The offers and products of a platform can also change and adapt over time. Thus, auction platforms become professional marketplaces at the expense of stationary retailers and regional shops. Once the users have agreed to the terms of the virtual platform, they are practically committed to it and must live with the changing conditions – for better or for worse.

In individual cases it may be the case that the provider of the platform also appears as an application provider (Tiwana, A. 2013). Examples of this are Amazon when it competes with its own listings with its sellers, and Google when its own listings are preferred in the search results. From the consumer's point of view, caution is called for here. If platforms compete with their suppliers on the geographical periphery, then they could possibly present their own products more prominently. Consumers may be restricted in their choice. In addition, platform providers have more than suppliers the chance to take over markets and to displace virtual as well as stationary competitors – regarding certain applications (Feldman, M.P. *et al.* 2019). They thus also strengthen their own competitive position in relation to other platforms. This has a lasting effect on the consumer, as its influence on the market is limited. What we also know from the interviews: from a geographical point of view, moreover, stationary suppliers are much more limited in their market opportunities than monopoly-like platform companies.

'Privacy bargain' vs. data sovereign

Many platforms are kind of "steering" their users through optical presentations and presettings. This has implications for consumer protection and it also has effects on relations with geographically located as well as platform-based competitors of the platform. Consumers may be restricted in their choice. In addition, under the keyword 'Privacy bargain' it says that if the user does not pay for the use, he can assume that he is the product himself. The operators of the platform are accused of always leaving the users in the dark about the value of the data that the users bring in. The use of data for advertising purposes suffers from an information and transparency gap between provider and user. The user who consents to the use of data for these purposes is blind because he does not know the true value of his data. In return, however, experiments show that users are all too willing to contribute their data in order not to have to make the slightest financial contribution to a service (privacy paradox) (Barth, S. and De Jong, M.D.T. 2017). When it comes to privacy, there is also a need for supporting and to give incentives for technical solutions.

The principles 'Privacy by design' and 'Privacy by default' are also part of the GDPR (European Union, 2019). Already in the development stage of a system, data protection is to be technically integrated (Privacy by design). In addition, the factory settings should be designed to be data protection friendly (Privacy by default). Users who are not that into technology and therefore not able to adapt data protection settings are protected by this principle. Data-mining algorithms could take privacy and data sovereignty into account as an intrinsic property (privacy-preserving data analytics). This is also in the interest of regional market players who could be subject to discrimination due to the market power of the platform monopolists. However, there is a lack of relevant economic geography research.

Dynamic and individual pricing vs. transparency of algorithm-based decision processes

Regarding consumer and stationary seller protection, algorithm-based decision processes are a topic that is widely discussed (Metawa, N. *et al.* 2017). One field of application of algorithm-based decision processes is pricing. Today, repricing algorithms are among the most important success factors in international e-commerce. In repricing, an algorithm uses publicly available data sources (including price search engines) in order to enable retailers to quickly adjust their own prices to the current competitive and demand situation at any time. Unlike repricing, individual pricing focuses on the consumer. Individual pricing is particularly common in the US. For example, some US companies made pricing dependent on the device used. The reasoning behind this refers to the higher prices of Apple devices, for example. It is assumed that Apple users have a higher budget than the average consumer and would therefore accept higher prices. With individual pricing, however, prices can also be set into marital status, age and gender, time, place of residence and numerous other variables. From a consumer protection point of view, this form of pricing raises questions. It already finds its limits in Germany through data protection. Regarding algorithm-based decision process, there's a discussion about establishing transparency and accountability.

New industrial opportunities with artificial intelligence

What was repeatedly heard in the expert interviews is that data is becoming an economic good, which is what inspires some to speak of the data economy or data capitalism (Brynjolfsson, E. and Kahin, B. 2002). The required data are merged, analysed, and interpreted on digital, usually cloud-based technology platforms, with the help of artificial intelligence and machine-learning methods and tools. Autonomous software systems such as self-learning robot advisers or assistance systems contribute to a personalized and convenient user experience (Acatech, 2017). Reconfiguration is no longer a manual process but autonomous and dynamic. This provides us with highly adaptable processes on all organizational levels for the first time: from the factory floor to the business level, which is often referred to as a new wave of business process reengineering. As a result, the collection and use of data will become omnipresent. Self-learning and autonomous systems driven by artificial intelligence use that to make independent decisions, also building on their own learning processes. These developments represent a challenge, but above all an opportunity for Europe. The guiding principle of action here should be that digitalization is primarily shaped by people for people.

Current research and progress in the field of artificial intelligence are mainly based on advances in machine learning, which in turn are made possible by the development of powerful algorithms, more powerful hardware, increasing computing power and the cost-effective availability of mass data (Wahlster, W. 2014). Learning ability was already defined at the beginning of artificial intelligence (AI) research as the basic cognitive ability of "intelligent" technical systems. Machine learning aims to ensure that machines automatically deliver meaningful results without explicit programming of a specific solution path. Special algorithms learn models from the existing example data, which can then also be applied to new, previously unseen data. Three learning styles are distinguished: monitored learning, unsupervised learning and intensified learning. Machine learning with large neural networks is called deep learning. Machine learning methods are used for data mining, generating smart data and in practically all modern AI systems. All these new technologies and analytical methods can provide new opportunities for the whole economy, particularly for manufacturing industry, and this also means a new challenge for economic geographical research.

Conclusions and outlook

As stated before, the concept of Industrie 4.0 is – with few exceptions – underrepresented in economic geography research. Consequently, it was the purpose of this paper to intensify the Industrie 4.0 debate in economic geography by showing the evolutionary and disruptive potential of Industrie 4.0 on Europe's industrial landscape.

As the empirical results of the qualitative study show, Europe's small and medium-sized enterprises play a crucial role in the innovation process of the manufacturing industry. These often family owned companies distinguish themselves from other companies through an extraordinary level of specialization, know-how and innovative capacities. Often, they are world leaders in their niche markets – and literally hiding in many of the small towns and villages throughout Europe. Although mainly unknown in public, besides multinational corporations and state-owned companies, small and medium-sized enterprises form an essential backbone of the European economy and are actively contributing to the industrial transformation process. Europe's strong automotive, machinery and plant manufacturing companies and their know-how in embedded systems as well as automation engineering are reasons for the continent's pole position in the international race towards the fourth industrial revolution. These so-called hidden champions have also been successfully introducing information and communication technologies for several decades.

The trend towards Industrie 4.0 is inspiring enterprises to set up their core processes more efficiently and develop products and services digitally. This transformation will take a rather evolutionary path. At the same time, digital business models, two-sided platform markets, and data-driven innovation ecosystems have a disruptive potential. That is because contemporary business models can be cannibalized by new market participants and well-funded start-ups in a short time. In addition, disruptive innovations can hurt successful, well-managed companies as well as previously competitive regions. The boundaries between manufacturing industries, service enterprises, IT-providers and tech giants are becoming blurred. Corporates as well as small and medium-sized enterprises need additional competencies and skills, for example in the areas of data science, data analytics, machine learning and agile working methods.

However, intense software know-how and the awareness of new data-driven business models might still prove to become the Achilles' heel of many of the countries' hidden champions. Uncertain about how Industrie 4.0 will change (evolutionary, but radical) their current business models, mechanical firms keep a careful watch over the Silicon Valley, where venture capital driven high-tech-start-ups are currently also discovering the lucrative new markets that are about to come into being. Another crucial aspect is the development of international standards and norms. Without compatible standards, a comprehensive integration of machines, products and services will be difficult to achieve as the study results show.

Even though European companies build open digital platforms and develop data-driven business models, the implementation remains a major challenge for many countries and regions in a heterogeneous European industrial landscape. Nevertheless, nothing is lost yet. The global race in the industrial sector is still open as to which communication and cloud infrastructures will set the standards, what the dominant Business-to-Business platforms will be in the future and which companies will be most successful in turning data into concrete added value. It is therefore the right moment to take a step forward and shape the digital transformation of the industry to our common benefit. The goal of the European Union to create a single digital market to allow digital opportunities for people and businesses and enhance Europe's position as an industrial world leader is honourable. The final implementation of the single digital market is still pending. However, this implementation is the next step in achieving the competition-relevant economies of scale and making Europe's regions fit for the global Industrie 4.0 race.

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Geographical approach of Industry 4.0 based on information and communication technologies at Hungarian enterprises in connection with industrial space

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Abstract

In the short history of Hungarian industry there were relevant changes several times, which had a great impact not only on industrial production and employment, but also on the spatial pattern of industry. After the regime change and latest economic crisis Industry 4.0 or/and the fourth industrial revolution mean(s) newer challenge. Due to information and communication technologies (ICT), which can be considered the basis of Industry 4.0 radical changes can be expected in all fields of life and numerous questions will emerge. The primary aim of this paper is to reveal the geography of older and newer information and communication technologies and their relationship with the spatial pattern of Hungarian industry. The main question is whether the digital divide follows the industrial divide in the Hungarian economic space or not. According to the analysis based on different ICT and industrial indicators, there is no close correlation between the digital and industrial spaces. The geography of Industry 4.0 is characterised by a sharp North–South division.

Keywords: Industry 4.0, fourth industrial revolution, ICT, industry, enterprise, spatial pattern, Hungary

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Introduction

In recent years Industry 4.0 has been the biggest challenge for the Hungarian economy as well. The concept was first used in Germany in 2011 (known as Industrie 4.0 at that time) for a combination of measures to strategically develop the industry there (Hermann, M. *et al.* 2015; Bartodziej, C.J. 2017). In the international literature, however, it is known as Industry 4.0, but also referred to as Advanced Manufacturing Technology, Smart Factory or Internet of Things (Fonseca, L.M. 2018). Industry 4.0 essentially means new technologies that are based on digitalisation, automation and robotisation, and which are revolutionising industrial production. However, the impact of Industry 4.0 goes far beyond industry and will transform the economy and society as a whole (Kovács, O. 2017). Today we are still at the beginning of this fundamental transformation from Industry 3.0, characterised by human-operated machines, towards production by automatic machines communicating with each other and with humans too (Devezas, T. *et al.* 2017).

There is no doubt that digital transformation, and these revolutionary changes will occur in different ways in both space and time (Rüssmann, M. *et al.* 2015). The transformation of countries and regions depends largely on their starting position and different capabilities (Šlander, S. and Wostner, P. 2019). Among the initial conditions the focus in this study is on the geographical assessment of the infrastructure and use of the information and communication technologies underlying the spreading and unfoldment of Industry 4.0. After all, these (such as computer or internet access) are very im-

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portant to the widespread application of new technologies and, thus, to the realisation of the fourth industrial revolution. Therefore, it does matter what characterises the provision of ICT to companies and their application. Their geographical examination, which has so far been little in the literature, provides indicative information to some extent, on the one hand, on the spatial differences in the use of ICT in Hungarian companies, and on the other hand, on how advanced they are in Industry 4.0. It can be assumed that the ICT indicators of enterprises are more favourable in regions in Hungary with more advanced industry, the verification of which is also one of the tasks of this analysis.

The present study consists of five main parts. Following the introduction, the concept of Industry 4.0 and fourth industrial revolution is discussed, and then the major conditions and characteristics of ICT at enterprises based on special literature are evaluated with particular regard to the geographical aspect. After the chapter on the methods, the spatial disparities of the older and more recent application of ICT by Hungarian companies are explored in the third part. Correlations between the info-communication maturity and the spatial structure of the industry are analysed in the fourth part before the conclusions.

Theoretical background

Terminology and main research directions

There have been three industrial revolutions over the last two hundred years, each of which had its own specifics, driving forces and major innovations. These appeared and spread differentiated in space and led to huge changes not only in industry, but also in the economy and society (Mokyr, J. 1985; Jensen, M.C. 1993; Abonyi, F. and Miszlivetz, F. 2016).

The fourth industrial revolution or Industry 4.0, driven by nine fundamental technologies (Big Data, Autonomous robots, Simulation, Horizontal and vertical integration, Internet of Things, Cybersecurity, Cloud service, Additive manufacturing, Augmented reality) began to unfold in the early 21st century, however, the use of the word only spread rapidly in recent years. While the third industrial revolution (Industry 3.0), also known as the revolution of the computer or digital revolution (Schwab, K. 2016), focused on the automation of individual machines and processes, the fourth industrial revolution (or Industry 4.0) focuses on the digitisation and automation of the entire process of production. Machines and production are organised into smart networks, integrating entire production chains, while deepening vertical and horizontal integration. Since it is highly likely that the current digital transformation will also result in radical changes in all aspects of life, many of which are not yet visible today, it can be considered rather revolution, by all means in the long-term, than evolution (Geissbauer, R. *et al.* 2016; Demeter, K. *et al.* 2019). However, some scientists supporting the latter consider the fourth industrial revolution being essentially the result of the further development of the third one, in other words, its completion (Holodny, E. 2017).

The fact that the terms Industry 4.0 and fourth industrial revolution are not fully cleared today can be explained partly by the above (Hermann, M. *et al.* 2015; Fonseca, L.M. 2018). It has not been decided either whether the two concepts have the same or different meanings. Thoben, K.D. *et al.* (2017) used them as synonyms because they believe these concepts have the potential to disrupt the entire conventional approach to manufacturing. In contrast, others think that in a closer sense Industry 4.0 refers to changes in the industry that cause significant transformation in the organisation and method of production, management, technology, etc. (Nagy, J. 2019). In short, Industry 4.0 means „the trend towards a digital revolution in manufacturing…" (Santos, C. *et al*. 2017, 972) or „…a collective term for technologies and concepts of value chain organisation" (Hermann, M. *et al.* 2015, 11). According to

Brettel, M. *et al*. (2014, 43), „ … Industry 4.0 is a popular term to describe the imminent changes of the industry landscape, particularly in the production and manufacturing industry of the developed world." At the same time, the concept of the fourth industrial revolution can be interpreted more broadly because it represents changes in the economy and society as a whole, most of which are not yet known. In this study, the two concepts are used as Industry 4.0 refers to initial technological changes that then lead to deeper, more comprehensive economic and social transformations. In fact, this is what Schwab, K. (2016) refers to: namely, Industry 4.0 is no different than one of the manifestations of this revolution.

Although Industry 4.0 or the fourth industrial revolution had only begun to gain ground in recent years, still the available, mostly foreign literature is abundant. Various experts have studied the new industrial revolution in many different ways. However, they – probably due to the short time elapsed – have only focused on the history of industrial revolutions, the interpretation of concepts and the role of the recent industrial revolution in industrial production, technical and technological, production organisation and structural issues, as well as, its impact on businesses (Zezulka, F. *et al.* 2016; Devezas, T. *et al.* 2017; Reischauer, G. 2017; Ibarra, D. *et al.* 2018; Luthra, S. and Mangla, S.K. 2018). This is no coincidence, because changes, as ever in history and also now, have appeared in the industry first. Major transformation can also be expected in the field of – not in the order of importance – transport, energy, infrastructure, well-being (Caylar, P-L. *et al.* 2016; Santos, C. *et al*. 2017). Moreover, all these changes will not leave the economic space intact, however, their manifestation will also be differentiated. Brettel, M. *et al.* (2014), who classified the publications of eight scientific journals based on three topics (individualized production, production network, end-to-end engineering in virtual process chain) and defined research directions within them, also demonstrated that greatest attention has been given to the industrial and production connections of new technologies in recent years.

At the same time, the examination of Industry 4.0 in a geographical context has received a more modest focus so far (Nagy, Cs. and Molnár, E. 2018; Nick, G. 2018; Nick, G. *et al*. 2019). This can be explained, among others, by the novelty nature of the phenomenon and by the fact that the spatial manifestation of the changes takes longer, and that some of them no longer occur in real space. In spite of this they (or at least part of them) will or can have spatial implications, but they render real space less relevant. Although the role of virtual world will increase and in the digital ecosystems different players get connected and do businesses (Winter, J. 2020), this does not mean "the end of geography" (Tranos, E. and Nijkamp, P. 2013). The closer fusion of industrial production and ICT results in the interconnectedness and complex relationship between the real and virtual worlds in cyber-physical systems (Ibarra, D. *et al.* 2018). This presents another challenge to economic geography.

Characteristics and conditions of ICT at enterprises

There are a number of conditions for the implementation and fulfilment of Industry 4.0. One of these is the availability of the necessary ICT infrastructure because it is the backbone of a connected economy (Bouée, C-E. and Schaible, S. 2015). Regarding info-communication tools, the computer is perhaps the most important and the Internet is also indispensable connecting virtual and physical systems and revolutionising the global value chain organisation (Schwab, K. 2016). ICTs play a very important role not only in the development of individual enterprises but also in the development of the economy as a whole (Müller, J. M. *et al.* 2018). Over the last decade, the development of ICT infrastructure has also intensified in Hungary and demand for services that help the economy (mainly industrial production) or even the population in the digital transition has increased. This will have an impact on the global competitiveness of individual regions and countries (Barsi, B. 2003) and can have a positive impact on it, while there will be also marked changes in production, consumption and trade.

The speed and success of certain areas for the use of new technologies depends heavily on how enterprises are supplied with ICT and the readiness of the enterprises to use them. It is therefore not surprising that a number of recent studies addressed the digital maturity of businesses (Schmidt, H. 2014; Caylar, P-L. *et al*. 2016). According to a survey by McKinsey & Co. in 2016, which included more than 300 manufacturing professionals from Germany, Japan and the US, barely 16 per cent of industrial manufacturers had a comprehensive Industry 4.0 strategy and only 24 per cent indicated that efforts were made to work out one (Caylar, P-L. *et al*. 2016). The majority, however, are not prepared for the new technological revolution, therefore Caylar, P-L. *et al*. (2016, 7) laid out some key tasks ("… prioritize and scale up, adopt a test-and-learn approach, put foundations in place, treat data as a competitive advantage, work across functions and manage change the organisation …") for companies to help them move forward in the fourth industrial revolution.

Sommer, L. (2015) called attention to that Industry 4.0 should be implemented successfully not only in large enterprises in Germany, but also in small and medium-sized enterprises, because both groups play a relevant role in employment. Furthermore, it is necessary to encourage the progress of small and medium-sized enterprises in Industry 4.0 because the interconnectedness of the economy only allows for a limited technological gap between small and large enterprises. If the digital gap between the two groups is too large, co-operation could be hindered. The experience of research in Hungary also supported the assumption that the chances and opportunities of large multinational companies and that of SMEs are not the same in Industry 4.0, although the latter also have advantages (e.g. organisational factors are less complex, lower profitability requirements, less technological dependence) compared to the former (Horváth, D. and Szabó, Zs.R. 2019). However, if smaller businesses are unable to adapt to new challenges, they can easily become victims of the industrial revolution (Sommer, L. 2015). And this danger is not only a threat to German SMEs, but also to Hungarian ones. Not only the size of companies but also the origin of their owner(s) can have relevant impacts on the process of Industry 4.0. The research carried out in Eastern Hungary in 2019 has proved that Industry 4.0 is more advanced in the companies with foreign interest (Nagy, Cs. *et al.* 2020).

Many factors limiting the realisation of Industry 4.0 have been identified in previous researches that, despite their diversity, can be divided into a number of major categories (e.g. inadequate qualification of human resources, technological, infrastructure deficiencies, scarce financial resources, organisational problems) (Horváth, D. and Szabó, Zs.R. 2019). The weight of different factors is different depending on the size and sector of the enterprise. The lack of a well-qualified workforce is the most important limiting factor in the case of small and medium-sized enterprises, while in multinational companies organisational and technological factors are the most important. In many cases, Hungarian businesses also have problems with the lack of adequate ICT infrastructure or, even if available, it is not fully suited to make the transformation to Industry 4.0 (Erdei, E. 2019). Other research emphasized the lack of human and financial resources in German businesses as an obstacle. These resources would be important because they could help companies to transform their internal structure, improving thereby the ability of businesses to receive new ICT (DIHK 2015). In the beginning many small and medium-sized enterprises lacked interest in Industry 4.0 in Germany partly because they did not see information security and data protection. And because of this lack of trust there was fear that the technological transformation of the country will fall behind in the fourth industrial revolution (Eisert, R. 2014).

The largest global survey to date, involving 2,000 businesses from 26 countries in nine major industries emphasized that new technology is not the biggest challenge for companies, but the lack of the digital culture and qualification in the case of their workers necessary for implementing Industry 4.0, and this needs to be developed (Geissbauer, R. *et al.* 2016). According to a Czech survey in 2017 the lack of accurate information on the benefits of Industry 4.0 is also hampering the realisation of the fourth industrial revolution. This is why several companies in Czechia did not attach much importance to consider Industry 4.0 and to prepare for it, and in the long-term this could result in a serious lag in development (Kopp, J. and Basl, J. 2017). To avoid this, the EU and national governments help companies (mostly SMEs) and regions (mostly less developed) in different ways (funding, education) particularly from 2014 to be able to prepare for the digital transformation (Nick, G. 2018; Bailey, D. and De Propris, L. 2019; Šlander, S. and Wostner, P. 2019). In Hungary there also have been special strategy programs and several kinds of funds for supporting enterprises in the transition of Industry 4.0, particularly since 2016. But so far not so many enterprises have competed for those (Nick, G. 2018).

Although many German enterprises did not even know the concept of Industry 4.0 in 2014 (Eisert, R. 2014), in 2016 the results of the global survey showed that enterprises in Germany and Japan would be the most advanced among the countries in digitalisation within five years, while the same will be true for America among the continents in 2021 (Geissbauer, R. *et al.* 2016). Although the level of digitalisation may increase in the coming years, thus, globalisation as well, regional differences may remain significant depending on local conditions (Geissbauer, R. *et al.* 2016). It is particularly important to know the characteristics of each location (e.g. ICT infrastructure, qualification and capabilities of workforce), the social and economic environment of the enterprises there, as those can strongly determine the competitiveness of a given area (Šlander, S. and Wostner, P. 2019).

It is most likely that areas with more advanced economy and more advanced industry are in a better position from the view point of ICT infrastructure and application (Schwab, K. 2016; Luthra, S. and Mangla, S.K. 2018). A number of researches have now shown that there may be significant differences in the spatial distribution of ICT at different spatial levels (Grasland, L. and Puel, G. 2007). Within the EU Finland, Sweden, the Netherlands, Denmark and the United Kingdom are the leading, while Italy, Poland, Greece, Romania and Bulgaria are the tail-enders following Hungary, despite a significant increase in e.g. internet access in countries in the latter group, for example, between 2010 and 2016 (DESI 2019). The close correlation between economic development (GNI/person) and internet use was confirmed by our previous correlation study using the SPSS software. The Pearson correlation coefficient was 0.846 (Balog, Zs. *et al.* 2018).

Digital development varies within countries as well. This may be due to a number of reasons (e.g. geographical location, social, economic, infrastructure, etc. factors), however, the fact that the needs of each industry for new technologies and their different digital development may also contribute to it. The industries that dominate the economy of a given area can have a strong impact on the digital maturity of enterprises there.

The geographical differences of industries may also have an impact on the spatial progress of Industry 4.0. Industry is one of those sectors of the economy where Industry 4.0 develops fast and it is much more advanced than in other industries like tourism or agriculture (Berta, O. 2018; DESI 2019). Thus, industry has its first benefit and positive impact (Caylar, P-L. *et al.* 2016; Geissbauer, R. *et al.* 2016). In line with international experiences, it can therefore be also assumed that industry is the sector in Hungary where the fourth industrial revolution is more advanced. Consequently, the spatial pattern of digital development may be closely related to the spatial concentration of industrial production (Kiss, É. 2002, 2010). Its verification is also attempted in this study, while also exploring the spatial characteristics of the application of new technologies in Hungarian enterprises. Considering the theoretical foundations of the paper the main research question is how the "digital divide" relates to the "industrial divide" in the economic space of Hungary.

Data and research methods

This study is based on the analysis of the relevant literature and official statistical data and, as well as, the cartographic representation and evaluation of the rankings by county of various indicators. The geographical context was explored using two indicator systems: one related to ICT and the other to the industry. In both complex indicator systems there were several variables, which are detailed in the tables. Two groups were formed out of the 20 ICT indicators. The first group – "old" or traditional ICT indicators – included those that had a long history of statistics and a longer track record in operating enterprises (e.g. computers and the Internet). The so-called "new" ICT indicators (e.g. cloud service, 3D printing) have started to spread in businesses in recent years and can be more directly linked to Industry 4.0. Only a few of the studied ICT indicators – due to length limitation – are presented (in four figures) with the most significant regional differences and which are more representative of industrial enterprises. Ten indicators were used to illustrate the regional differences in the Hungarian industry.

The selected indicators included extensive and intensive ones as well. The former represents the amount and size of the elements of a factor (e.g. number of enterprises), while the latter are weighted averages obtained by the merging of the elements (e.g. computer per 1,000 enterprises).

Necessary data on the info-communication capabilities of enterprises, i.e. the database of the study, were provided by accessible official statistical data with a county breakdown (NUTS-3 level) for 20 regional units (the capital Budapest and 19 counties). The novelty of the topic is also shown by the fact data collection of many ICT indicators, especially in the case of the new ones, has only started in recent years. Therefore, the focus was on static rather than dynamic analysis due to the lack of longer time series. For each indicator only the most recent available data were used. The one to two-year difference in the year of origin of the data did not hinder the interpretation of spatial differences.

ICT data were only available by counties, as data by settlements would have allowed the identification of certain large companies, and this is not permitted by the Data Protection Act. Considering its content, the information and communication (IC) industry comprises three different levels of network: physical infrastructure, the services they create and their use (Houzet, S. 2007). These levels are also represented by the ICT indicators selected to identify spatial differences.

Since the studied ICT data cover all Hungarian enterprises, they only provide indirect information about the industry, which accounted for 9.2 per cent of all corporate businesses in Hungary in 2018. (Industry is the secondary sector of the economy and includes mining, manufacturing and electricity generation, gas, steam and water supply.) This is a very low value, but if we look at the importance of industry, e.g. based on its share of gross value added, a much higher value (58.7%) is obtained compared to other economic sectors. Industry concentrates 11.4 per cent of working companies with foreign interest (more than 2,500 enterprises). This is worth mentioning because multinational enterprises tend to have better digital preparedness (Nagy, Cs. *et al.* 2020) and because they also played a decisive role in shaping the spatial pattern of the industry (Kiss, É. 2002, 2010).

Studying the spatial structure of ICT and industry was supported by summarizing the county rankings of the various indicators. The data for each indicator were available for 20 regional units and their values were indicated by ranking numbers from 1 to 20. Number 1 referred to the most favourable area regarding the given indicator, while 20 was the most unfavourable position. If the value of the indicator of two spatial units was the same, they were given the same rank number. The cumulative rank that is generated by aggregating the rank numbers is a complex indicator that reveals geographical characteristics. The "old" and "new" of ICT indicators were also plotted separately based on their cumulative rank due to their spatial characteristics. Then a figure showing the rank numbers of all ICT indicators were created. Based on it, the regional types of the digital advance of Hungarian enterprises can be clearly determined.

The figure of the spatial structure of the industry based on the cumulative rankings of the county values of the industrial indicators was compared with that of the ICT to reveal the spatial similarities and differences and to answer the question whether the spatial patterns of industrial and digital maturity are closely intertwined or not.

Regional differences in information and communication technologies

Old indicators

Counties with favourable and unfavourable positions can now be clearly distinguished based on the ranking number of the values of the following ten old ICT indicators (ICTo):

ICTo-1: Number of IC enterprises per 1,000 enterprises in 2018;

ICTo-2: Number of IC employees per 1,000 employees in 2018;

ICTo-3: Use of personal computers and work stations in enterprises in 2018, %;

ICTo-4: Use of internet in enterprises in 2018, %;

ICTo-5: Number of computers per 1,000 enterprises in 2017;

ICTo-6: Ratio of large computers within the computer equipment of enterprises in 2017, %;

ICTo-7: Ratio of employees using computers in enterprises in 2016, %;

ICTo-8: Ratio of employees using internet in enterprises in 2016, %;

ICTo-9: Ratio of employees using mobile web in enterprises in 2016, %;

ICTo-10: Ratio of enterprises providing remote access for their employees in 2016, %.

If a county has got several low rank numbers, it means that the county is in a good position in the supply of different old ICT *(Table 1).*

The number of information and communication enterprises is important because they provide essential services to businesses in other fields of the economy thereby they contribute to the realisation of Industry 4.0 and – in wider sense – the fourth industrial revolution. In 2018 there were more than 64,000 IC enterprises operating in Hungary and their national average was 36 IC enterprises per 1,000 enterprises. However, the county average was everywhere below the national average except for the capital city and Pest county. This can be explained by less favourable conditions of factors attracting IC enterprises (e.g. technological background, infrastructure development, economic environment, market size, social factors, workforce training, cultural milieu) (Kanalas, I. 2004). In 2018, 63 per cent of the enterprises of the IC industry were concentrated in the region of Budapest, in contrast, in Békés, Jász-Nagykun-Szolnok or Szabolcs-Szatmár-Bereg counties only one to two per cent. The spatial pattern of the employees of IC industry is similar to this. The high value of Budapest (361 people per 1,000 employees) can be explained primarily by the size of the city and its central role in the country, among many other factors. According to a research, the classification of towns of the Hungarian town network into IC types depends most on the size, historical traditions, economic, administrative role and geographical location of the town (Rechnitzer, J. *et al*. 2003).

Table 1. Ranking of old ICT (ICTo) indicators by county in Hungary, 2016–2018*

Capital, county	ICTo-1	ICTo-2	ICTo-3	ICTo-4	ICTo-5	ICTo-6	ICTo-7	ICTo-8	ICTo-9	ICTo-10	Cumulated ranking
Budapest	1	1	13	14	1	19	1	1	1	1	2
Pest	2	2	7	6	5	16	2	6	4	2	1
Fejér	3	5	1	1	4	8	9	16	13	3	4
Komárom-Esztergom	4	7	1	3	2	16	7	3	6	6	3
Veszprém	8	11	4	7	8	18	5	17	12	8	8
Győr-Moson-Sopron	7	3	3	3	3	20	8	10	2	5	5
Vas	11	4	6	9	6	2	4	14	13	3	6
Zala	14	8	5	7	17	12	18	15	9	7	13
Baranya	4	9	17	18	16	8	11	2	5	12	9
Somogy	17	14	16	17	11	5	9	9	10	20	15
Tolna	12	18	19	15	12	6	15	8	16	18	17
Borsod-Abaúj-Zemplén	9	12	10	12	7	15	3	10	15	10	10
Heves	12	6	12	13	9	12	6	7	17	13	12
Nógrád	9	10	11	10	18	12	17	19	20	10	16
Hajdú-Bihar	14	19	15	15	13	11	11	4	3	13	14
Jász-Nagykun-Szolnok	14	16	18	19	10	3	19	20	19	17	19
Szabolcs-Szatmár-Bereg	20	20	20	20	20	8	20	13	11	19	20
Bács-Kiskun	17	15	8	2	14	1	14	12	7	15	11
Békés	19	16	14	11	19	3	16	18	18	16	18
Csongrád	6	13	8	3	15	6	11	5	7	9	7

*For the denomination of the indicators see the text. *Source:* Based on the data of Hungarian Central Statistical Office Information database.

As computers became widespread their use and that of the Internet by enterprises is already common today. In 2018, over 90 per cent of enterprises in all counties use computers, and the use of the internet fell short of 90 per cent in only a few counties (e.g. Jász-Nagykun-Szolnok, Szabolcs-Szatmár-Bereg) suggesting small regional differences. In terms of both indicators, Fejér county was at the forefront because the ratio of enterprises using computers (96%) and the Internet (93%) was the highest there. Computers are used for different purposes, but there are not relevant differences by county in the ways how they are being used. The most often (in the 50–60% of Hungarian companies) computers are used for emailing while in 25–35 per cent of companies for administrative tasks. The applications of software are the most rarely, only 10–20 per cent of enterprises use those.

In Hungary, there were more than 1.3 million computers in enterprises with more than 10 employees in 2018. On average 779 computers were used per 1,000 enterprises, with more than double that value in the capital city (1,733). The outstandingly high number is the result of a particularly high spatial concentration (41%) of businesses. In the northern counties of Transdanubia, the number of computers was between 700 and 900 per 1,000 enterprises. Worst computer supply was found along the southern and eastern borders, as well as in Nógrád county, where only a quarter of businesses had computers. The reasons can be found in the socio-economic conditions of the counties with roots dating back long in history *(Figure 1).*

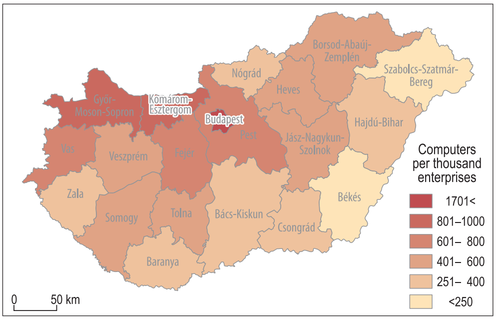

Fig. 1. Number of computers per 1,000 enterprises by county in Hungary, 2017. *Source*: Data of Hungarian Central Statistical Office.

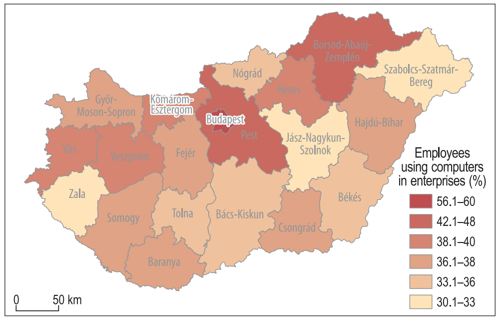

Fig. 2. Ratio of employees using computers in enterprises by county in Hungary, 2016. *Source*: Data of Hungarian Central Statistical Office.

The ratio of large computers within all computers of enterprises has a very specific spatial structure, because it is almost the opposite of computers per 1,000 inhabitants. The latter has reached a considerable number in the northern half, while the former has high numbers in the southern part of the country. According to the definition of the Statistical Office large computers are non-portable computers or, alternatively, computers longer than 50 cm in all directions. This suggests that large computers are more common in certain industries and in larger enterprises. Their share reached the highest level (75%) in Bács-Kiskun county, followed by Vas and Jász-Nagykun-Szolnok counties with 60 per cent and 59 per cent respectively. This is mainly due to the car manufacturers and/or their suppliers there.

The share of employees using computers in businesses is now surely much higher than it was in 2016. Fewest employees worked with computers at their workplace in Szabolcs-Szatmár-Bereg county (31%) and the most in the capital city (58%), however, in the vast majority of the country their proportion varied around 35–38 per cent, that is below the national average (45%). The ratio of employees using computers is especially high in the northern part of the country, North of the Nagykanizsa–Dunaújváros–Tiszaújváros line (*Figure* 2).

On average, one in four employees used the internet in enterprises in 2016, and this has certainly improved since then. The situation is more favourable only in the capital city with almost one in three employees used computers. The value of this indicator was also high (23–25%) in Baranya, Hajdú-Bihar and Csongrád counties, which are important higher education centres. Even in Jász-Nagykun-Szolnok county with the lowest value (17%) only a few per cent fewer people used the internet in enterprises indicating not marked spatial differences. In Slovakia, low ratio of internet availability has been identified as an indicator of periphery situation, which has shown close connection with some economic and social-demographic periphery indicators (Rosina, K. and Hurbánek, P. 2013).

A few years ago mobile internet was used by 11 per cent of employees in businesses. In 2016, enterprises in the belt from Nógrád county to Békés county except for Heves county were in the worst situation, where only a few percent of workers used mobile internet. This can also be attributed to the unfavourable overall social and economic development of the region. GDP per capita was also among the lowest in this region in 2017, reaching 43–65 per cent of the national average.

The share of enterprises providing remote access to workers is highest in the capital city (60%) and in its region (51%) which can be attributed mainly to the importance of the service sector. This type of work is not typical for workers in the industry or directly in production. The ratio of such enterprises is also high in Northern Transdanubia. In the eastern and southern part of the country, however, this value is well below the national average (48%) for probably a number of reasons (e.g. less remote working, less trust in it, industrial affiliation of enterprise).

New indicators

The first data available on the application and spreading of new technologies in Industry 4.0 are from 2018 and show that they are not very common yet. This is also supported by experience in the EU. Digital technologies (e.g. electronic exchange of information, social media, cloud services, online trading) were integrated by small ratio of enterprises in Hungary (5–15%) in 2019. Therefore, Hungarian companies were among the worst performers regarding EU member states (DESI, 2019). Based on the index measuring the development of digital economy and society (Digital Economy and Society Index – DESI), Hungary is 23rd among the 28 member states of the EU between 2017 and 2019 (DESI, 2019). (DESI includes the following indicators: connectivity, human capital, use of internet services, integration of digital technology, digital public services.) Although the country's digital development has improved over this period (from 40% to 45%), it is still below the EU average (53%).

Consequently, counties with favourable and unfavourable positions can be also distinguished based on the ranking number of the values of the following ten new ICT (ICTn) indicators:

ICTn-1: Purpose of mobile web use: use of software application, as a percentage of enterprises in 2018;

ICTn-2: Ratio of enterprises using cloud based services in 2018, %;

ICTn-3: Cloud based service: use of Customer Relationship Management (CRM) application, as a percentage of enterprises in 2018, %;

ICTn-4: Ratio of enterprises using service robots in 2018, %;

ICTn-5: Ratio of enterprises using industrial robots in 2018, %;

ICTn-6: Ratio of enterprises using their own 3D printer in 2017, %;

ICTn-7: Ratio of enterprises where 3D printing was used for the following purposes: manufacturing moulds, tools, parts, semi-finished products for sale in 2017, %;

ICTn-8: Ratio of enterprises using 3D service provided by other enterprises in 2017, %;

ICTn-9: Ratio of enterprises performing Big Data analysis: with their own employees in 2017, %;

ICTn-10: Ratio of enterprises performing Big Data analysis: with external, outside the enterprise, service providers in 2017, %.

The use of new ICTs has reached mostly only a few per cent, however, their spatial distribution is characterised by some sharp and unconventional differences *(Table 2).*

Only two of the new ICT indicators had relatively high values: namely, the number of enterprises using mobile internet for software applications and that of enterprises using cloud-based services. Values of the former indicator varied between 10.6 per cent (Szabolcs-Szatmár-Bereg county) and 23.8 per cent (Budapest), while in the case of the latter values ranged from 10.2 per cent (Békés county) to 24.7 per cent (Budapest). Enterprises using mobile internet for software were more abundant in the northern part of Transdanubia, the capital city region and in Northern Hungary, while those using cloud based service were more concentrated in a couple of areas (Budapest, Baranya, Somogy and Pest counties).

The lowest values (usually 1% or less) were in the use of service robots, i.e. this is the least prevalent in the counties. Only a fraction of enterprises used service robots. The share of such enterprises was the highest (1.3%) in Győr-Moson-Sopron county in 2018. At the same time, industrial robots were used in a higher ratio (2–6%).

Table 2. Ranking of new ICT (ICTn) indicators by county in Hungary, 2017–2018*

Capital, county	ICTn-1	ICTn-2	ICTn-3	ICTn-4	ICTn-5	ICTn-6	ICTn-7	ICTn-8	ICTn-9	ICTn-10	Cumulated ranking
Budapest	1	1	1	13	19	8	10	9	10	4	5
Pest	2	4	4	1	12	5	6	3	17	16	3
Fejér	6	7	4	9	1	9	12	6	6	9	2
Komárom-Esztergom	11	5	11	3	2	16	17	7	7	5	8
Veszprém	9	8	7	7	5	13	10	5	9	10	7
Győr-Moson-Sopron	3	9	11	1	3	5	5	9	17	1	1
Vas	5	12	16	3	7	10	7	12	16	3	11
Zala	4	17	17	8	13	18	9	17	19	2	14
Baranya	14	2	2	16	8	5	12	11	8	6	8
Somogy	15	3	3	19	8	9	7	15	13	16	13
Tolna	17	6	6	20	6	4	4	8	20	11	12
Borsod-Abaúj-Zemplén	7	16	13	9	8	1	1	2	1	18	5
Heves	8	18	7	3	8	3	3	3	2	20	4
Nógrád	10	19	19	9	4	1	2	1	5	19	10
Hajdú-Bihar	18	10	15	9	18	19	19	18	3	14	18
Jász-Nagykun-Szolnok	19	15	20	6	13	16	18	20	10	15	19
Szabolcs-Szatmár-Bereg	20	13	18	13	20	19	19	15	4	12	20
Bács-Kiskun	13	14	13	15	15	12	14	14	12	6	15
Békés	16	20	7	16	15	13	14	19	14	6	17
Csongrád	12	11	7	16	17	13	14	12	15	12	16

*For the denomination of the indicators see the text. *Source:* Based on the data of Hungarian Central Statistical Office Information database.

Generally, robots perform work that, for example, involve heavy physical work, may have negative health effects, require high accuracy or it is quite monotonous work. Automotive industry is the primary user of robots, which is followed by electronics, metal industry, chemicals and food industry (Nagy, Cs. and Molnár, E. 2018). As a consequence, the spatial pattern of industrial robots is closely connected to these branches. Most of the enterprises using industrial robots can be found in Northern Transdanubia (Fejér 5.7%, Komárom-Esztergom 5.6%, Győr-Moson-Sopron 5.3% and Nógrád county 5.2%) related to the significant industrial activity there *(Figure 3)*.

3D printing has only started to spread in Hungary lately. It is popular in manufacturing industry where the basic purpose is to manufacture moulds, tools, parts, etc. for sale. The share of enterprises using 3D printing was also characterised with very low values except for three counties (Borsod-Abaúj-Zemplén, Heves and Nógrád), which constituted one of the pillars of the former socialist heavy industry. 3D printing is most widespread in enterprises in the above counties, however, only in a very low per cent (1.9–2.2%) of the enterprises *(Figure 4)*.

The values of other ICT indicators (e.g. Big Data analysis) varied mostly between 2 and 6 per cent, indicating the early stages of digital transformation in enterprises. However, depending on their industrial affiliation values show smaller or greater variation. The level of the appli-

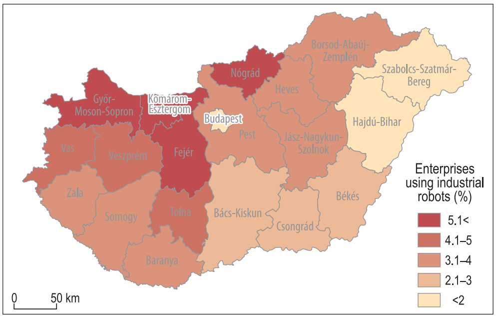

Fig. 3. Ratio of enterprises using industrial robots by county in Hungary, 2018. *Source*: Data of Hungarian Central Statistical Office.

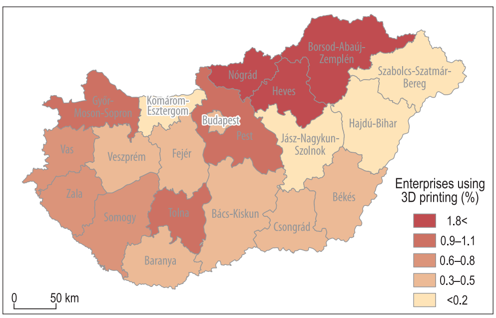

Fig. 4. Ratio of enterprises by county in Hungary where 3D printing was used for the manufacturing of moulds, tools, parts, semi-finished products for sale, 2017. *Source*: Data of Hungarian Central Statistical Office.

cation of new technologies in industrial and manufacturing enterprises is usually higher than in the economy as a whole *(Table 3).*

According to the empirical research carried out in Eastern Hungary in 2019 there are considerable differences between Hungarian and foreign-owned enterprises in the advancement of Industry 4.0 (Nagy, Cs. *et al.* 2020). Usually enterprises with foreign interest are those where on the one hand the application of new technologies is more frequent, on the other hand several kind of new technologies are applied. Although Hungarian enterprises are interested in new technologies, they have applied only a few of them, mostly robots and 3D printers. The reasons for this (e.g. lack of money and skilled workers, less developed organisational structure) are very similar to the results of other researches (e.g. (Horváth, D. and Szabó, Zs.R. 2019).

Geographical types of ICT development

The ranking based on the cumulative ranks of the "old" and "new" indicators of ICT shows that older info-communication technologies are particularly significant in the region of the capital city and in Northern Transdanubia and Csongrád county (*Figure 5* and *6).*

The geography of more recent ICT shows a stronger North–South divide. At the same

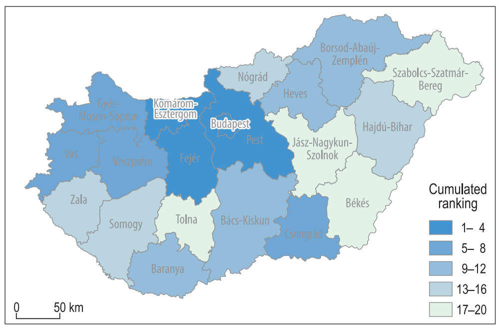

Fig. 5. Cumulated ranking of old ICT indicators by county in Hungary. *Source*: Based on *Table 1.*

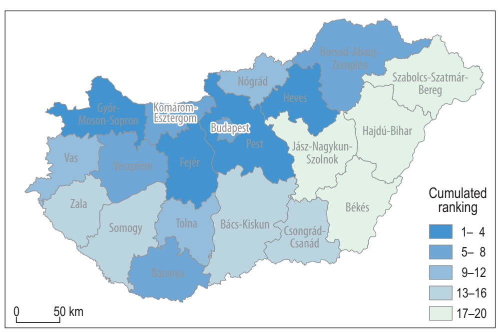

Fig. 6. Cumulated ranking of new ICT indicators by county in Hungary. *Source*: Based on *Table 2.*

Table 3. Use of ICT in Hungarian enterprises, 2018*

Denomination	Manufacturing, %	Industry, %	All sectors of national economy, %
Enterprises with fixed broadband internet connections	84.6	91.0	82.7
Ratio of enterprises with mobile broadband connections	72.0	81.2	70.8
Purpose of mobile web use: access to the e-mail system of the enterprise	64.1	73.7	62.6
Purpose of mobile web use: access to documents	33.9	42.1	36.5
Purpose of mobile web use: using software applications	18.2	26.5	19.3
Ratio of employed informatics professionals	27.7	38.0	26.1
Cloud based service: use of CRM application	3.2	3.3	4.9
Ratio of enterprises using cloud based services	17.2	22.7	18.0

*Enterprises employing more than 10 people. *Source:* Data of Hungarian Central Statistical Office Information database.

time, in the eastern and southern counties of Hungary (with the exception of Baranya county) the digital transformation of enterprises is much less favourable which can be related to the historical past, the disadvantages of the starting conditions, lower economic performance, periphery location, etc. After 1989 these regions were not very attractive targets for foreign investors and their deindustrialisation was intensive. All these led to that they fell behind in development in last decades. Moreover, the eastern-southeastern parts never belonged to the more developed regions of the country. Even today this is the semi-periphery of the EU, while the southwestern part has become a "lock-in" area which hardly finds the way out.

By forming a cumulative ranking based on the rankings of all ICT indicators the final ranking of the counties has been established reflecting the degree of progress of each region and the enterprises there, i.e. how they perform in the supply and application of info-communication tools and technologies. Based on the ranking, five main types can be identified, where the spreading of ICT and digitalisation are:

1. Well-advanced: Pest, Győr-Moson-Sopron and Fejér counties, and Budapest;
2. Advanced: Komárom-Esztergom, Vas, Borsod-Abaúj-Zemplén and Veszprém counties;
3. Moderately advanced: Heves, Baranya, Csongrád and Nógrád counties;
4. Less advanced: Bács-Kiskun, Zala, Somogy and Tolna counties;
5. Least advanced: Hajdú-Bihar, Békés, Jász-Nagykun-Szolnok and Szabolcs-Szatmár-Bereg counties *(Figure 7)*.

Areas in the first group of categories are the leading ones, while the fifth group leads the army. The two extremes in space are the region of the capital city, together with Northern Transdanubia and Northern Great Plain. In a different way, there is a North–

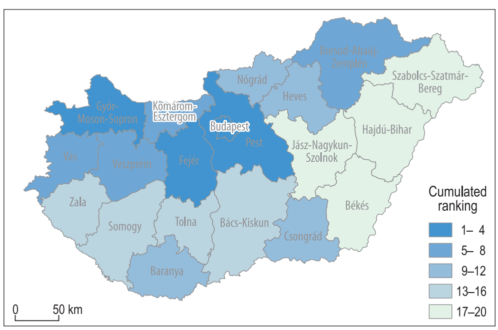

Fig. 7. Cumulated ranking of all ICT indicators by county in Hungary. *Source*: Based on the *Table 1* and 2.

South divide in the spreading of Industry 4.0, as the degree of the digital transformation of the enterprises is better in the North and poorer in the south. Attention should be drawn, however, to the fact that the digital maturity of the population and enterprises of the counties may vary considerably (Balog, Zs. *et al.* 2018; Nedelka, E. 2019). There is no doubt that greater IC preparedness of the population can have a positive impact on the supply and application of infocommunication technologies and tools contributing thereby to the improvement of the economy and the competitiveness of the given area.

Spatial connections between ICT and industry

Following the regime change, radical changes took place in the Hungarian industry, which also manifested in space (Kiss, É. 2002). The process of deindustrialisation was very strong in the 1990s, while a number of new investments were made forming a new spatial structure of the industry based primarily on foreign capital. This was modified by reindustrialisation by today. Cumulative rankings calculated based on the rankings of the variables of industry in 2018 clearly show the importance of industry in each county and their position in the whole country (*Table 4*). The following industrial indicators (IndI) were used:

IndI-1: Number of industrial enterprises in 2018;

Table 4. *Ranking of industrial indicators (IndI)* by county in Hungary, 2017–2018*

Capital, county	IndI-1	IndI-2	IndI-3	IndI-4	IndI-5	IndI-6	IndI-7	IndI-8	IndI-9	IndI-10	Cumulated ranking
Budapest	1	16	1	20	1	2	1	20	1	20	8
Pest	2	3	2	19	13	7	2	15	3	12	6
Fejér	7	4	6	9	4	3	4	6	5	3	3
Komárom-Esztergom	12	1	4	6	2	4	6	1	6	1	1
Veszprém	9	2	9	10	10	11	8	5	10	8	7
Győr-Moson-Sopron	4	7	3	16	3	1	3	2	2	2	2
Vas	18	10	7	15	5	12	12	3	8	5	10
Zala	13	12	11	17	12	20	18	16	15	11	17
Baranya	10	6	10	11	20	16	16	18	17	19	14
Somogy	17	18	16	14	16	10	15	9	19	18	19
Tolna	19	5	15	3	11	19	19	10	16	9	12
Borsod-Abaúj-Zemplén	5	7	8	5	8	5	7	12	4	4	4
Heves	15	10	13	8	6	9	14	4	11	6	11
Nógrád	20	7	20	4	15	18	20	11	20	13	18
Hajdú-Bihar	6	17	13	13	19	13	11	19	12	17	13
Jász-Nagykun-Szolnok	14	14	12	1	9	8	9	7	9	7	9
Szabolcs-Szatmár-Bereg	11	20	16	12	17	14	10	17	13	13	15
Bács-Kiskun	3	12	5	7	7	6	5	8	7	10	5
Békés	16	18	19	2	18	17	17	14	18	15	20
Csongrád	8	14	18	18	14	15	13	13	14	16	15

For the denomination of the indicators see the text. *Source:* Based on the data of Hungarian Central Statistical Office Information database.

IndI-2: Ratio of industrial enterprises of all enterprises in 2018, %;
IndI-3: Number of enterprises with foreign interest in manufacturing in 2017;
IndI-4: Ratio of manufacturing enterprises with foreign interest of all enterprises with foreign interest in 2017, %;
IndI-5: Value of industrial production per inhabitant in 2018, 1,000 HUF;
IndI-6: Export sales of industry in 2018, million HUF;
IndI-7: Number of employees in industry in 2018;
IndI-8: Ratio of industrial employees of all employees in 2018, %;
IndI-9: Gross value added of industry in 2017, million HUF;
IndI-10: Share of industry of total gross value added in 2017, %.

Cumulative rankings provide a good basis to identify areas where industry is more important in the economy and where it is less so. The main types of counties are the following, where industry is:

1. Very significant: Komárom-Esztergom, Győr-Moson-Sopron, Fejér and Borsod-Abaúj-Zemplén counties;
2. Significant: Bács-Kiskun, Pest, Veszprém counties and Budapest ;
3. Moderately significant: Jász-Nagykun-Szolnok, Vas, Heves and Tolna counties;
4. Less significant: Hajdú-Bihar, Baranya, Szabolcs-Szatmár-Bereg and Csongrád countie;
5. Least significant: Zala, Nógrád, Somogy and Békés counties *(Figure 8).*

The current spatial structure of the industry has many similarities to the spatial structure developed in the second half of the 1990s (Kiss, É. 2002). After the regime change, in the 20th century, the focus of industrial production shifted to the northern part of Transdanubia, because the NE–SW industrial axis, built on the resources of the mountains during the socialism, took up a direction of NW–SE. Foreign capital investments played a leading role in the development of the new industrial district (Kiss, E. 2007). By today, the industry has continued to develop and expanded in space as a result of re-industrialization.

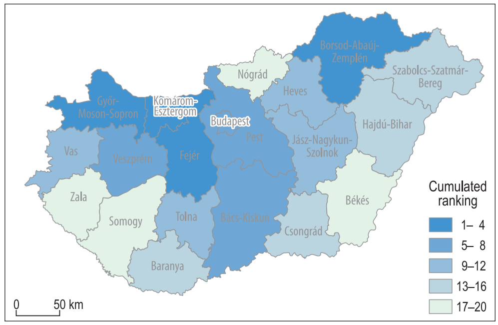

Fig. 8. Cumulated ranking of industrial indicators by county in Hungary. *Source:* Based on *Table 4.*

Industry remains relevant in Győr-Moson-Sopron, Komárom-Esztergom and Fejér counties, which, together with Vas county, form a group of FDI-based processing industrial counties (Lengyel, I. and Varga, A. 2018). Many of the industrial indicators (e.g. share of gross value added, share of industrial employment, value of industrial production) have favourable values in these counties, and though they change somewhat each year they do not influence significantly the position of counties. They basically occupy a permanently relevant place in the Hungarian industry (Nemes Nagy, J. and Lőcsei, H. 2015).

Industrial activity is also significant in the central part of the country, in the capital city, in Pest and Bács-Kiskun counties. Although Budapest is still the largest industrial centre in Hungary, its industry has lost weight after 1989, because many industrial facilities ceased to exist, were restructured and other sectors developed more dynamically (Kiss, É. 2010). Industry has strengthened due to the investments of the Mercedes car factory and its suppliers in Bács-Kiskun county, and it took a prominent position in Hungary's industry in 2018: based on e.g. the number of industrial enterprises (4,681), the ratio of industrial enterprises with foreign interests (31%) or the number of industrial employees (45,000 people). In the last decade, the industry of Borsod-Abaúj-Zemplén county also becomes more significant and together with

Bács-Kiskun, Veszprém, Heves and Jász-Nagykun-Szolnok counties they form the group of reindustrialising counties (Lengyel, I. and Varga, A. 2018). In contrast, the importance of the industry of Northern Great Plain and Southern Transdanubia decreased, because of the reasons mentioned above, and today, the values of the counties there are mostly among the poorest ones. However, based on their ICT cumulative rank their position in the ranking is often even less favourable which can also have a negative impact on the regional development (Bailey, D. and De Propris, L. 2019).

Comparing the spatial structure of industry and ICT, the spatial distribution of the two phenomena shows no close correlation. Only one quarter of the studied 20 spatial units can be classified into the same group based on the rankings of both indicators. (Therefore, the trial factor analysis did not produce any meaningful results beforehand – Nedelka, E. 2019.) There are only two counties (Fejér, Győr-Moson-Sopron), where both industry and ICT are most advanced, and one county (Békés) where the situation is most unfavourable based on the cumulative ranking of both indicators. The former ones belong to the most developed (industrialized) regions of the country with excellent supply by ICT while the latter one was previously classified as "Rural" (Lengyel, I. and Varga, A. 2018) that generally includes counties that are far away from the centres mostly along the borders. Either their economic development or their social characteristics are considered, they often belong to the tail-enders. For example, in 2017, the GDP per capita of Békés county reached only 59 per cent of the national average, but the share of its industry (1.8%) regarding the gross value added was well below that of Győr-Moson-Sopron (11.9%) or Fejér (7.9%) counties. In addition to the counties at the two extremes, Veszprém and Heves counties were part of the same group considering both indicators. The former can be characterised by a relatively developed industry and advanced digital transformation, while the latter belonged to the midfield. The significance of the two indicators differs in the rest of the counties: either the weight of the industry or the degree of digital progress provides a higher ranking.

Conclusions

Following the latest economic crisis those involved in the global economy, enterprises in Hungary and abroad have to face another challenge, Industry 4.0 and/or the fourth industrial revolution. In this study the characteristics of ICT giving the basis of the new trends and their application are examined in geographical terms in relation to the spatial structure of Hungarian industry.

Depending on the geographical location of enterprises marked differences may be found in the supply of old and new ICT. The reasons for this can be very diverse, however, they can be explained mainly by the nature of the local social and economic environment. History, infrastructure development, transport links, qualification and skills of human resources, etc. are important. The peculiar path of development and the past of each area have a major impact on the current ICT maturity of the given place and the enterprises there. Dependence on the past, on the starting conditions, or in other words "path dependency" also prevails here to some degree it identifies the path of development and determines current differences.

Comparing the geography of the two phenomena, ICT and industry, it can be concluded that the spatial match is relatively modest. Thus, the degree of ICT progress cannot be closely linked to industry. ICT indicators follow a characteristic North–South divide, but industry shows no sign of such spatial regularity caused partly by reindustrialisation in the last decade. Digital divide and industrial divide do not match. This is primarily due to the spatial distribution of the older ICT indicators, as newer technologies are more closely linked to industry. In the digital transformation, counties and enterprises in Northern Great Plain are the least advanced, and this could lead to serious disadvantages in the long-term. Therefore, areas where ICT indicators are still unfavourable require further investment and improvements. Probably the available special funds of the EU and the government will help in this. In the future the digital development will play a much more important role not only in social and economic, but also in regional development.

The comparison of the spatial pattern of ICT and industry has also shown that the latter one plays an important role in the spreading of ICTs, but it is not enough in itself. Other (social, economic etc.) factors are also necessary for the application of IC technologies, tools or services by as many enterprises as possible. This can also explain that the spatial distribution of ICT and industry is different and that the industry is more significant in more counties, or in another way, the prevalence of ICT in space is more concentrated. In these counties, industry also plays a prominent role in the application of ICT, however, the social and economic environment, the qualification and skills of workforce, the financial resources and possibilities of enterprises, the general development of infrastructure, geographical location and many other conditions (e.g. different financial supports) are also favourable or relatively favourable for Industry 4.0 to progress. In fact, the more modest scale or the lack of the former conditions causes that digital transition is less advanced in many counties.

The study is essentially related to the first phase of a multi-year project. It can be seen as a kind of introduction, partly to the geographical examination of Industry 4.0 and partly indirectly to the spatial research of the digital maturity of the industry, which, in theory, has several ways to be continued. One way is a deeper analysis of the social and economic causes of spatial differences, the exploration of local peculiarities. This is necessary in order to define precisely what needs to be done in the area in order to mitigate the unfavourable conditions and to reduce regional differences. Another possible research direction is a stronger focus on the ICT maturity of industrial enterprises at local and regional level, paying particular attention e.g. to the size structure of enterprises and to sectoral differences. Both research options require the promotion of empirical studies, as the range of official statistics is very limited. Furthermore, to reveal the spatial pattern of the financial supports what Hungarian enterprises have gained to promote their digital transformation would be also an interesting research direction. However, concerning the current Covid-19 pandemic a new research idea may come to the front in the near future, namely to study its impact on the process of Industry 4.0.

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Electrifying Times: restructuring and decision-making in an automobile concern in the 21st century – The case of BMW Group

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Abstract

The aim of this paper is to capture the changed location decision-making processes and location factors of the automotive industry, resulting from the current challenges brought by electro mobility. From the Taylorist assembly-line production system in the "Fordism" era to the just-in-time focused manufacturing of the Japanese carmakers during "post-Fordism" and at the turn of the millennium with global production and new technologies in the digital age, location analysis has changed massively over time. The same is to be expected for the fourth revolution in the industry. For this reason, the decision-making process of a major German car manufacturer is analysed in a field study conducted over a two-year period. Based on this, a decision process that takes the new framework conditions into account is modelled. The relevant location factors are then examined in a survey of the relevant departments in the BMW Group. Due to the changed production requirements in the course of the electrification, the uncertainty in the technological change and the unstable political trading conditions, the factors: network suitability, risk exposure, optimal sunk cost usage and sustainability play central roles. Before the latest economic crisis, the industry was focused on exploiting opportunities and expanding the production network. This tendency now seems to be transformed by a volatile technological future and by cost pressure. This means that 'sustainability' is increasingly important in automobile industry decision-making, but in specific ways.

Keywords: automotive industry, location decision, network suitability, restructuring, sustainability, BMW Group

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Introduction

Automobile industries currently face a vast number of challenges (Bailey, D. *et al.* 2010). After decades of large scale plant restructuring including massive investments in Greenfield sites combined with development of strategic alliances and global production networks, they are now confronted by different challenges. These include changing environmental regulations (Whitmarsh, L. and Köhler, J. 2010), environmental reporting using double bottom line and corporate social responsibility (Ormond, J. 2015) and dramatic failures related to them like the diesel scandal (Jung, J.C. 2017). The list of challenges seems endless when counting in e-mobility, new consumption formats like car sharing, leasing and rental markets (Bailey, D. *et al.* 2010) or new public and private infrastructure investments such as loading stations for electric vehicles. Moreover, design and innovation requirements are being transformed by the need for automation in driving and production, e-mobility, new materials enhancing simpler and lighter models as well as greater computing power and digitalization. Additionally, rising protectionism combined with upcoming adversaries in China has dramatically increased competition among automobile manufacturers worldwide (Bailey, D. *et al.* 2010).

In consequence, automobile firms again need to be restructured in terms of their production network and their production strategy. The financial crises at GM and Ford as well as the decline of the American rust belt demonstrate

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the consequences of delayed restructuring and act as warnings for the whole industry (Oxelheim, L. and Wihlborg, C. 2008; Klier, T.H. and Rubenstein, J.M. 2010; Financial Times, 2017). Some of these challenges have been picked up in the economic geography literature, for example, organizing e-mobility and re-planning mobility systems (e.g. Tanner, A.N. 2016; Cranois, A. 2017) but others have not. Notably omissions include emerging new production geographies and restructuring in relation to technological change in business, and this paper aims to address this set of issues. We argue that there have been signs of fundamental change in the decision making frameworks of automobile companies when restructuring their investments and plants.

This research considers the decision making of a German automobile industrial company conducting its regular seven-yearly model planning cycle. This kind of planning affects every plant the new models are supposed to be manufactured at. The focus of this paper's research is on one firm's smallest and oldest production plant which is located in the downtown area of a major German city, Munich. The next product lifecycle of the model assigned to that established plant involves a change to the production of an electric car. So, in addition to the traditional internal combustion engine (ICE) models, there will be a plug-in hybrid electric (PHEV) and an electric vehicle (BEV) Version. These changes to the power train require a much more complex production and, thus, comprehensive restructuring of the established production site close to downtown. Even if the focus is on the BMW Group, generalizing assumptions can be transferred to the whole industry. Schamp, E. (2005), for example, describes four types of automobile manufacturers when differentiating their strategies. The quality-oriented manufacturers such as BMW and Mercedes are strategically very similar. This is also evident from the choice of the locations operated on.

Based on these considerations and the economic framework, this paper aims to explain why the automobile manufacturer decided to upgrade the established downtown site rather than to relocate to a (new) Greenfield site. Our expectation is that the site analysis has changed fundamentally due to new challenges. Previous analyses, which focus on singular site discussions (Schamp, E. 1978) or neglect the time frame (Witlox, F. 1999), are no longer sufficient to explain the location decision-making of large manufacturing corporations. In this context, the case study concerning the restructuring process of the large German car manufacturer was conducted over two years. A wide range of field notes was compiled, covering planning sessions, document analysis and expert discussions. The data was documented at regular intervals and evaluated and clustered through key categories. This was followed by a series of interviews with those involved on the planning. Subsequently, a conjoint analysis of the decisive management functions regarding the process parameters and the actual meaning of sustainability was conducted in order to check the consistency within the group. The intent was to analyse the interaction among rating patterns and to identify key factors for site selection.

This study, thus, allows not only identification of the decision framework used, including its novelty, but also discussion of the implications of this framework and setoff factors for economic geography research on the geographies of automobile restructuring. It turns out that the key factors are shifting: central requirements of recent years are becoming less important. Therefore, in this paper we first present a review of the location analysis in the automobile industry and a brief overview of the strategic situation of the BMW Group. The specific decision-making related to the Munich plant upgrade is analysed. The final discussion focuses on the implications of the revealed decision-making framework and factors for understanding the location decision process. The questions that need to be answered are how a company proceeds in its decision-making process in the changed framework conditions of industrial change and which factors play a key role in this process.

Location analysis in the automobile industry

The automobile industry's changing production geographies have been a prominent focus of economic geography research. Over the years, though, the research focus and findings have shifted, with, generally, a change in focus from location decision making related to individual auto assembly plants (De Souza, A.R. and Stutz, F.P. 1994) to what constitutes the optimal global production network and organization (Dicken, P. 2015). This shift in focus is widely understood as a reaction to changing regimes of accumulation or industrial revolutions. Most recently, economic geographers (Klier, T.H. *et al*. 2010; Fromhold-Eisebith, M. 2018; Iammarino, S. *et al.* 2018; Palmer, J. and Schwanen, T. 2019) are noting signs of a new revolution associated with digitalization, protectionism, e-mobility and environmental regulation.

The changing regimes of the industrial environment and technology have always been accompanied by changing location analyses. In these terms, Alfred Weber's (1929) work set the starting point. Key factors of his cost-minimized location consideration are transport routes and weights. He demonstrated through reference points for the raw materials and places of sales of the products, the optimal sites in space. Many other factors, such as labour costs, agglomeration effects and resource substitution effects, are constantly being accepted and neglected across the entire area. Hoover, E.M. (1937) and Böventer, E. (1962) picked up on Weber's theory and expanded it to include agglomeration effects, which lead to relevant contributions to assessing business connectivity in site selection (Bathelt, H. and Glückler, J. 2012, 154). In the early 1970s, Smith, D.M. (1971) introduced a new perspective on site analysis by relaxing the assumption of companies as profit maximizers. Thus, an optimal location is not defined to an exact point but can be located within a certain space. Smith also primarily considered the costs of site assessment using a spatial cost function with location-dependent costs that include transport costs. In his theory, Smith, D.M. described the different effects of, for example, price increases, subsidies and bad management on location decisions. Considerations like these shifted the focus to new location factors in economic geography.

With the rejection of the explanation of industrial choice by rational action, Pred, A.R. (1967) developed the behavioural approach to location theory. He assumed that the total numbers of location-relevant factors cannot be perceived by decision-makers and therefore cannot be included in assessment. The choice of the optimal location, thus, depends on a matrix of two categories: on the one hand, the amount of available location information is relevant; on the other, decision makers must be able to make use of that kind of information. By combining these two categories, a location is decided. The probability of an optimal choice is greatest with high information availability and processing. Pred's approach also helps to explain the occurrence of wrong site decisions. In summary, traditional site theory, as it was developed at that time, represented initial explanations for location decision with an emphasis on profit maximization, cost orientation and the predetermination of location factors.

During the "Fordist era" the location factors focused on a specific framework of commodity flow and production factors. The distance/cost allocation later shifted from a material-oriented to a customer-oriented view (Kellerman, A. and Paradiso, M. 2007). The result was the formation of a global manufacturing network of large factories. In terms of location decision making, this shift affected both the framework of location factors itself and the balance of the factors within it. Over time, specific organizational needs became increasingly important whereas spatial restrictions lost some relevance (Lloyd, P.E. and Dicken, P. 1990). Holmes, J. (1983) described the Fordism period as the first "of major reorganization". He argued that the spread of production on a global level increased the competition in automobile industry and forced manufacturers to rethink and reorganize their production and work processes.

After industrial changes to "post-Fordist" and into the "information age", location analysis also went through a logic development (Bailey, D. *et al.* 2010). In this era both the importance of particular location factors and the logic of industrial location theory have again been critiqued. Since the value per volume combined with a low weight of the products makes up for a low transport cost share of the sales, the location factor of the transport costs in this time loses importance. Accessibility and speed, however, still play a major role. The trend at that time was towards a location factor catalogue in which the different industries can accurately determine the importance of each factor. Factors such as agglomeration advantages (with customers, competitions, indifferent ones), labour market aspects, state influences, capital markets as well as environmental and living conditions were actively included in assessments (Bathelt, H. and Glückler, J. 2012).

Increasing attention was given to Grabow, B. *et al.*'s (1995) distinction between "hard" and "soft" location factors. The hard factors are the quantitatively measurable cost factors. Hardly quantifiable factors such as living conditions, site image and political climate, on the other hand, are soft location factors and are of significant importance for the decision of a location. Florida, R. (2002) went a step further and changed the overall decision-making approach. Based on the scarcity of resources among highly qualified personnel, he assumed that company decisions are based on the location of the "creative class" and not the other way around. A realistic representation of company decision-making processes provided the approach of a "decision tree". This method was developed from qualitative data collection from practice and was initiated by Rees, J. (1972) (see De Souza, A.R. and Stutz, F.P. 1994). The advantage of this processing is the integration of the time-sphere in addition to the dominant sphere of space via learning and feedback effects. Together, these methods were used to explain the location decisions of the enterprises in this time.

Foci of recent research are the challenges of the upcoming "fourth industrial revolution" in the automobile industry resulting in the end of the stable geographies of production (Fonseca, L.M. 2018). The automobile industry's future is as uncertain as never before (Schade, W. *et al.* 2012). Current technological changes enable a much greater connection between products and their digital environment (Krawczyński, M. *et al.* 2016). Moreover, innovative manufacturing processes and IT solutions have increasingly been applied regardless of industrial branches and have accelerated the overall economic innovation process (Tanner, A.N. 2016). The power of information technology has increased to such a great extent that processing of huge amounts of data in a short time as well as customer-centred production have become possible and highly flexible (Büttner, R. and Müller, E. 2018). This development also enables revolutionary product innovations such as autonomous driving.

Nowadays, even the development of the automobile industry to a mobility service provider is conceivable. This research area requires a great deal of human and financial resources and represents a major challenge for the automotive industry in the next decades (Verband der Automobilindustrie, 2018). Despite improved customer access, proximity to the market of production sites has gained greater importance. Protectionism has increased significantly since the financial crisis of 2008–2010 (Yalcin, E. and Steininger, M. 2018). Sales figures in the triad (USA, EU, and Japan) are stagnating at a high level (Verband der Automobilindustrie, 2018). A major drop in sales due to a lack of local content in production and associated tariffs has become a problem for carmakers. By contrast, large growth markets are developing in the BRICS countries (Brazil, Russia, India, China, South Africa) (Schade, W. *et al.* 2012). For example, China is now the largest car market in the world despite a state-regulated economy (Dicken, P. 2015; Verband der Automobilindustrie, 2018). This development requires a strategic positioning of the original equipment manufacturers (OEMs) within stable free trade agreements in order to provide for the global market volume without any extra investment (Klier, T.H. and Rubenstein, J.M. 2017). Among the biggest challenges accompanying the current "fourth industrial revolution" are climate policies based on the rejection of fossil fuels. In the course of the climate change debate, governments are trying to ensure the transition to ecologically sustainable mobility concepts through increasing regulation of emission standards (Schade, W. *et al.* 2012).

So this advancement of information technologies, the volatility of the sale regions through demand and regulation as well as the emergence of new technologies and greater sustainability orientation require an intelligent factory. Such a factory is able to organize itself in a mutable manner, to produce in an efficient way, and to integrate customers and stakeholders into the manufacturing process. The requirements for such a factory are different from the previously relevant location factors and, thus, also affect the decision-making process (Pfliegl, R. and Keller, H. 2015). The afore-mentioned challenges have barely found their way into economic geographic literature. There is hence a need to work on the combined challenge of global site decisions and environmental conditions in economic geography analysis of the auto industry.

BMW's strategic situation

In this study, the focus is on a German car manufacturer, the BMW Group. Along with Daimler, Audi and Porsche, the Munich-based company competes in the premium segment. Audi and Porsche belong to Volkswagen, which is one of the two largest manufacturers in terms of volume in the world. German car production has highly depended on exports and this trend has increased in recent years. With a 77.5 per cent export rate in 2017, a new record was achieved. BMW's largest sales markets are the EU internal markets, the USA and China (Verband der Automobilindustrie, 2018).

After decades of success producing and selling powerful, fossil-fuel powered, quality vehicles, the BMW Group is now confronted by a competitive situation that reflects the challenges of the entire automotive industry. Global trade regulations have put massive pressure on the company as they not only boost import tariffs on vehicles but also prices for cross-border trade in components. Even stable trade relations, such as those between Europe and the United Kingdom, are now under threat, in this case from Brexit. Great Britain has played a major role in BMW's internal combustion engine supplier structure. In order to reduce customs costs for finished vehicles, BMW has positioned its production of certain derivatives in associated main markets. For years, the US has been the largest sport utility vehicle (SUV) market, thus, these models are produced locally, mainly in Spartanburg. Currently the plant produces large SUVs for markets worldwide. Smaller models are manufactured in rising large markets, and notably in China. China is indeed a special challenge (BMW Group 2018). Its state-protected economy only allows production in cooperation with a Chinese partner. Supplying markets outside the country is subject to high tariffs, which can add up to 40 per cent depending on engine performance (Germany Trade & Invest, 2017). Apart from a few derivatives, the Chinese factories in Dadong and Tiexi produce almost exclusively for China's local market. Exports from China to the world are currently barely noticeable.

Adapting to dynamic markets therefore requires regular investment in new regions. Small-scale manufacturing in India, Brazil and Russia, for example, facilitates BMW's access to the potential growth markets of the BRICS countries. Both the construction of plant in new locations and upgrades of the existing product network present a financial burden. In particular, the conversion to the production of electric vehicles in the same line of conventional powertrains requires great investment. In order to ensure market flexibility despite capital bound in new locations, upgrades and electric vehicles, BMW, like its competitors, organizes its production in smaller sub-networks within its established production system. Thus, the production volume can be shifted globally among plants and so extensions can be ensured without interrupting the market supply.

The central production system of the BMW Group comprises five sub-networks. Whereas Regensburg (Germany) and Oxford (UK) form a sub-network for small vehicles, Munich (headquarters, Germany) and San Luis Potosi (Mexico) constitute a network for the compact models. Dingolfing (Germany) and Goodwood (UK) manufacture luxury-class vehicles. Spartanburg (USA) supports Rosslyn (South Africa) in the production of SUVs. The only plant which is currently not part of a sub-network is Leipzig (Germany), because the factory has a diverse product portfolio and is currently still the only factory, albeit with a different production logic, for e-vehicle production. The new plant in Debrecen, which is under construction, primarily serves the purpose of increasing the flexibility of the network and solving dependencies (see Molnár, E. *et al.* 2020). For example, SUV models could be manufactured in Europe instead of just in the US. But there is also the option of building a competence factory for electric models there. The Chinese plants are considered separately because of their characteristics as a joint venture. Munich, Hams Hall (UK), Steyr (Austria) and Shenyang (China) are sites of BMW engine production and form their own supply network (BMW Group 2018) *(Figure 1).*

From 2008 to 2018 production units increased in all plants with the exception of Munich. Munich's decline in production units in 2018, however, is a cyclical effect and is followed by a high-volume year 2019, which is marked by the production of the new 3-Series. Striking are the increases in units in the US and in China (no plant in 2008). The German locations also produce more units then they did in 2008. Oxford and Rosslyn have remained at a constant production (unit) level. With the launch of the Mexico plant in 2019, the network of the 3-Series will be expanded and Munich will have spare capacity for an electrified vehicle in 2021.

In addition to the expenditure on plant restructuring, there is currently a great need for research on battery technology and autonomous driving. Massive spending on R & D is needed to help shape the future industry

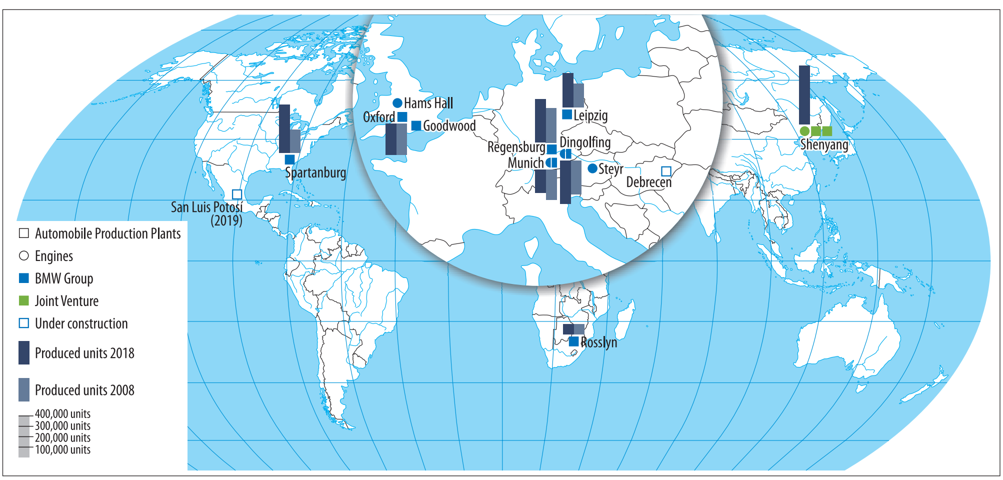

Fig. 1. BMW production network and produced cars, 2008–2018. *Source*: BMW Group, 2018.

standard and to avoid losing competencies. Cooperation can significantly reduce expenses, with know-how being available to all partners. BMW has decided to take this step in autonomous driving by cooperating with Daimler (Hägler, M. 2019). Investments in research and in implementation of e-mobility are necessary because of the EU regulatory framework. Due to a sustainability concept that is gaining importance at the moment, the new vehicle fleets are subject to strict CO_2 emission limits. As a premium manufacturer with many large luxury-class vehicles and high engine performance, balancing carbon emissions with electric vehicles is one of BMW's many key competitive requirements. That is why a fast but efficient integration of BEV and PHEV into the plants of the production network is necessary, and requires major investments in plant infrastructure. Since the traditional production process of a conventionally-powered vehicle differs from that of an electrified vehicle, the production sections must be redesigned and rebuilt to be suitable for both production platforms. Such a split-line strategy with all types of drive significantly increases the flexibility of a plant, but requires massive expenditure and severe interventions in the existing network (BMW Group, 2018).

Munich plays a special role in this network. This site houses the corporate headquarters and the Vehicle, Technology and Component Development Research and Innovation Centre. The campus for autonomous driving is located in close proximity on the outskirts of Munich. With the BMW World, the BMW Museum and the BMW Classic, Munich is also the centre of the lived brand history and perception. Within these capacities, the BMW plant Munich also fulfils its function as a production facility with an annual output of over 200,000 units of midsize vehicles. It is the oldest and smallest plant in the production network. Located in the district of Milbertshofen, the plant is close to downtown and surrounded by densely populated residential units. Therefore, the site entails a variety of peculiar requirements but also offers some advantages (BMW Group, 2019).

In terms of infrastructure, the plant is integrated in a cooperation network of various partners to reduce negative effects of the mentioned site-specific factors. With the Traffic Concept 2030+, the city of Munich is planning to satisfy requirements that will sustainably improve the traffic situation in the North of Munich. Such a project would ensure the supply capability of the plant. Therefore, the plant participates with its expertise in the goal setting. In the context of plant supply, cooperation with logistics service providers is also an option. With partners like Deutsche Bahn / Schenker and Scherm, joint supply centres are founded and operated. Parts can be stored and precommitted via these centres. The Just in Sequence delivery at the plant can then be planned more reliably over a smaller distance between supply centre and plant. In addition, these partnerships enable new supply concepts such as transporting the parts via an e-truck. This truck has limited ranges, but is CO_2 neutral and can reduce the risk of increased emissions legislation in downtown Munich. Other partnerships in this regard include supplying the plant with energy or providing a digital infrastructure.

Within the production network, Munich is the lead plant regarding the middle class models and forms a sub-network with the plant in San Luis Potosi, Mexico. Should there be an increasing demand for a specific derivative for example within the NAFTA region, the production volume within the sub-network can swiftly and flexibly be exchanged from Munich to Mexico. Since 2015 the Munich plant has undergone a process of continuous restructuring characterized by the vehicle life cycle, technological change, and sustainability and efficiency upgrades. Initiated by the new model of the 3-Series, reconstruction work in Munich factory halls started and saw the construction of a more efficient and sustainable paint shop among others (Schulenburg, C. and Hemmerle, A. 2015). With the launch of the i4-model, an all-electronic mid-range executive vehicle, further restructuring is necessary (BMW Group 2019).

The BMW Group has created opportunities to deal with the challenges of the automotive industry. With the implementation of a shared platform for all types of engines, the BMW Group can exploit economies of scale despite niche production. By using and implementing small subnetworks across the globe, it is possible to react flexibly to different market changes. Despite the global nature of the production network, three of the four lead plants (Munich, Regensburg, Dingolfing) are concentrated within a radius of 100 kilometres and can exchange information concerning the core tasks of the subnetworks in no time. This results in a mix of global activity and geographical proximity. By focusing on sustainability in production, the company is also trying to prepare for further future challenges (BMW Group 2018).

Analysis of Munich plant's upgrade decision

The construction or reorganization of a production site is always a long-term decision that binds large sums of capital. In addition, a site must meet the requirements of many different functions. Logistics must ensure optimal supply and sufficient space to supply the production line. The availability of skilled workers over a longer period of time is in the interest of the Human Resources Department. The assembly and production of the painted body relies on a large amount of contiguous and, at best, ground level, surfaces. Due to legal regulations, it is the task of the facility management to ensure compliance with fire safety and other safety regulations.

For these reasons, interdisciplinary teams are formed for all location decisions, which are to work out and evaluate an optimal cross-departmental solution. These teams are guided by the strategic control of the production system. Important parts of the project are the planners of the core technologies, logistics, body shop, paint shop and assembly. For existing sites, other affected technologies are involved. In Munich this includes engine construction, seat production and material analysis. In addition, special functions such as facility management, human resources, IT, corporate strategy and sustainability as well as the internal structure planners participate.

Basically, a location decision is based on a strategic and technical framework. In the automotive industry this often combines aspects and interactions among the manufactured product and the related life cycle as well as the overall volume development of the vehicles. Depending on the plant, further site-specific challenges may arise. For Munich, these are the structural shell of the plant and the urbanity of the location. The product life cycle of the old 3 Series ended in 2018/19. The successor model has already been integrated into the structure. From 2021 on, a fully electric vehicle is to be integrated into the factory, requiring large investment. In addition, the plant faces the challenge of having some assembly halls from the early days of production at the site and having conformity risks that entail greater redevelopment efforts. The last difficulty is the urban situation. With an increase in traffic, the supply continues to be burdened, which makes an alternative logistics concept necessary. This bundle of difficulties justifies the range of decision-making latitude, from maintaining the status quo to phasing out the plant in Munich that marked the Munich plant upgrade decision process. Field study of the more than two year-long decision-making process of the Munich location revealed a framework used for the location decisions process at BMW Group *(Figure 2)*.

The existing production network always represents the starting point. The need for site intervention in this production system can be triggered by either internal or external factors. These stress factors have a fundamental effect on the production network in total. The external parameters include the production volume. This must, sensibly distributed over the network, be produced in the sum of the factories. If the network or one of its sub-instruments is fully occupied, the system must be intervened. New markets constitute a second external factor. In

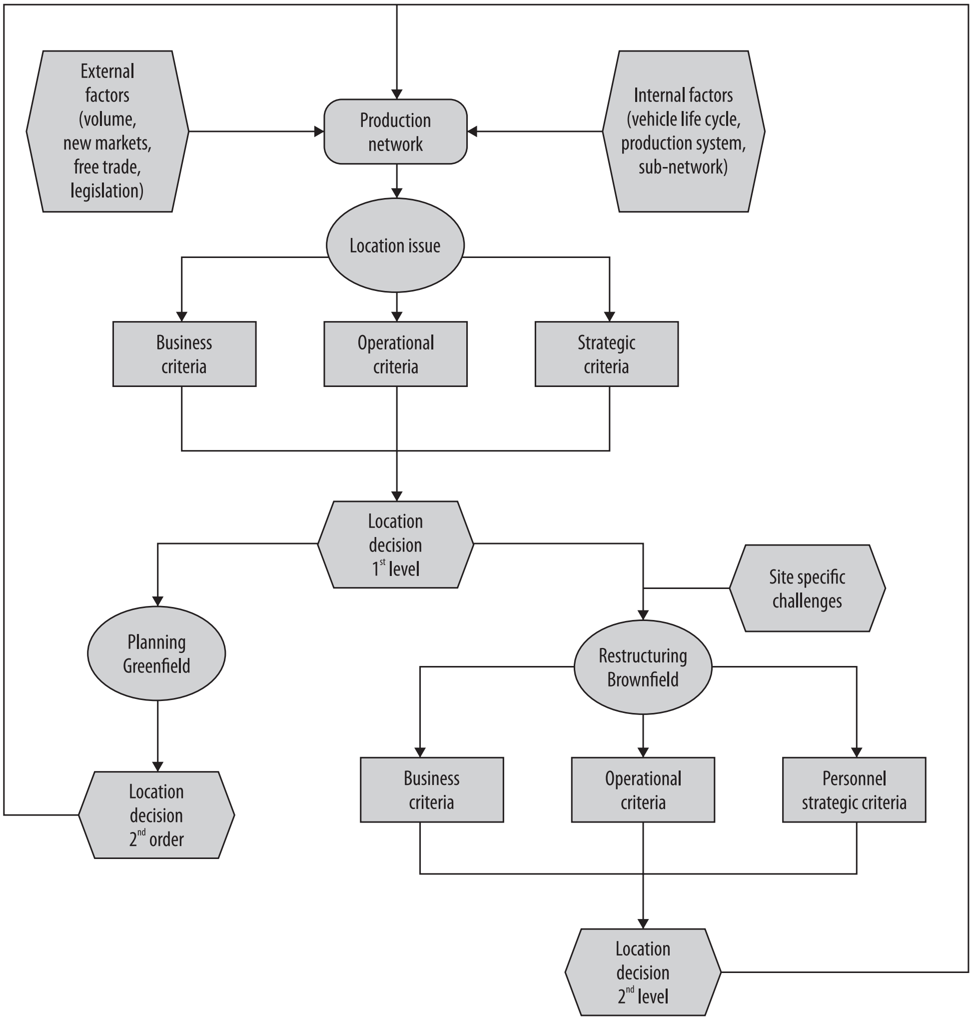

Fig. 2. Decision making framework in location matters of the BMW Group. *Source*: Edited by the author.

the case of strong growth in a single market, such as China, BMW Group's presence in the country should be strived for, or an existing small-scale production should be expanded in its capacity and be more integrated into the network. Free trade agreements allow easier and cheaper trade between the countries involved. The emergence or cessation of such regulations will result in changed framework conditions for action in the network (Klier, T.H. and Rubenstein, J.M. 2017). The last external factor, legislation, can involve many things. From the increased taxation of corporate profits and regulations, for example CO_2 limits, to subsidies and tax advantages, a change in activity in the state can have positive as well as negative effects. Internal factors include the end of a vehicle's life cycle, which is always linked to investment decisions in the production network. The plant in which the model is manufactured has to be adapted and modernized in its structures.

Production system refers to the clear increase of the hourly output by structural extensions. These are necessary if this increase can no longer be achieved through efficiency improvements. In many plants, space reserves have been created for this purpose. The factor sub-network describes the organization within the large overall network. If the logic is changed, the sites have to be rebuilt for other vehicle classes or drive types.

These factors act directly on the production network and must be recognized and evaluated there. If a need for action is derived on the basis of the changed environment, then this results in a location issue. This issue is discussed, evaluated and decided in the central control of the production network. This evaluation includes business, operational and strategic criteria. In the business analysis, scenarios are weighed, for example, against their investment, planning, material, production and transport costs. With the assessment of complexities in start-up and operation, the criticality of the decision, personnel policy issues as well as flexibilities and responsiveness, the operational criteria provide another form of comparability. The strategic criteria focus on risk assessments in the network. Dependencies on individual sites play a significant role in the course of regulatory measures. This criterion aims at robustness to changes in a volatile environment, such as volume or technological change to e-mobility. The result of the evaluation leads to an initial location decision. This is achieved without much involvement of the individual sites. The overall optimum of the production system should therefore be in the foreground.

This first-level location decision is one of the key findings of the field study and has not yet been taken up in the economic geographic literature. This approach guarantees the network suitability of the decision, which enables a flexible response to customer needs, improves the Group's cost position and creates a balanced risk position. Following this site decision, in the case of a network extension in the Greenfield, the planning units will be commissioned with the site search and the optimal plant structure. In the case of a Brownfield restructuring, the plant departments will be integrated into the valuation process of the existing site and an optimal conversion based on the given decision-making state that will be sought.

It is noticeable that the original analysis approaches of site theory are less important in the current model. Transport costs as a function of weight and distance are virtually absent from the evaluation. The understanding of space changes from a transport and distance-oriented approach to an assessment of the location in spatial units. These spatial units are shaped by political actors. They do not have to exist constantly or retain their meaning over longer periods of time. So the time frame, which was later included in the analysis (for example, De Souza, A.R. and Stutz, F.P. 1994), also plays an important role in this model. Several determinants, such as a changed network and altered demand developments or life cycles, integrate the time frame into the model. However, a fairly new consideration in the evaluation is the peculiarity of the decision maker per se. The existing production network influences the decision both spatially and temporally. In order to position the company's locations in the space units, the existing structure must be assumed. If a decision is postponed to a later point in time, the network might have changed by then due to the decisions made in the meantime. This kind of altered framework will be explained in more detail on the basis of the location decision of the Munich plant.

The field study conducted at the Munich plant focuses on the restructuring of the Brownfield. In this type of network intervention, various location-specific challenges play a significant role. For Munich, these challenges are mainly about the plant's urban surrounding, its difficult supply situation, its spatially limited factory premises and its established structures. Nevertheless, the plant's proximity to the research and development departments, the availability of many university graduates and high-skilled workers as well as the perception as a regional player have a positive effect on the Munich location. All these aspects must be taken into account to allow a productive discussion about the restructuring of the Brownfield. The assessment of the site discussion is made in greater detail by a large number of affected site functions and central offices. The logic here is comparatively similar to the first location decision, but neglects the connection to the network. This connection has already been ensured via the network suitability and its associated premises. At this stage, assessment of the business criteria focuses strongly on the structural investment and the running costs of production. The strategic criteria target personnel strategy issues in particular. Here, a potential shift in the future employment structure must be kept in mind. Further interesting points of the analysis can be deduced from the operational criteria. While the proportion of qualitative evidence is very high, the evaluating functions enjoy a wide range of interpretation within the assessment. For this reason, improvements in production value flow, flexibility, quality and employee orientation and better adaptation to site-specific challenges can be assessed in a comparative analysis. Based on the sum of these three evaluation clusters, a site-specific decision was reached to implement a specific type of restructuring for the singular factory. This choice, by analogy with a decision for a Greenfield plant, implies a second-level location decision. Thus, the production network is either extended (Greenfield) or renewed/restructured (Brownfield). This second decision provides a conclusion and a new starting point for future location decisions.

Following this logic, two site decisions were also made for the Munich plant taking both internal and external factors into consideration. The upper middle class vehicles built in Munich have a large market worldwide. Both the US and Europe as well as Asia, which shows strong growth in this segment, require high production volumes. Due to the facts that the processes of site search and construction in the Greenfield would take too much time and that compensation for the required volume in the network is impossible, Munich is already a preferential choice at this time. In addition, the launch of e-mobility requires a new type of vehicle architecture in the plants. In order to make maximum use of the existing structures, to install technological transformations in a leading plant and to distribute the produced volumes optimally to sales markets, Munich was chosen as a Brownfield restructuring project. This first location decision attests a network suitability and a balanced risk position for future product and market changes to the Munich plant. Furthermore, the investments that had been made a few years earlier to launch the successor model of the 3 series continued to be used beneficially (Schulenburg, C. and Hemmerle, A. 2015).

The specific challenges which the Munich plant brings with itself at the second decision stage have already been explained. Of further interest now are the evaluation criteria which were taken into account in the business, operational and personnel strategy analyses. Personnel Strategic Assessment reviews possible implementation of future site scenarios in terms of staffing and residual costs. Due to the presence of many different technologies, especially the engine construction at the factory site, both perspectives, business and operational, have one thing in common: uncertainty. Since potential modifications in the plant's structure will affect other technologies in the future, or even possibly displace them, costs for compensation must also be assessed. The transition to e-mobility, for example, results in an evaluation uncertainty. If change is stronger, a scenario of greater displacement of old technologies may be more cost-effective than a weaker one. This would affect almost all categories of business valuation, such as investment or running costs. An alternative perspective is provided by the operational criteria. The parties involved can include their production-relevant framework conditions in a qualitative assessment and, thus, increase comparability to other scenarios. Relevant aspects of sustainability, such as neighbourhood acceptance or development minimization can also be added to the equation.

Overall, the location decision from the case study regarding the Munich plant is based on a few key criteria. First and foremost, network usability plays a significant role. The location is well integrated in the established system taking the leadership role of a sub-network with well-performing supplier and personnel structures. This key suitability factor has already been discussed in the first location decision. Network suitability represents a change in the value of the location, since in previous decisions the topic of network expansion had clearly been more important than its basic suitability. Since a complementary network ensures a balanced risk position in this first decision, a closer look must be taken on the second factor. The established structure of the plant also fulfils the factor of risk exposure. With rather stable political conditions and a consistent sales market in the regional economic area, the Munich plant holds a relatively secure position. This fact is important in both types of location decisions and manifests itself in different ways. This kind of risk centering also represents a change in the analysis of the locations. In previous years, location decisions were opportunity-oriented. With the uncertain future of the industry, the key driver of risk appetite has also changed. In addition, the BMW Group aims to optimize the use of existing structures. To some extent this indicates an escalating commitment to the concept of sunk costs. The need for security seems to correlate with an increased orientation towards existing structures. In this context, 'sustainability' has become more prominent in decision-making and represents a special case. In the underlying assessment, some topics are taken up directly by the valuating departments, whereas others are not explicitly mentioned. However, the following discussions point to a stronger position of sustainability in location decisions than is currently the case in the model. Further, it is becoming apparent that the assessment of sustainability is geared towards new indicators which make a further perspective on location decision necessary.

Changes in location factors and location decision

How do these findings affect the location research of economic geography? At least since the last economic crisis 2008–2010, the framework conditions in the choice of location have changed massively. This concerns the technological capabilities of the industry as well as their considered location factors. The competitive pressure within the industry, especially in the automotive industry, is also a major cost burden and an uncertain factor for future development. Against this background, the risk appetite of the actors is changing from an aggressive investment culture to the passive optimization of proven structures and partnerships (Klier, T.H. and Rubenstein, J.M. 2012; Häntsch, M. and Huchzermeier, A. 2016). The large research needs of automotive technology, such as battery technology and autonomous driving, are preferably developed in cross-competition cooperation in order to spread the risk and the immense costs (Eriksson, R.H. 2011; Hägler, M. 2019). The change to e-mobility increases the pressure even further (Nieuwenhuis, P. and Wells, P. 2015). A conversion of the existing works to a changed and diverse product architecture is necessary. In addition, a worldwide charging infrastructure must be set up. This infrastructure is also to be implemented in Europe in a joint venture of European automobile manufacturers (Mayr, S. 2018). The questions to be discussed are the following: How does this need for security in the currently challenging situation affect decision-making about locations? And how does the approach of location decision-making change in comparison to the existing scientific relevance of economic geography?

The location decision analysis has changed in four key criteria. The exposure to risk is one of them. The need for security in terms of costs, benefits and future prospects has significantly increased since the turn of the millennium (Klier, T.H. and Rubenstein, J.M. 2012). The financial difficulties of large car manufacturers in the wake of the economic crisis are also due to an unbalanced risk position (Klier, T.H. and Rubenstein, J.M. 2010). The location factor of the network suitability is closely related to this. The production network is the basis for any global action of a manufacturing company. This network can be used to enter new markets, to serve existing markets in a customer-centred manner, to avoid trade barriers as best as possible and to reduce dependencies on individual sites. In the manufacturing industry, the expansion of production into the world through globalization has been a major driver in site planning for many years. For many automobile companies, this process of expansion has meanwhile been completed: global production networks have already been set up. Additions usually only take place when new, large sales markets are emerging. China is the best example in this regard. Globalization as a driver of the choice of location therefore loses importance (Krawczyński, M. *et al.* 2016). The focus shifts to an optimal organization of the existing global production network. Flexibility and adaptability are the new framework conditions of this network.

Based on the above mentioned production network, another location factor is derived. It is an optimal use of existing structures and investments made in the past. This sunk cost phenomenon is not new in the field of economic geography research, as the management of sunk costs has long been recognized as an important part of the operational restructuring process. Of particular importance when considering the location decisions from an existing production network are the accumulated and the exit sunk costs (Clark, G. and Wrigley, N. 1995). These costs are largely relevant to the location. The initial investments made result in configurations of production due to a particular geography and/or history. These start-up investments can be very different for each company in the business. If an enterprise wants to shift the basis over a changed production orientation, the initial investments are often hardly recoverable (Clark, G. 1994). This special position of sunk costs is also recognizable in the decision-making process of the industry today. In addition, the change to electro-mobility requires a changed production environment and, associated with that, a difficult use of the differently centred investments of the past. For this reason, sunk costs develop in the current consideration to a key factor of the location choice.

The last location factor of particular importance is sustainability or, better, a sustainable alignment of the network and the individual plant locations. This factor changed a lot in recent years. In the evaluation departments, economic aspects still dominate. However, social and ecological characteristics are increasingly being integrated into the evaluation. This has two main reasons. First, there is an imbalance in the assessment of sustainability between the clerks and the key management. The focus on social and ecological criteria is receiving much more attention in management and, despite the lack of a monetary assessment, is of greater interest than it is at the operational level. Second, the transformation to electro-mobility is largely driven by sustainability considerations. The decarbonisation of the automobile industry is the central content of politics and public perception. This industrial restructuring process will take time due to external factors and the associated large financial outlay (Seto, K.C. *et al*. 2016). But, in the name of 'sustainability' a transition to low carbon mobility is underway in the auto industry. However, despite the BMW Group Chief Executive Officer's certainty that electro-mobility is the future, the transition involves risks and therefore careful transition steps associated with this model cycle.

Relevant for the economic geography is the change in the consideration of all described location factors. The expansion of the network to realize all the opportunities offered, combined with a neglect of socially relevant aspects, is no longer the status quo of the industrial decision-making process. The process at the BMW plant in Munich shows that reinforced structures and their location factors can gain in importance in the difficult framework conditions in the industrial environment. This means attention to what the advantages of old or existing factory locations are. First and foremost, the site is part of the production network. Thus, the network and its sub-organizations around this plant co-developed. A high degree of suitability is, thus, ensured. In addition, suppliers and cooperation partners have set up the site in terms of either space or organization. There is a solid structure that can respond more quickly and more effectively to potential risks. Moreover, the internal connections, supply networks, cooperation partnerships and research institutions still play important roles in the site analysis of existing plants. These spill-over effects lead to innovation and to advantages in development costs, especially in what is technically a very volatile time (Tanner, A.N. 2016).

In this context, the Munich plant is of course an old factory. It is important to mention that network, cooperation and spillovers play a particularly important role in this plant due to its geography and history. The above-mentioned urban situation not only entails higher costs and challenges, but also has many positive effects. In addition to the corporate headquarters, the research and development centre is in the immediate vicinity. Furthermore, three of the four subnetworks are led by Bavarian plants. This enables a physical exchange with the other regional plant locations. Munich is also home to many large industrial groups that tend to work together more closely in the face of new technological challenges. Collaborations with renowned universities are also possible at this location. Tanner, A.N. (2016) describes how new technologies in metropolitan areas increasingly occur and are further developed. Due to the increasing significance of the new key factors in site analysis, old factory locations are becoming more important. Existing investments and cooperation are maintained and tend to be further deepened and optimized. In this technologically and financially uncertain time, it is important to avoid risks and still provide a sustainable structure. To secure the company's success, a corporation must position itself best in a globalized world. The resulting production network forms the basis for long-term success. If an existing, old location has proven its worth, its suitability and the contribution to the company's success are secured until the next analysis. A secure base serves as a starting point for the great tasks of the coming years. The change to electro-mobility is the beginning of a major decarbonisation of the automotive industry and other manufacturing industries (Seto, K.C. *et al.* 2016). This requires the development of sustainable vehicle concepts and production structures. The relevance of 'sustainability' is growing, driven both by the state and by companies. Precisely what this 'sustainability' looks like in detail deserves further attention but is beyond the scope of this paper.

However, in general this research finds evidence that BMW Group is thinking about 'sustainability' by rethinking its sunk costs and risk profile, reacting to societal pressure for decarbonisation and paying attention to social issues of work force retention and restructuring. These findings confirm the idea that a 'fourth revolution' is occurring in the automotive industry. As described, this revolution is caused by three driving factors. On the one hand, there is the progressive individualization of the product range in ever new niches. On the other hand, states and organizations are putting great regulatory pressure on the industry. The last factor is the advancing digitalization, which enables significantly leaner production by combining high automation with individual demand. The automotive industry decides differently today than ten years ago. The analysis reported in this paper reveals those key parameters that were integrated into location decision-making and the framework within which they had effect. These were the decisions and framework used lately. Regulations and protectionism are further important drivers that can influence site analysis in the future. Exactly how the factors and technologies identified will be integrated into the industry and its production has yet to be seen.

The last remaining question is the extent to which this paper's findings can be generalized. Are the results of the case study of just one automobile company applicable to the whole industry? As discussed, the manner in which location decisions are made depends on several parameters such as production network, type of production, size and historical decisions. These influencing factors allow conclusions for the general validity. All major automotive groups, such as VW, Mercedes or General Motors, have a production network that spans around the globe. This structural feature is common to almost all OEMs. The decision history and the type of production, on the other hand, generally allow for selective differentiation in the process. Type 2 OEMs, such as BMW or Mercedes, specialize in product quality and individuality. As opposed to that, VW is an economies of scale producer and therefore operates on a different strategy (Schamp, E. 2005). Nevertheless, the first step of every decision is to aim for structures that are optimal within the company's network. Optimal for a company in this context means to guarantee sustainable company success in connection with the existing structures and networks, and not to take negligent risks. This applies to both a mass producer and a quality leader. In conclusion, it can be said that the data, although they stem from one particular company, do speak for a change relevant to the industry. This can also be seen in large investments in new plants and plant restructuring visible industry-wide (Häussler, U. 2020). The form of these investments can of course differ. For example, a mass producer may build a completely separate plant for electric vehicles and opt against the path of plant integration. Due to the larger number of production units, the company would still optimize its production networks, which would be a justifiable option. Research in another company would further support this thesis.

Conclusions

In addition to the network suitability, sunk costs and risk exposure, the topic of sustainability is revealed as particularly important in this location analysis. In the first three, a contrarian change in the direction is evident. Network suitability replaces network expansion, optimizing investments supplant capital stock expansion and avoiding unnecessary risks trump an expansive opportunity orientation. Sustainability, however, is a further development. While economic trends have clearly dominated over the past few years, social and environmental factors are becoming increasingly important. A detailed analysis of the changed perception of sustainability is to be considered in further studies, but is already to be regarded as a key factor in the industrial context. With the advent of electromobility, a key technology is now turning into a sustainability-oriented product. This orientation is new in the automobile manufacturing industries and argues for a global trend beside what we have come to know as the economics of plant restructuring. This research reveals that as decarbonisation, digitalization and protectionism grip the automobile industry, location decision-making is already taking on new frameworks, a changed repertoire of factors, and an orientation toward risk averse notions of 'sustainability'.

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Upgrading and the geography of the Hungarian automotive industry in the context of the fourth industrial revolution

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Abstract

The present study focuses on the geographical investigation of the automotive industry in Hungary that has been integrated into the global production networks as a relevant sector of the reindustrialization in East-Central Europe. The aim of the paper is to reveal the dominant spatial trends in this sector since the economic crisis of 2008, and how these are connected to the issue of upgrading influenced also by digitalization. The analysis is primarily based on the official industrial employment data however other secondary sources are also used. It has been stated that the growth of the Hungarian automotive industry showing to the direction of geographical concentration and expansion is accompanied by the regional stability of the sector. Quality indicators expressing upgrading indicate correlation with the spatiality of car factories and Tier 1 suppliers carrying out more complex activities, but a more significant functional upgrading is only realised in the capital city with increasingly research-development focused profile. Results suggest only moderate upgrading despite the gradual adaptation of Industry 4.0 technologies.

Keywords: Industry 4.0, upgrading, automotive industry, geography, Hungary.

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Introduction

It is expected that the "fourth industrial revolution" based on the combined application of various key-innovations, the so called cyber-physical systems (CPS) will drastically transform current production networks and thus the geography of industry (Boston Consulting Group, 2015). Such changes may affect deeply the automotive industry that became an important sector of the East-Central European economies over the last three decades. Countries relying on foreign direct investments, following an export-oriented growth model and treating the automotive industry as a strategic sector have increasingly significant roles in the international production networks of the sector (Schamp, E.W. 2005; Pavlínek, P. *et al.* 2017). In certain countries vehicle production has a great impact even on the spatial structure of manufacturing industry and in this way, for example in Hungary, it has an important role in shaping spatial economic inequalities (Kiss, É. 2010; Lengyel, I. and Varga, A. 2018). As a result, the future of the automotive industry is also the question of general modernization and regional development.

Although the innovations of the fourth industrial revolution are already present in Hungary, the volume of changes is hard to estimate due to the lack of comprehensive analyses. Furthermore, the boundaries of Industry 4.0 are flexible: technological innovations occur not as the result of an overwhelming revolutionary transformation, but rather

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as the part of a gradual evolutionary process; their rationally selective adaptation depending on company demands and possibilities is typical (Szalavetz, A. 2016; Nagy, Cs. *et al*. 2020). The effects of the transformation are clear primarily in the increase of the production efficiency – related mostly to automation – in the Hungarian automotive industry that has predominantly a production function (Losonci, D. *et al*. 2019; Szalavetz, A. 2019). Nevertheless, certain innovations (modelling, simulation, uniform company software) help to establish functions beyond production, to share certain tasks with the centre and to specialize to partial tasks in some fields relevant from digitalization point of view (Szalavetz, A. and Somosi, S. 2019).

At this point Industry 4.0 connects to the research of upgrading. In the case of semi-periphery economies like Hungary, upgrading – which means higher local value added – would be especially important in the change of position in the international production networks. This could be achieved by increasing the production efficiency, changing product structures and the functions in the production networks or by shifting towards more promising industries and value chains (Humphrey, J. and Schmitz, H. 2002; Kaplinsky, R. 2013). According to the global production network theory upgrading is essential to avoid exclusion from the production networks due to the increase of expenses (by keeping low cost-capability ratios) triggered by going beyond the role of cheap producer (Yeung, H.W. and Coe, N.M. 2015).

The role of the "fourth industrial revolution" shall not be regarded absolute, either from the future of the automotive industry or from the point of view of the upgrading perspectives of East-Central European economies. The geography of this sector is also greatly influenced by new products (e.g. electric, autonomous and connected cars, car sharing) and business models. These will influence not only the structure of value chains but also – depending on the involvement of info-communication companies playing an increasingly important role in the innovations of the automotive sector – who leads these networks (Peters, S. *et al*. 2016; Yin, Y. *et al*. 2018). Apart from the technology and the products, changes in trade regulations determining production organization and stricter environmental protection specifications influencing product development are also important factors (Dicken, P. 2011).

The present study focuses on the geographical investigation of the automotive industry in Hungary. The dominant regional trends since the economic crisis of 2008 are studied and their relationship with the process of upgrading influenced by digitalization as well. The study can be divided into four major structural units. In the first unit – based on the relevant literature background – the spatial structure of the automotive industry, its characteristics in East-Central Europe and in Hungary, and the relevant correlations with the fourth industrial revolution and upgrading are discussed. The second unit presents the database and methods of the empirical investigation in detail. Regional data are analysed in the third structural unit and the obtained results are interpreted in the fourth unit. The main contribution of this paper to the economic geography literature is that it reveals the connection between the way of participation in the international production networks and the geography of the automotive industry on case of Hungary.

The geography of automotive industry reflecting Industry 4.0 and upgrading

The automotive industry has a specific "nested structure" (Sturgeon, T. *et al.* 2008). Car companies and the major suppliers work mainly at a global scale while their production systems are organised either regionally or at the level of national economies. This phenomenon is the result of the different product preference of regional markets, logistical reasons and political pressure due to the "sensitivity" of the sector expecting cars assembled locally to use preferably locally manufactured parts. Those elements of the production networks that prefer cost efficiency move to the so called integrated peripheries (Pavlínek, P. 2018) where they target regions close to the centre (e.g. the core regions of the EU) in both geographical and cultural sense offering appropriate infrastructural background and relatively well-trained labour. In this way, they can enjoy the closeness of markets and the possibility of favourable cost-value production (Barta, Gy. 2012; Domański, B. *et al.* 2013).

Beside this tendency, the formation of local clusters within the above regional production systems can be observed. As platform concepts aiming for the partial standardization of products for different markets and economies of scale become widespread car producers require their suppliers to follow them to new markets (Humphrey, J. and Memedovic, O. 2003). Geographical closeness is especially advantageous for the manufacturers of large, heavy and model specific parts, not only saving logistic costs but facilitating just-in-time supply and more flexible responses to customer demand. Spatial concentration is made even stronger by the modularization of production (Túry, G. 2017). In the course of modularization, the car is assembled using pre-assembled modules making the establishment of pre-assembly plants and supplier parks next to the automobile factories. As suppliers are also interested in the development of component parts and modules, they move next to automobile factories because direct communication between them is possible in this way in the course of joint developments (Sturgeon, T. *et al*. 2008).

The above regional and local site selection strategies resulted in the development of an automotive agglomeration (Grosz, A. 2006; Pavlínek, P. *et al.* 2009) identified in East-Central Europe extending over the neighbouring areas of Czechia, Slovakia, Poland and Hungary crossing the borders of national economies. This concentration of the automotive industry can be explained by – apart from the already discussed factors – historical traditions (Hardi, T. 2012), multistage investments of car companies entering the region after the regime change and gradually increasing degree of intra-regional division of labour (Molnár, E. *et al.* 2015). Although the recent economic crisis had its effects on the automotive industry of the region (Kiss, É. 2012), its position – despite the partial relocation of the more labour-intensive activities – strengthened (Pavlínek, P. *et al.* 2017). Upgrading in the East-Central European automotive industry also had its role in achieving this better position. However, the realisation of this upgrading seems to be – regarding especially the functional elements – limited (Jürgens, U. and Krzywdzinski, M. 2011; Éltető, A. *et al.* 2015; Pavlínek, P. 2018).

According to certain scenarios, the "fourth industrial revolution" may question the role of the East-Central European region in the international production networks. While experience so far does not justify negative expectations, analysts see the state of "the calm before the storm" in the situation (Szalavetz, A. and Somosi, S. 2019). Despite the effects of Industry 4.0 innovations on upgrading the gap between value production by foreign parent companies and that by local subsidiaries does not seem to be reduced (Szalavetz, A. 2019). This supports the suspicion that technological innovations cement core-periphery relations (Lengyel, I. *et al.* 2016).

Analyses focus very little on the local effects of Industry 4.0. However, there is a suggestion that the adaptation of innovations is influenced by the dual character of the Hungarian industry. Certain industries (including automotive manufacturing), large companies and businesses with foreign ownership (i.e. actors with better resource supply) are ahead in the process. Their unequal spatial distribution also influences the geography of the adaptation of innovations in Hungary (Nick, G. *et al*. 2019). The applications of new technologies take place gradually and this means primarily the development of existing capacities instead of building new factories (Szalavetz, A. 2016). Finally, according to some opinions, Industry 4.0 appreciates locally available competent suppliers: in changing circumstances not foreign investments bring a technological catch-up, but the technological catch-up of local businesses generates foreign investments (Szalavetz, A. and Somosi, S. 2019). These ideas indicate the important role of quality location choice factors that are difficult to reproduce and of local or regional clusters with a significant history even in the age of Industry 4.0.

The role of local clusters in upgrading is explained by the idea of "dynamic strategic coupling" in the global production network concept. According to this, the development of a region is the result of successful global – local interactions influenced at a local scale by the concentration of knowledge, abilities and experience in the industry (economies of scale), and by co-operation and learning possibilities (economies of scope) (Coe, N.M. and Hess, M. 2011). The regional institutional background is important in the coupling process and it can be regarded as the derivate of national and supranational actors that is specific to the location. Institutes can steer upgrading forward with strengthening local factors while local factors showing greater complementarity with the demands of companies controlling production networks strengthen the position of regional institutes against global actors (Coe, N.M. *et al*. 2004). Accordingly, the East-Central European automotive cluster presented earlier – based on local synergies – has relatively advantageous chances for upgrading (Pavlínek, P. *et al.* 2009).

The analysis of the relationship between spatial concentrations and upgrading occurs in several papers on automotive industry. In the case of the supplier network of the Czech Skoda, for example, simultaneous spatial expansion and concentration were observed. While low cost and excessive labour are offered in the periphery, quality location factors dominate in the traditional core areas. The development of spatial concentrations is driven by increasing interdependence of automobile factories and suppliers due to modularization, just-in-time organisation of supply, reducing logistic costs and service requirements for the products that can be satisfied easier from closer areas (Pavlínek, P. and Janák, L. 2007). According to experience from Poland, the embedding of automobile manufacturers and their shift towards products with higher value added, i.e. upgrading results in the rise of spatial agglomerations. In the development of the largest concentration in Upper Silesia, for example, historical traditions, establishment of automobile factories as focus points in the neighbouring Czech and Slovakian regions, the concentration of part factories, the local possibilities of research and development and higher education together with the concentration of industry and population all had a major role; and they provided greater resistance for the region at the time of the crisis (Gwosdz, K. and Micek, G. 2010; Domański, B. *et al*. 2013).

The spatial structure of the Hungarian automotive industry with no automobile manufacturing traditions and supplier network prior to the regime change (in contrast to the Czech or Polish examples) can be explained by the importance of geographical location close to the western regions, industrial traditions associated with commercial vehicle production (skilled labour) and well-established infrastructure (motorways, industrial parks) (Barta, Gy. 2002; Kiss, É. and Tiner, T. 2012). The retaining strength of industrial concentrations is suggested by the regional stability of the automotive industry and also by its decreasing and increasing spatial concentration at the time of growth and recession respectively (Molnár, E. 2013). The process of embedding – interpreted initially via the development of the local supplier network and then in a much more complex way – received significant attention due to the dominance of the greenfield investments of large foreign companies (Sass, M. and Szanyi, M. 2004; Fekete, D. and Rechnitzer, J. 2019). The relationship between embedding and upgrading occur in the strategy of the major companies in the automotive industry established in Hungary following the turn of the millennium that accelerate their embedding in order to create the local atmosphere required for upgrading sooner (Józsa, V. 2019).

The automotive industry – due to its size and extensive industrial connections – leaves its mark on the geography of the entire Hungarian industry. Micro- and macro-scale radical changes, the strong differentiation of the spatial dynamics of the industry were in the background of the drastic transformation at the time of the regime change (Kiss, É. 2002; Nemes Nagy, J. and Lőcsei, H. 2015). The dominance of the north-western part of the country and that of the agglomeration around the capital became general; however, this seems to ease somewhat as a consequence of the reindustrialization – partly due to automotive investments – of certain counties in North Hungary and the Great Plain after 2008 (Barta, Gy. 2002; Kiss, É. 2010; Lux, G. 2017).

The inclination of the automotive industry to form clusters at the local level, the quality factors of selecting site location associated with the spatial concentrations of the sector and relevant upgrading (and Industry 4.0), and the experience that the geographical transformations of the industry reflect the structural changes of those involved form the theoretical basis of the present spatial research at the subnational level.

Database and methods

Industrial employment data necessary for the county level (NUTS 3) analysis were provided by Hungarian Central Statistical Office. The 20 units (the capital city and 19 counties) allow only a general regional analysis, but no more detailed time series data are available. It has to be noted that, although the interpretation of counties as industrial geographical units always raises questions, the use of county data has a well-established practice. Officially, counties are classified into seven regions (NUTS 2 level) in Hungary. But, in this study the regional division of counties follows the historical traditions of Hungarian industry and the location choice of the automotive firms.

Employment data were chosen primarily because they are suitable for structural analyses. Linking the geography of the automotive industry to the issue of upgrading influenced by Industry 4.0 makes it necessary to focus on indices reflecting structural changes. For this the number of non-manual workers and average gross earnings of those working in the sector were used. A higher proportion of non-manual workers suggest the lower significance of labour-intensive physical activities, increasing automation of production and also the significant role of research and development, logistics and other strategic functions beyond direct production (Szalavetz, A. and Somosi, S. 2019). As different activity structures may be behind the data on the employment of manual and non-manual workers, ratios of average gross earnings relative to the national industry and local economic average were also analysed. It was presumed that the differences of the indicator reflect not only the labour market differences of the counties but also the structure of automotive industrial activities. To ground spatial research at the subnational level by investigating the effects of technological innovations on employment data is not without history in Hungary (Tóth, I.J. *et al.* 2016).

At the same time, a number of factors make it difficult to accurately outline the spatial footprint of the automotive industry. One of the factors is that the activities classified in the statistical category of motor vehicle industry do not cover the entire automotive industry because of the wide range of suppliers integrated into its value chains. Approximately there are 480 operating companies and more than 100,000 employees in the motor vehicle industry, but according to another source there is 900 companies and 175,000 employees (MAGE 2020). The latter numbers also include the automotive suppliers registered in other industries. At the same time, the aggregation of employment data at the sector level makes it impossible to systematically filter out suppliers outside the motor vehicle industry, therefore the present analysis was made using the smaller data that could be clearly assigned to the automotive industry. As a result, the present analysis can be applied primarily to the ‘upper regions' of the supplier pyramids dominated by transnational companies. However, focusing on the structural changes, this limitation – due to the uneven distribution of value-added in the supplier pyramid and the producer-driven character of the value chain – can only slightly influence the validity of our findings. A characteristic feature of functional upgrading the development of local suppliers registered in other industries remains partly hidden.

Another problem is the fact that the industrial classification of companies considered along value chains varies in time. Consequently, there may be statistical reasons – in addition to real developments – for the increase and decrease in data. Data register based on the headquarters of companies has a similar effect, which assigns the performance of companies present in some counties to the county designated as headquarters, showing its role as more significant than it is. When analysing employment data, the fact that the employment of temporary workers offered by specialized agencies became widespread in the studied period has to be addressed. The automotive industry employed the greatest number of temporary workers – 16,900 people – in 2018 (Pénzügyminisztérium 2019). In the light of the sector's statistics this not only means that they do not contain a large portion of temporary workers and the real significance of motor vehicle industry is underestimated, but also that in some counties temporary workers can also be the cause of reduced employment (not shrinking in fact) in automotive industry. Since the ratio of temporary workers is higher among manual workers, therefore this phenomenon also affects the indicators of employment structure.

In order to identify dominant spatial trends (concentration vs. expansion, differences in quantity and quality indices), simple spatial inequality indices (concentration index, Hoover index) were also calculated based on employment data. Changes in centres of gravity were also examined. In the analysis, employment data were complemented with other secondary sources. In addition to foreign trade statistics, the spatial data of economic organisations, data of investments supported by so called individual government decision, annual reports from certain companies and press releases on businesses in the industry were utilized. The timeframe for the research (2008–2018) is optimal for comparison not only because of the unchanged statistical framework of the industry, but it also enables the uniform analysis of the economic crisis, the recovery and then the new growth period together.

Description of the spatial processes

The long-term growth of employment in the motor vehicle industry in Hungary has only been temporarily disrupted by the economic crisis. The number of people employed fell by 18 per cent from 2008 to 2009, only to increase again every year afterwards. Pre-crisis conditions were restored roughly in 2013, but taken as a whole there was a 35 per cent increase between 2008 and 2018. Although the county concentration of employment in the period of crisis and recovery was rather strengthened and then slightly weakened, the distribution of the automotive industry between regions is stable. The loss of significance of Central Hungary was offset by an increase in the share of three other regions. However, while in the first half of the period Northern Transdanubia was the winner of a moderate realignment, in recent years the share of Northern Hungary and the Great Plain could grow even at the expense of the former *(Table 1).*

The development trajectory of each county is more colourful. Between 2008 and 2013 half of the counties showed an increase in the employment of automotive industry while between 2013 and 2018 17 of the 20 spatial units. However, in almost a third of the counties – including Komárom-Esztergom and Pest – employment in the sector in 2018 did not come even close to the level of 2008. Apart from the rise of Győr-Moson-Sopron, the increasing number of counties with sig-

Table 1. Number and share of employees in the Hungarian motor vehicle industry, 2008–2018

Regions, counties	2008		2009		2013		2018	
	Number	%	Number	%	Number	%	Number	%
Central Hungary	*11,562*	*15.1*	*9,153*	*14.5*	*8,332*	*11.3*	*9,557*	*9.2*
Budapest	2,468	3.2	2,178	3.5	1,652	2.2	2,709	2.6
Pest	9,094	11.9	6,975	11.1	6,680	9.0	6,848	6.6
Northern Transdanubia	*45,411*	*59.2*	*37,891*	*60.2*	*46,593*	*62.9*	*64,695*	*62.5*
Fejér	11,069	14.4	9,319	14.8	8,307	11.2	10,811	10.4
Győr-Moson-Sopron	14,701	19.2	12,607	20.0	20,028	27.0	25,279	24.4
Komárom-Esztergom	9,764	12.7	7,756	12.3	5,990	8.1	8,245	8.0
Vas	5,364	7.0	4,724	7.5	6,536	8.8	8,974	8.7
Veszprém	4,513	5.9	3,485	5.5	5,732	7.7	11,386	11.0
Southern Transdanubia	*2,711*	*3.5*	*2,132*	*3.4*	*3,350*	*4.5*	*3,748*	*3.6*
Baranya	891	1.2	626	1.0	980	1.3	1,189	1.1
Somogy	202	0.3	242	0.4	304	0.4	239	0.2
Tolna	539	0.7	399	0.6	741	1.0	1,002	1.0
Zala	1,079	1.4	865	1.4	1,325	1.8	1,318	1.3
Northern Hungary	*9,433*	*12.3*	*7,765*	*12.3*	*8,328*	*11.2*	*14,139*	*13.7*
Borsod-Abaúj-Zemplén	3,457	4.5	3,099	4.9	5,768	7.8	9,237	8.9
Heves	5,120	6.7	3,930	6.2	2,338	3.2	4,055	3.9
Nógrád	856	1.1	736	1.2	222	0.3	847	0.8
Great Plain	*7,615*	*9.9*	*5,992*	*9.5*	*7,457*	*10.1*	*11,384*	*11.0*
Bács-Kiskun	2,477	3.2	1,967	3.1	5,358	7.2	9,142	8.8
Békés	1,929	2.5	1,525	2.4	128	0.2	210	0.2
Csongrád	392	0.5	298	0.5	143	0.2	205	0.2
Hajdú-Bihar	218	0.3	191	0.3	210	0.3	286	0.3
Jász-Nagykun-Szolnok	754	1.0	708	1.1	905	1.2	958	0.9
Szabolcs-Szatmár-Bereg	1,845	2.4	1,303	2.1	713	1.0	583	0.6
Hungary total	*76,732*	*100.0*	*62,933*	*100.0*	*74,060*	*100.0*	*103,523*	*100.0*

Source: Central Statistical Office, Budapest, 2019.

nificant employment in automotive industry can be observed. Two of the newly emerging counties are east of the Danube: Bács-Kiskun and Borsod-Abaúj-Zemplén, however, have an increasing ratio of employment in the automotive industry in their region *(Figure 1* and *2)*.

The change in the number of non-manual workers mostly followed the indicators of the total number of employees. The ratio of non-manual workers increased almost continuously and approached the average of the manufacturing industry. The spatial concentration of non-manual workers remained always below the index calculated for the total number of employees, while differences in the distribution of non-manual and manual workers decreased. Most non-manual workers are related to the automotive industry of Győr-Moson-Sopron, Fejér and the rapidly growing Veszprém county. Apart from the latter, only Budapest and some eastern counties showed ratios of non-manual workers characteristically above the national average (*Table 2).*

In counties with the largest expansion of employment in the automotive industry, the ratio of non-manual workers increased only slightly. This suggests that the growth of this sector remains mainly linked to the deployment of production capacities requiring primarily manual workers. Labour hire registered not in the automotive industry may also contribute to the above trends. It also causes, on the one hand a more modest increase of employment in the automotive industry, and on the other hand a higher ratio of non-manual workers. Significant differences among the counties indicate internal structural differences in the sector. Budapest pulled from the rest of the counties from 2017 to 2018, however,

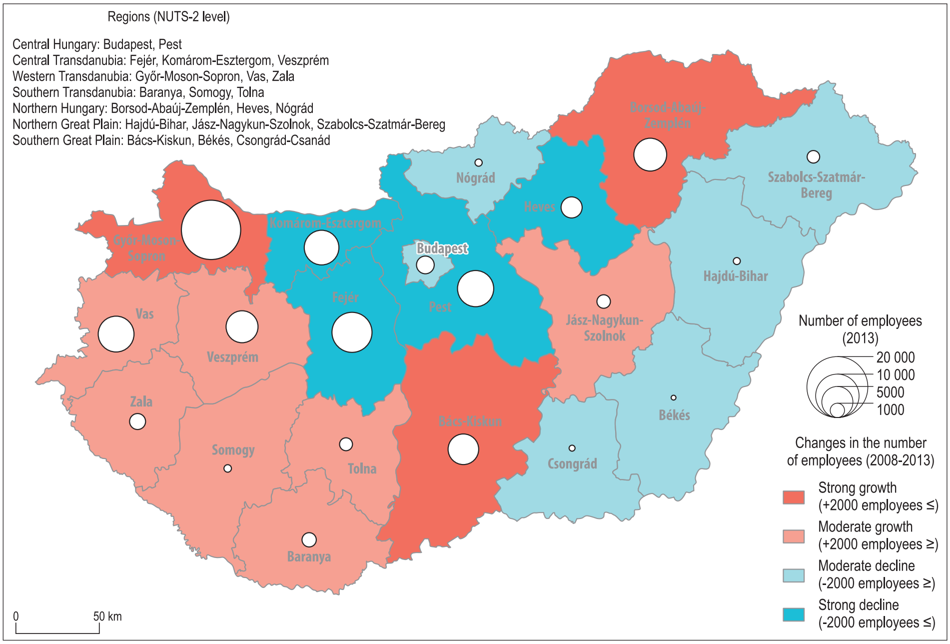

Fig. 1. Dynamics of the Hungarian automotive industry by the number of employees between 2008 and 2013 and its state in 2013. *Source:* Data of Central Statistical Office.

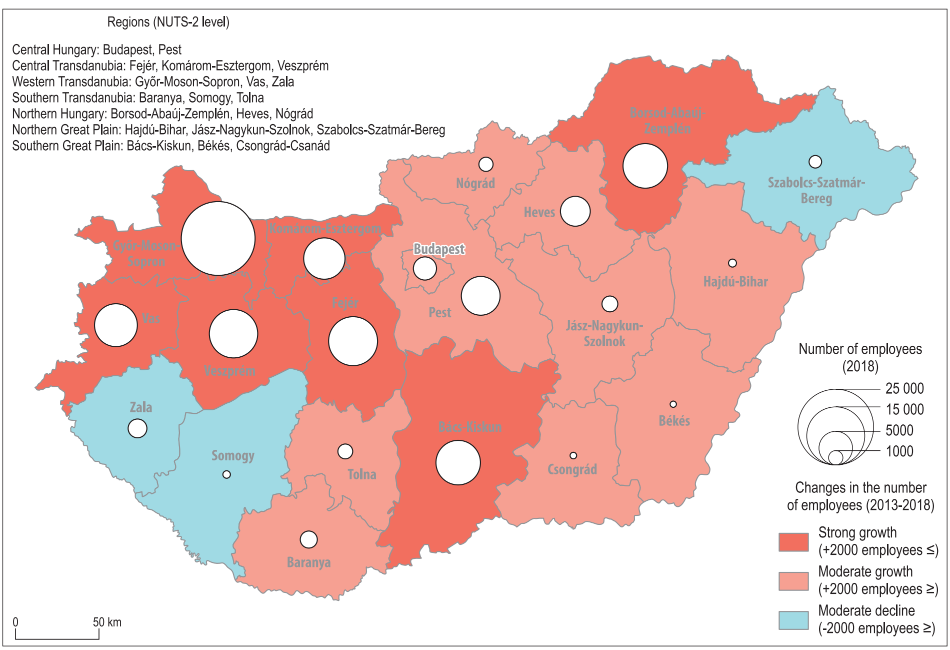

Fig. 2. Dynamics of the Hungarian automotive industry by the number of employees between 2013 and 2018 and its state in 2018. *Source*: Data of Central Statistical Office.

Table 2. Number and share of non-manual employees in the Hungarian motor vehicle industry, 2008–2018

Regions, counties	2008		2009		2013		2018	
	Number	%	Number	%	Number	%	Number	%
Central Hungary	*1,822*	*15.8*	*1,647*	*18.0*	*1,779*	*21.4*	*2,987*	*31.3*
Budapest	509	20.6	498	22.9	464	28.1	1,294	47.8
Pest	1,313	14.4	1,149	16.5	1,315	19.7	1,693	24.7
Northern Transdanubia	*8,176*	*18.0*	*7,713*	*20.4*	*10,804*	*23.2*	*16,433*	*25.4*
Fejér	2,016	18.2	1,843	19.8	2,150	25.9	3,085	28.5
Győr-Moson-Sopron	2,937	20.0	2,723	216	4,236	21.2	5,867	23.2
Komárom-Esztergom	1,323	13.5	1,378	17.8	1,500	25.0	2,379	28.9
Vas	930	17.3	896	19.0	1,323	20.2	1,970	22.0
Veszprém	970	21.5	873	25.1	1,595	27.8	3,132	27.5
Southern Transdanubia	*359*	*13.2*	*316*	*14.8*	*502*	*15.0*	*600*	*16.0*
Baranya	155	17.4	131	20.9	177	18.1	204	17.2
Somogy	35	17.3	34	14.0	49	16.1	24	10.0
Tolna	72	13.4	59	14.8	138	18.6	192	19.2
Zala	97	9.0	92	10.6	138	10.4	180	13.7
Northern Hungary	*2,332*	*24.7*	*2,109*	*27.2*	*2,061*	*24.7*	*3,805*	*26.9*
Borsod-Abaúj-Zemplén	840	24.3	835	26.9	1,276	22.1	2,337	25.3
Heves	1,254	24.5	1,054	26.8	731	31.3	1,314	32.4
Nógrád	238	27.8	220	29.9	54	24.3	154	18.2
Great Plain	*1,516*	*19.9*	*1,352*	*22.6*	*1,860*	*24.9*	*2,831*	*24.9*
Bács-Kiskun	657	26.5	554	28.2	1,413	26.4	2,317	25.3
Békés	433	22.4	390	25.6	42	32.8	66	31.4
Csongrád	49	12.5	38	12.8	37	25.9	53	25.9
Hajdú-Bihar	47	21.6	47	24.6	47	22.4	68	23.8
Jász-Nagykun-Szolnok	169	22.4	171	24.2	196	21.7	223	23.3
Szabolcs-Szatmár-Bereg	161	8.7	152	11.7	125	17.5	104	17.8
Hungary total	*14,205*	*18.5*	*13,137*	*20.9*	*17,006*	*23.0*	*26,656*	*25.7*

Source: Central Statistical Office, Budapest, 2019.

the increase in the rate of non-manual workers was accompanied by a sharp decline in the number of people employed in the sector.

Average gross earnings recorded in the motor vehicle industry showed a significant increase with values above the national average throughout the studied period. The spatial concentration of gross earnings exceeded that of the employees, while the differences in the spatial distribution of employed people and gross earnings decreased. Counties are polarized: solely the front-runner Győr-Moson-Sopron performed always above the industrial average. Regarding the counties with high employment growth, Veszprém was also able to achieve relative average gross earnings growth. Although average gross earnings also depend on the local labour market environment, it is notable that the figures of counties outstanding from the national average of the motor vehicle industry – with the exception of Budapest – also showed the highest difference compared to local average earnings *(Table 3).*

As a summary, it can be concluded that, between 2008 and 2018, on the one hand, the number of counties standing out in relation to at least one of the analysed indicators (share of non-manual workers, average gross earnings) was reduced, and, on the other hand, showed greater overlap with the major locations of the sector *(Figure 3* and *4).*

Not only the industry as a whole, but also its qualitative indicators show increasing spatial concentrations only during the period of crisis and recovery, while differences in the distribution of qualitative and quantitative indicators decrease. As a consequence there is a geographical convergence regarding the (quantity and) quality factors *(Figure 5* and *6).*

Table 3. Average gross earnings of employees in the Hungarian motor vehicle industry in percentage of the sector's average and the average of the given area's economy, 2008–2018

Regions, counties	2008		2009		2013		2018	
	NAS%	GAE%	NAS %	GAE%	NAS%	GAE%	NAS%	GAE%
Central Hungary	*92*	*82*	*91*	*83*	*85*	*89*	*95*	*100*
Budapest	103	85	105	89	75	75	108	107
Pest	89	108	88	108	87	119	90	123
Northern Transdanubia	*106*	*128*	*107*	*132*	*108*	*144*	*107*	*137*
Fejér	84	98	83	102	85	112	88	112
Győr-Moson-Sopron	126	145	132	156	126	156	123	148
Komárom-Esztergom	109	126	105	123	98	125	97	123
Vas	112	146	104	140	102	146	100	135
Veszprém	85	112	94	128	101	150	102	141
Southern Transdanubia	*58*	*75*	*56*	*76*	*58*	*90*	*62*	*93*
Baranya	74	91	71	93	65	100	66	101
Somogy	60	82	60	86	60	95	64	96
Tolna	59	74	58	74	63	88	62	84
Zala	44	61	43	61	51	82	58	92
Northern Hungary	*106*	*136*	*101*	*135*	*91*	*142*	*88*	*132*
Borsod-Abaúj-Zemplén	84	109	83	113	85	138	84	132
Heves	124	149	118	146	109	149	100	135
Nógrád	84	116	79	115	60	103	62	100
Great Plain	*83*	*112*	*84*	*119*	*93*	*151*	*93*	*144*
Bács-Kiskun	112	154	113	161	99	156	97	142
Békés	77	108	78	114	85	148	70	118
Csongrád	56	73	55	73	72	110	74	107
Hajdú-Bihar	62	81	63	84	65	101	66	100
Jász-Nagykun-Szolnok	96	134	95	140	82	133	86	131
Szabolcs-Szatmár-Bereg	51	71	55	81	76	132	61	108
Hungary total	*100*	*107*	*100*	*110*	*100*	*126*	*100*	*124*

Notes: NAS% = in percentage of the sector's (motor vehicle industry) average. GAE% = in percentage of the average of the given area's (county, region) economy. *Source*: Central Statistical Office, Budapest, 2019.

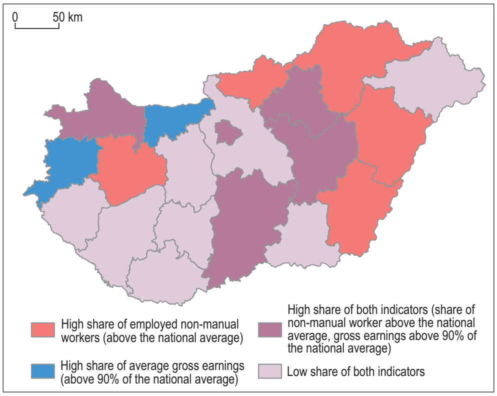

Fig. 3. Types of counties by share of non-manual workers and average gross earnings in the Hungarian motor vehicle industry, 2008. *Source*: Data of Central Statistical Office.

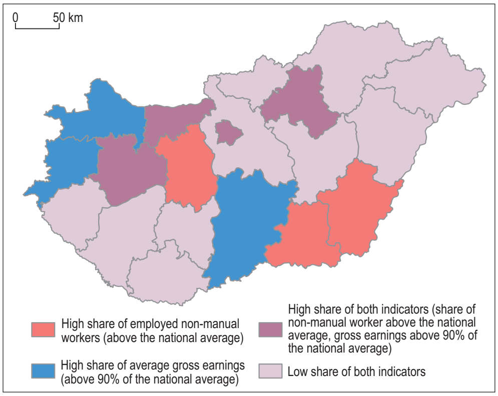

Fig. 4. Types of counties by share of non-manual workers and average gross earnings in the Hungarian motor vehicle industry, 2018. *Source*: Data of Central Statistical Office.

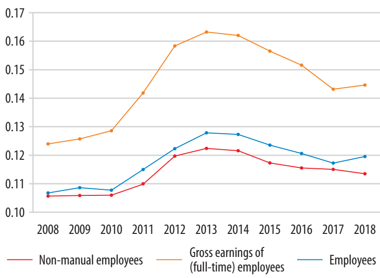

Fig. 5. Concentration indices of the analysed indicators. *Source*: Data of Central Statistical Office.

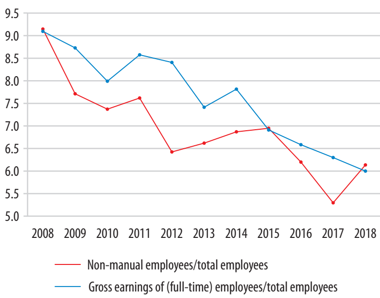

Fig. 6. Hoover indices of the qualitative indicators and the total number of employees. *Source*: Data of Central Statistical Office.

According to our calculations the location of the centres of gravity of the studied indicators is in the central part of Transdanubia. The indicators also show a typically westward shift between 2008 and 2018. The centres of gravity of non-manual employment can be found further east, while those of the gross earnings are further north-west compared to the number of people employed *(Figure 7)*.

The results declined that – despite the strengthening of some eastern "bridgeheads" – a significant eastern shift in the Hungarian automotive industry would have taken place. The impact of Budapest and some better-performing eastern counties on non-manual employment as well as the effect of Northern Transdanubia showing higher average values in the spatiality of earnings are also accentuated. The position of the centres of gravity also reflects the recurrence of the traditional North–South differences of Hungarian industry.

Explanation of the spatial processes

The geography of the Hungarian motor vehicle industry reflects the location decision of foreign companies and – to a much lesser extent – the spatiality of the emerging domestic automotive industrial suppliers. 97 per cent of the turnover in the sector can be related to foreign-controlled companies, and this is well above the national average of 53 per cent and one of the highest in the manufacturing industry (KSH, 2016). The expansion of the employment in the automotive industry indicates that Hungary remains an investment destination, and the negative expectations associated with the spread of Industry 4.0 innovations do not appear to be confirmed during the studied period. Automation has not caused a decrease: even if some of the workforce was liberated due to technological reasons, it is mostly redeployed within the firms in "headcount neutral transformation", because capacity expansion is still common. The progress of automation is delayed partly, because foreign workers are employed in order to ease labour shortage (Székely, S. 2019).

The vast majority of the sector's employment growth is attributable to some prominent companies in five counties. These are mostly foreign-owned subsidiaries established before 2008, whose multi-stage investments play a decisive role in the stability of the space structure of the Hungarian automotive industry *(Table 4)*.

However, the success of these subsidiaries in the competition for new investments can only be partly explained by technologically-based improvements in cost-capability ratios even in ideal cases. Government support may have also contributed to their success. The most spectacular example of new developments on old sites is the functional upgrading of Audi's factory, where the car assembly plant was transformed into a full car production plant (including stamping plant, car body factory and paint shop) – with the relocation of activities from Germany – employing thousands of people. The growth of a company however was not always linked only to loca-

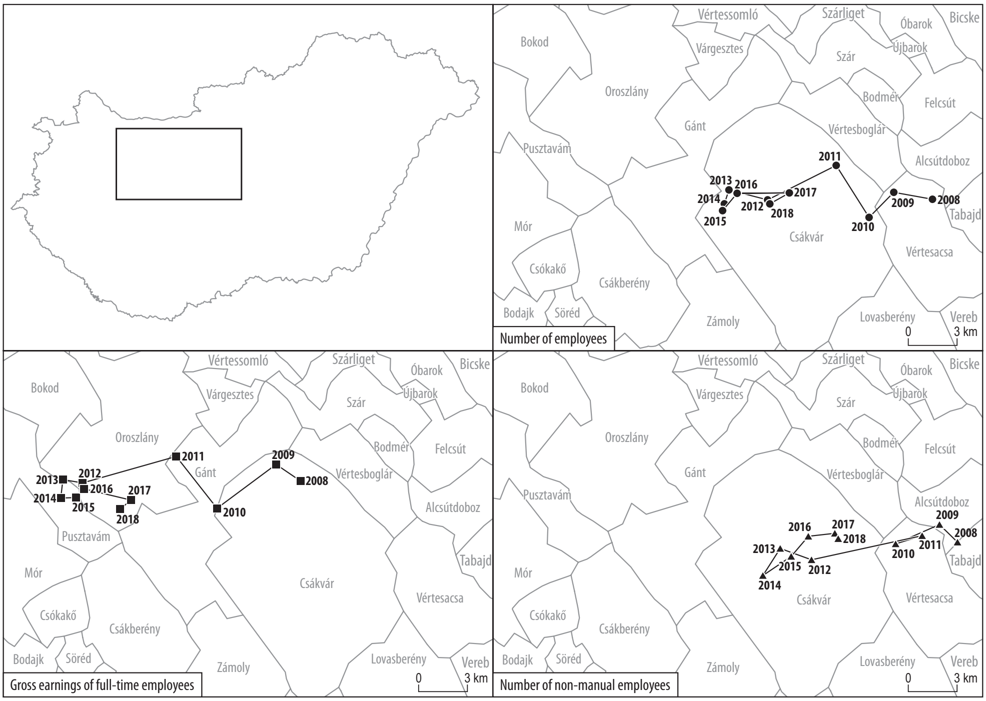

Fig. 7. Changes in the centres of gravity regarding the studied indicators of the Hungarian motor vehicle industry. *Source*: Data of Central Statistical Office.

tions within the priority counties. For example, hundreds of employees were employed at the newly established and purchased sites (in the Great Plain) of SMR Automotive Mirror Technology headquartered in Győr-Moson-Sopron county and nearly 1,500 employees were employed at the Budapest unit of the Continental subsidiary located in Veszprém county in 2018. In fact, data suggesting spatial concentrations mask geographical expansion in the case of Northern Transdanubian companies operating in other regions too.

In the strengthening of the eastern bridgeheads of the automotive industry the process of expansion concentrated in space, with both quantitative and qualitative elements is realised. The location selection of the companies in the east is justified by the fact that new investments with employment growth are increasingly constrained in Northern Transdanubia due to the scarcity of human resources and, on the other hand, the development of transport and other infrastructure the number of potential locations for investments increase (Molnár, E. 2013). In Borsod-Abaúj-Zemplén and Bács-Kiskun counties, however, the concentrated presence of automotive companies in the county seats (Miskolc and Kecskemét) is not unprecedented. Their accelerating embedding process, one of the most important fields of which (due to upgrading as well) is education supplying the human resources (Józsa, V. 2019), could hardly be met without the infrastructure and industrial traditions of their cities. For this reason, it is particularly true that for Bács-Kiskun county that its automotive industry is highly concentrated in its county seat. The fact that Daimler chose Kecskemét is not ground-breaking, considering that the city already had significant foreign capital (including the German automotive industry) at the turn of the millenni-

Table 4. Major companies in the Hungarian automotive industry by the number of employees and county, 2008–2018

Name of companies by counties	Year of foundation	Number of employees (ca.)		Change in employees in % of the county	Year of largest employment
		2008	2018*		
Győr-Moson-Sopron county	–	*14,701*	*25,279*	*100*	–
Audi Hungaria Motor Ltd. / Audi Hungaria Co.	1993	5,939	12,726	64	2018
SMR Automotive Mirror Technology Hungary Lp.	1993	788	2,549	17	2018
AUTOLIV Ltd.	1990	942	2,198	12	2016
BOS Automotive Products Magyarország Lp.	1992	681	1,128	4	2018
Rába Futómű Ltd.	1999	1,415	666	–7	2008
Rába Járműalkatrész Ltd.	2001	987	598	–4	2008
Vas county	–	*5, 64*	*8,974*	*100*	–
Schaeffler Savaria Ltd.	1996	1 220	3 485	63	2018
BPW Hungária Ltd.	1991	1 259	1 518	7	2018
GM Powertrain Ltd. / Opel Szentgotthárd Ltd.	1990	659	1 007	10	2017
Veszprém county	–	*4,513*	*11,386*	*100*	–
Continental Automotive Hungary Ltd.	1990	1,127	3,770	38	2018
Johnson Controls / Yanfeng Hungary Ltd.	2014	–**	2,345	34	2018
Valeo Auto-Electric Magyarország Ltd.	1998	737	1,936	17	2018
Johnson Controls / Adient Mezőlak Ltd.	2002	265	874	9	2018
Poppe + Potthoff Hungária Ltd.	1996	237	551	5	2018
Borsod-Abaúj-Zemplén county	–	*3,457*	*9,237*	*100*	–
Robert Bosch Energy and Body Systems Ltd.	2003	960	2,306	23	2015
S.E.G.A. Hungary Ltd.	2016	0	1,601	28	2017
Joyson Safety Systems Hungary Ltd.	2013	0	1,799	31	2018
Bács-Kiskun county	–	*2,477*	*9,142*	*100*	–
Mercedes Benz Manufacturing Hungary Ltd.	2008	0	4,281	64	2018
Knorr-Bremse Fékrendszerek Ltd.	1989	890	1,011	2	2018
Bosal / ACPS Automotive Ltd.	2003	154	935	12	2018
Magna / Antolin Hungary Ltd.	2010	0	604	9	2018

*Motor vehicle companies with at least 500 employees in 2018. **The factory of Johnson Controls at Pápa existed in 2008 as a unit of the company's subsidiary, thus its data is not involved in the data of Veszprém county. *Source*: County TOP 100 publications, ceginfo.hu, Ministry of Justice database of electronic reports.

um (Marsa, A. 2002). This was induced by a number of factors, such as its central location close to the agglomeration of Budapest, its transport capabilities and, consequently, the proximity of European and local suppliers, as well as its educational culture and technical higher education (Vápár, J. 2013; Szemereyné Pataki, K. 2014).

The benefits of geographical proximity and the exploitation of industrial agglomeration indicate concentrated growth in space. Suppliers located near car factories played a significant role in the development of several industrial parks in Northern Transdanubia in the 2000s (Molnár, E. 2013). A similar phenomenon can be observed with Mercedes in Bács-Kiskun county, where the German car maker was followed by several companies (e.g. Brose, Magna/Antolin). The main driving force of the process is to reduce logistical costs and make deliveries flexible and safer. Geographical proximity is especially important for large, components difficult to transport and also for just-in-time components. A good example is the factory "Kirchhoff" established close to the Suzuki's automobile factory in Esztergom, for which it manufactures car body parts. Like this is experienced at companies (e.g. Lear in Győr, Magyar Toyo Seat in Nyergesújfalu and Adient in Kecskemét) producing seat modules near car factories.

Geographical proximity can also cover relationships that go far beyond local dimensions. The experiences of a survey carried out by PriceWaterhouse Coopers (2018) on the final users of suppliers' products also proved this. According to their study the final users of the surveyed Hungarian suppliers' products are Volkswagen in 61 per cent, Audi in 56 per cent, Daimler in 51 per cent, BMW in 49 per cent, Renault in 42 per cent, Ford in 40 per cent, PSA in 37 per cent and Suzuki in 37 per cent. Merely

19 per cent of companies sell only in Hungary, and only 7 per cent of those surveyed delivered within 50 kilometres and just over 15 per cent within 200 km (PriceWaterhouse Coopers, 2018). The positive impact of the automotive agglomeration in East-Central Europe on the growth of the Hungarian automotive industry is demonstrated, in addition to the above results, by that of Slovakia, directly adjacent to the counties of Northern Transdanubia, became the second largest market for engines and vehicle parts manufactured in Hungary, but Czechia, Poland and Austria are also ranked high *(Table 5).*

Counties with good quality indicators are the plants of car manufacturers near the peak of the supplier pyramids and also those of Tier 1 suppliers engaged in more complex activities. In counties that performed well almost continuously (Bács-Kiskun, Heves and Veszprém) the influence of one or two prominent Tier 1 suppliers with significant local value added can be recognised. These international companies were among the first to arrive to Hungary and largely built on local industrial traditions (Knorr-Bremse settled in Kecskemét utilised the heritage of the Tool Works, ZF from Eger based its activities on the transmission plant of the Csepel automobile factory, but former Bakony Works also had a history motor vehicle parts production in Veszprém). Significant functions apart from production can also be observed in these companies: e.g. R&D (at Continental and Valeo in Veszprém, at Knorr-Bremse in Kecskemét, at ZF in Eger) or IT services (at ZF in Eger), often involving departments in Budapest too. In addition to their increasing non-manual worker employment rate, which is significantly above the average of the automotive industry, their relevant local supplier background should also be highlighted (Marsa, A. 2002; Sass, M. and Szanyi, M. 2004; Józsa, V. 2019). Not primarily the car assembly plants, but these companies producing greater local value added seem to be the real success stories of the FDI-based Hungarian automotive industry.

The ratio of non-manual workers in the automotive industry does not fully reflect the importance of non-production functions, as these activities may not be recorded for the motor vehicle industry. The best example for this is the R&D in the automotive industry because many of companies (e.g. development bases of TNCs, Hungarian engineering offices, higher education – research institutions) taking part in it belong to the "official" motor vehicle industry only in a small ratio. The R&D experts of the sector exist in greater numbers in the regions of Budapest and Győr. (The latter is the largest location of the Hungarian motor vehicle industry.) Several prominent automotive companies registered in the field of engineering activities, technical consulting, technical testing and analysis,

Table 5. TOP 10 market of the export of Hungarian motor vehicle industry, 2008–2018

Country	Export,* million EUR		Change 2008–2018, million EUR	Share of all export of motor vehicle industry in 2018, %
	2008	2018		
Germany	3,853	5,257	1,404	44.7
Slovakia	431	1,348	917	11.5
Czechia	528	674	145	5.7
Spain	432	581	149	4.9
United Kingdom	240	479	240	4.1
Poland	275	363	89	3.1
Sweden	49	359	311	3.1
Austria	217	351	133	3.0
Mexico	94	340	246	2.9
France	134	254	120	2.2

*Internal combustion engines and their parts, and motor vehicle parts (current prices).
Source: International Trade Centre.

and research and development (e.g. Robert Bosch and Thyssenkrupp Components Technology or Trigo Quality Support and EDAG) operate there. Robert Bosch, the largest unit of automotive R&D in Hungary, originally established as a sales and logistic centre, increased the number of its employees from nearly 600 to 3,000 between 2008 and 2018, and is now typically engaged in product and software development. Based on this, not only the role of Budapest in research and development will be enhanced, but the functions of Győr-Moson-Sopron beyond production will also be more visible.

Finally, supports granted on the basis of individual government decisions as part of the investment promotion policy also influence the spatiality of the industry. On the basis of data from ninety automotive investments registered not only in the motor vehicle industry in the narrow sense after 2008, it can be seen that, during the years of crisis and recovery, reduced investment has been concentrated in the old key areas of this sector *(Table 6).*

On the other hand, in contrast to the stability of the regional distribution of the sector between 2008 and 2018 – with the realisation of ongoing investments – an eastward shift is likely in the future. The largest growth in the Great Plain can be expected in Hajdú-Bihar county, which has been virtually absent from the map of the automotive industry, where, in addition to the BMW car assembly plant which is under construction and the attempt to establish local bus production, the concentrated occurrence and capacity expansion of several suppliers (Continental, Schaeffler, ThyssenKrupp) also play an important role in turning Debrecen into a centre of the Hungarian motor vehicle industry (Molnár, E. and Kozma, G. 2018).

Conclusions

The present study analysed the change in the geography of the significantly growing Hungarian automotive industry in the decade since the latest economic crisis in 2008. The overall increase in employment indicates that Hungary is still the target of capacity expansion. The spatially concentrated growth

Table 6. Financial supports and expected new workplaces in the Hungarian automotive industry by individual government decisions since 2008

Regions, counties	Share of all supports, %		Share of all expected new workplaces, %	
	2009–2013	2014–2018	2009–2013	2014–2018
Central Hungary	*13*	*2*	*27*	*3*
Budapest	7	1	13	0
Pest	6	1	14	3
Northern Transdanubia	*87*	*35*	*68*	*37*
Győr-Moson-Sopron	45	12	31	11
Vas	16	0	12	0
Komárom-Esztergom	6	12	7	12
Fejér	20	3	17	3
Veszprém	0	8	0	10
Northern Hungary	*0*	*28*	*0*	*27*
Borsod-Abaúj-Zemplén	0	8	0	11
Heves	0	18	0	14
Great Plain	*1*	*35*	*5*	*33*
Bács-Kiskun	1	12	5	8
Hajdú-Bihar	0	10	0	7
Jász-Nagykun-Szolnok	0	8	0	9
Hungary total, %	*100*	*100*	*100*	*100*
Hungary total in numbers	*141,664**	*621,766**	*6,997*	*20,327*

* In thousand EUR at price in 2018. *Source*: Ministry of Foreign Affairs.

expected from the upgrading in the international production networks and the increase in the quality of industrial concentrations have been only partially achieved. The result of processes towards both concentration and expansion is characterised, on the one hand, by the massive growth of certain counties in Northern Transdanubia and, on the other hand, by the expansion of the industry concentrated in one or two new counties. This results in stability in the distribution of the automotive industry between regions. In terms of quality indicators, there is typically a difference between significant and less important locations and (above all) in terms of Budapest – outside Budapest. The present analysis indicates a moderate upgrading mostly without strategic functions, defined by foreign subsidiaries, and an industry that is gradually and selectively adapting the innovations of the "Fourth Industrial Revolution". Like other studies (Gerőcs, T. and Pinkasz, A. 2019; Szalavetz, A. and Somosi, S. 2019; McKinsey & Company 2020), the present analysis obtained no proof of a spectacular shift in the productive role of Hungary and in the grounds of its growth in automotive industrial networks. However, the example of the capital city points out that – in the case of appropriate local conditions – there is still some room for the implementation of functional upgrading, despite the dependent situation.

However, based on the last year data a trend change is emerging. After the maximum reached in the first quarter of 2019 – for the first time in three consecutive quarters since the crisis – the number of people employed in the sector began to decrease, in almost all counties. In the background of the events general global economic developments and specific problems related to the competitiveness of the German automotive industry can be found (Haider, M. 2020). The large investment deferred in the second half of the year (Mercedes 2nd phase in Kecskemét) also suggests this. Although the relocation of certain labour-intensive activities was observed during the 2008 crisis, structural constraints are now more pronounced in addition to economic fluctuations. Efficiency increase of production based on innovations of Industry 4.0 and the disruptive effects of electromobility (reduced number of employees in the Hungarian economy specialized partly on the production of internal combustion engines due to the spread of electric motors with less complexity) are mostly cited as explanations (Fabók, B. and Stubnya, B. 2019). To these conjunctural and structural problems the negative effects of the coronavirus pandemic can also be added in 2020. The decreasing demand for cars, the disintegration of supply chains and the protection of employees can lead globally to the radical decrease of production (Rózsa, T. 2020). Its mid- and long-term consequences still cannot be foreseen. But significant changes are expected in the new decade which presumably also brings a new era in the history and geography of the Hungarian motor vehicle industry.

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Industry 4.0 in a dualistic manufacturing sector – qualitative experiences from enterprises and their environment, Eastern Hungary

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Abstract

Industry 4.0 developing on the basis of digitalisation is gradually transforming production, the conditions of competition and relationships in global industry, affecting its interpretation and expanding its limits. This paper attempts to explore changing economic geographical context with the revaluation of comparative and competitive advantages in a semi-peripheral area of the EU. Based on company interviews, the effects of the new technologies of Industry 4.0 on the dual Hungarian manufacturing industry and its spatial structure are studied, and that whether they contribute to the reduction of duality and geographical polarization. In Eastern Hungary – just like in most areas in East-Central Europe – internationally competitive manufacturing companies emerged almost exclusively as a result of foreign direct investment, while domestic companies are forced into secondary or dependent roles. The empirical research has revealed significant differences in the progress of companies in Industry 4.0. Hungarian-owned companies evolve in a specific way from several aspects and face many difficulties. In contrast, enterprises with foreign interest continue to be the engine of development, driven from the "outside". Duality is also reflected in the corporate structure, in space and in the realisation of Industry 4.0.

Keywords: Industry 4.0, manufacturing, dualistic economy, enterprises, economic geography, semi-periphery, Hungary.

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Introduction

Nowadays the development of industry can be characterized by digitalisation and growing interconnectivity, often referred to as Industry 4.0 (fourth industrial revolution), a name originated from Germany. Changes affecting both the production process and the nature of the products produced have an impact on the structure of value chains and on the applied business models as well. The comparative and competitive advantages of companies and their regions are being revalued, which may lead to the transformation of the spatial organisation and international production networks of the global economy.

The present study focuses on an East-Central European, semi-peripheral region of the global economy. In an intermediate, dependent area, the income of core-like activities is sufficient to block the forces driving towards peripheralisation, while its low-income (peripheral) activities make it impossible for them to become part of the core (Arrighi, G. 2014). Based on the results of qualitative field research (interviewing) we try to identify some economic geographic relations of the fourth industrial revolution. To this end, the technological preparedness, development and business strategy, resources, knowledge and relationships of the selected companies with the global and local environment were studied. Factors are to be explored that may influence the future prospects and the transformation of the spatial structure of the industry of Eastern Hungary. Considering the dual character of

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the region's economy, the main focus of our analysis will be a comparison between large foreign-owned companies and the Hungarian small and medium-sized enterprises (SME) which have a limited competitiveness.

The study focuses on the manufacturing industry that is expected to have the most pronounced transformation (Porter, M.E. and Heppelmann, J.E. 2014). From an economic geographical point of view, this sector is also made interesting by its large transnational and multinational companies organised globally and operating spatially fragmented production systems. Manufacturing industry accounts for 80 per cent of the EU's innovation output and 75 per cent of its exports, while its role in the economy of East-Central Europe is much higher than the EU average (Stehrer, R. and Stöllinger, R. 2015; Lux, G. 2017; Nagy, J. 2017).

In the first part of the study – based on foreign and Hungarian literature – the concept of Industry 4.0 and its potential economic geographical context are analysed, the former Hungarian experiences are discussed and the major specifics of the industry of the studied Eastern Hungarian region are presented. This is followed by a brief description of the research method and by the introduction of the ten enterprises selected. In the third part empirical results are demonstrated from different aspects compared with the conclusions of other researches. The final chapter draws general conclusions and raises further research problems.

Theoretical background

Industry 4.0 in connection with global economic geography

The common basis of technologies associated with Industry 4.0 is the development of IT tools with decreasing price and increasing performance, and that of networking and software competences. Similar meanings are associated with the terms of advanced manufacturing, smart manufacturing and Industrial Internet of Things (IIoT). Cyber-physical production systems (CPPS) are regarded to be the core elements. For the realisation of CPPS, the devices of our physical world have to be visualized in the virtual world using various technologies (e.g., sensors, radio frequency identification – RIFD, real-time locating system – RTLS). People can be involved in the system through different interfaces, such as a tablet, smartphone or augmented reality (AR). The most important, however, is the large amount of data (Big Data) that is constantly generated in the resulting digital ecosystem that can be handled by cloud computing. With the processing of the above data instant, automatic feedback and real-time decision-making are possible, increasing efficiency and flexibility (Brettel, M. *et al.* 2014; Monostori, L. *et al.* 2016; Strange, R. and Zucchella, A. 2017; Tortorella, G.L. and Fettermann, D. *et al.* 2018).

The new technologies are best completed with flexible, easy-to-change production tools such as (3rd generation, autonomous and collaborative) robots and additive (3D) production technologies. The latter is still limited in the manufacture of components with complex geometry, spare parts, prototypes and tools. Modular, networked reconfigurable manufacturing systems (RMS) allow for a degree of flexibility that can make mass customization profitable. In optimising processes, there are also new perspectives in contrast to traditional production systems, as new pathways can be formed at any time, not to mention the possibilities of artificial intelligence (AI) and machine learning. The decision-making process is decentralised and automated, and the product itself can control its production through autonomous devices and machine-level communication. The role of simulations in process design and product development is significant. Collecting and analysing data can help the planning and automation of procurement, and great progress in maintenance. Individualized traced data represent a major step forward in process development and quality assurance, which can extend to the entire supply chain (Brettel, M. *et al.* 2014;

Porter, M.E. and Heppelmann, J.E. 2014; RüßMann, M. *et al.* 2015; Strange, R. and Zucchella, A. 2017; Tjahjano, B. *et al.* 2017).

Digitalisation and Industry 4.0 transform not only production, but also the whole process of value creation, including development, logistics, marketing (e.g. customer involvement) and all (internal and external) relationships. Frequent quasi-continuous development on the basis of flexibility, parallel development of the product and manufacturing process, processing of information collected by smart products and the after-sales opportunities they offer also indicate changes. Integration of the entire value chain enables product lifecycle management (PLM) and could provide basis for circular economy (Brettel, M. *et al.* 2014; Porter, M.E. and Heppelmann, J.E. 2014; Nagy, J. 2017; Rouhamaa, H. *et al.* 2018).

Based on the above, it is clear that Industry 4.0 has certain prerequisites: high degree of automation, network connectivity of devices and their installation with sensors, manufacturing execution system (MES) aimed at the interconnection of processes, collection of real-time information, and control at lower levels, and its connection to IT capacities for the full integration of enterprise processes (e.g., enterprise resource planning – ERP), which enables fast and remote response from management. The new paradigm raises the claim for new standards, whilst interoperability and cybersecurity is essential for networking. The process and directions of standardization is an important element of creating the new balance of power in global industry (at the level of countries and companies), which is clearly going to be dominated by strong actors. New technologies, business models, flows and coordination of value networks, continuous change also require the resolution of a wide range of regulatory and ethical issues (Kagermann, H. *et al*. 2016; Strange, R. and Zucchella, A. 2017; Nagy, J. 2017; Czél, B. 2019).

The development of info-communication technologies enables the increasing coordination of dispersed production, optimisation of the entire value-creating network, foresight and avoidance of disruption for those who influence value chains (Alcácer, J. *et al.* 2016; Rouhamaa, H. *et al.* 2018). Further relative increase of the value of enterprise centres is suggested by fixed costs increasing due to the high investment demand of Industry 4.0 and innovativeness and also by variable costs (by units) decreasing due to efficiency (Porter, M.E. and Heppelmann, J.E. 2014). As a result, the value of production is decreasing even further (Szalavetz, A. 2016). The trend of recent decades has been to deploy production from more developed to less developed countries on a cost basis (60% of world trade is intermediate goods) (Kiss, E. 2007). If automation becomes cheaper, productivity increases, the proportion of logistics costs (including time) varies and protectionism is strengthened, then the location of production activities close to the consumer can become more attractive, and reshoring will be raised (Strange, R. and Zucchella, A. 2017; Laseur, L. 2019).

Closer co-operation with suppliers, the establishment of an ecosystem will be necessary, which will also put innovation pressure on participating companies. Automation of logistics, facilitating identification, using a blockchain mechanism in administration simplifies the flow of products and information in this chain (Nagy, J. 2017). The development of the technologies required for Industry 4.0, the creation of new tools – while ensuring a competitive advantage in the future – can in itself be a remarkable source of revenue, with expected value generation of the background industries providing the new processes amounting to 420 billion euros in 2020 (Monostori, L. *et al.* 2016). (However, this amount will be probably less because of the COVID-19 pandemic.)

As Industry 4.0 is best developed when more and widespread professions and industries work together, several authors emphasize the importance of the ecosystem approach, the framework of which is gradually established on both national and regional levels (Strange, R. and Zucchella, A. 2017; Götz, M. and Jankowska, B. 2017; Nick, G. 2018). Digitalisation, which bridges distances and the growing importance of local relations, and the apparent contradiction between agglomeration trends – in addition to the decreasingly obvious benefits in transaction costs – are explained partly by the demand for face-to-face interaction at competence-creating and the function of the network node and knowledge base of metropolitan spaces (Alcácer, J. *et al.* 2016). The role of traditional (hard) location choice factors is steadily diminishing and the focus on previous (even suboptimal) location decisions is increasing as the centres of large companies become more embedded. Clusters have similar historical benefits, and as a knowledge environment they can play an essential role in new processes. Local and regional co-operations make easier the flow and spread of knowledge, promotes the development of trust between those involved. The involvement of external resources for each company increases the capacity of innovation, moreover, the expected positive effects are also amplified by proximity (Götz, M. and Jankowska, B. 2017). In particular, for SMEs, a collaborative network is important (Brettel, M. *et al.* 2014). Higher productivity and exports can also be detected in cluster members. Universities can play a central role in innovation co-operation (Rouhamaa, H. *et al*. 2018).

Technological progress is significantly transforming workforce expectations: the role of digital competences, problem solving abilities, creativity or complex thinking is strengthened. It is common for firms to identify the lack of adequately trained workers as one of the main obstacles to exploiting the potential of new processes, particularly in less developed countries. At the same time, some Industry 4.0 solutions are designed to support low-skilled workers (e.g. visualised instructions), therefore expectations may be lowered in certain areas. The role of traditional qualifications is certainly reduced (for welding just like mounting orders are given via a digital interface) while learning and flexibility are increasingly valued (Autor, D.H. 2015; Nagy, J. 2017; Müller, J.M. *et al.* 2018; Tortorella, G.L. and Fettermann, D. 2018).

New technologies are a risky and expensive investment in the hope of cost reduction and growth, therefore it is important that company leaders realistically see the capabilities of the company (Nagy, J. 2017). The high costs of implementation, the increasingly complex planning and development processes represent increased difficulties for both smaller businesses and companies in periphery areas, and creating the possibilities of financing is critical for SMEs and, particularly for start-ups (Porter, M.E. and Heppelmann, J.E. 2014; Tortorella, G.L. and Fettermann, D. 2018). For small and medium-sized enterprises the lack of corporate governance competence, strategic thinking and low productivity are restraining forces (Kovács, Sz. *et al.* 2017; Müller, J.M. *et al.* 2018). The increasing flow of information between those involved in value chains, international co-operation and supplier contacts create opportunities for a more efficient spill-over of knowledge, technology and know-how, if there is a willingness to receive it. Compared to explicit knowledge, the spread of tacit knowledge is more difficult, and individuals have a key role in the process. However, the positive effects of this phenomenon have not been clearly demonstrated so far, especially when viewed in an aggregated way rather than at the level of individual companies, taking into account those who lost competition (Szanyi, M. 2010; Liu, C.L. and Zhang, Y. 2014).

The situation in Hungary

Sporadic experience so far shows that Industry 4.0 innovations are on the rise in Hungary, but in the light of the indices (e.g. DESI, 2019) used for international comparison, the country generally performs modestly (Nagy, J. 2017; Nick, G. 2018; Nagy, Cs. and Molnár, E. 2019).

The innovations that have been introduced gradually in the companies are designed to address operational challenges (quality, on-time production, flexibility, management of complex manufacturing, labour shortages, increasing productivity), and the openness and initiative of local management are also important for the subsidiaries of foreign companies. The role of innovations supporting upgrading can also be demonstrated: certain innovations (modelling, simulation, unified enterprise software) allow for the deployment of out-of-production functions, sharing certain tasks with the centre, specialisation for sub-tasks, becoming a competence centre in certain areas relevant to digitalisation. This is proved by the growth of non-manual employment as well. Comparing the situation of subsidiaries and their parent companies, it can be concluded that in the case of the former, development is aimed primarily to improve the efficiency of the manufacturing process (and functional upgrading by integrating more knowledge-intensive activities) while in the case of the latter, innovations related to products or strategic activities (e.g. value chain co-ordination, research and development) dominate (Szalavetz, A. and Somosi, S. 2019).

The employment-reducing effect of technological investments and production returning from Hungary to the parent country are not yet seen. At the same time, more modern capacities elsewhere can be a challenge for the Hungarian economy in the future. However, the gap between parent companies and subsidiaries in terms of value creation is not reduced, there is only a limited increase in local value added (Losonci, D. *et al.* 2019; Szalavetz, A. 2019). The failure to achieve a paradigm shift in the catch-up model so far appears to support suggestions about the effects of the fourth industrial revolution cementing the established core-periphery structures (Lengyel, I. *et al.* 2016).

The spatial effects of Industry 4.0 at subnational level appear little in the focus of analyses. The dual structure of the industry appears to significantly differentiate with Industry 4.0 solutions spreading faster in the motor vehicle and mechanical engineering industry, in foreign-owned companies, in (large) corporations and in those involved in international co-operation, the unequal spatial distribution of which influence also the geography of the acceptance of innovations in Hungary (Nick, G. *et al.* 2019). Industry 4.0 meanwhile increases the role of locally available competent suppliers in the location selection (Szalavetz, A. and Somosi, S. 2019). From the point of view of spill-over effects, it is promising that Nick, G. (2018) encountered data sharing to their value chain partners in 92 per cent of industry companies in Hungary involved in Industry 4.0.

The role of small and medium-sized enterprises in employment and competitiveness in the post-Fordist economy is significant, their development and Industry 4.0 maturity became an important competitive advantage. In Industry 4.0– at least until much closer co-operation among those involved becomes evident – the larger representatives of the category can have a role, since they can have the resources and organisational background for optimisation feasible due to interconnectivity and have the conditions to supply. The manufacturing industry is over-represented among medium-sized enterprises, however, this sector is still weak in international comparison, even though such companies could have a major role – due to their scattered location – in the development of the gradually emptying rural regions, small and medium-sized towns from economic point of view. The key-obstacles to their competitiveness are: low level of trust, low networking, rare positive examples, inadequacy of the legal system, lack of internationalisation, risk aversion, lack of leadership skills and unresolved financing (Kovács, Sz. *et al.* 2017).

All the above point to the important role of high-quality deployment factors that can be difficultly reproduced and older industrial areas and potential industrial clusters even at the time of Industry 4.0, therefore it is worth summarising the characteristics of the study area including nine counties (Nógrád, Heves, Borsod-Abaúj-Zemplén, Szabolcs-Szatmár-Bereg, Hajdú-Bihar, Jász-Nagykun-Szolnok, Békés, Csongrád and Bács-Kiskun) of the country. Eastern Hungary means the eastern half of the country, where the counties mentioned above form three regions (Northern Hungary, Northern Great Plain, Southern Great Plain).

During the market economy transformation, balancing industrialisation in the state socialist system was replaced by the preferences of foreign private businesses corresponding to an export-oriented modernisation model based on foreign capital resulting in the differentiation of industrial spatial processes (Nemes Nagy, J. and Lőcsei, H. 2015). The geographical location of Eastern Hungary, its inherited economic structure and its infrastructure conditions made it a loser of the change. Not only are heavy industrial crisis areas with strong deindustrialisation, but areas in the Great Plain experiencing above average the collapse of eastern markets, the crisis of agriculture and the external dependency of local industry have also gone through a deep recession (Kiss, J. 2003), which was at most mitigated by cities with a more stable industry, with a more successful transformation (Jászberény, Tiszaújváros) or foreign direct investment from the 1990s (Hatvan, Kecskemét) (Barta, Gy. 2002; Kiss, É. 2010) *(Figure 1).*

As a result of re-industrialisation after the millennium, the value of certain Eastern Hungarian regions increased and the internal differentiation of these regions could be observed, while the industrial dynamics of Heves and Jász-Nagykun-Szolnok, closer to the capital city, were already significant in the 1990s (Barta, Gy. *et al.* 2008), Borsod-Abaúj-Zemplén seemingly finishing deindustrialisation and Bács-Kiskun with an increasing value due to the location choice of the automotive industry were classified into the re-industrialising counties only later (Lengyel, I. *et al.* 2016; Lengyel, I. and Varga, A. 2018). County data, however, mask internal spatial disparities: in the re-industrialised

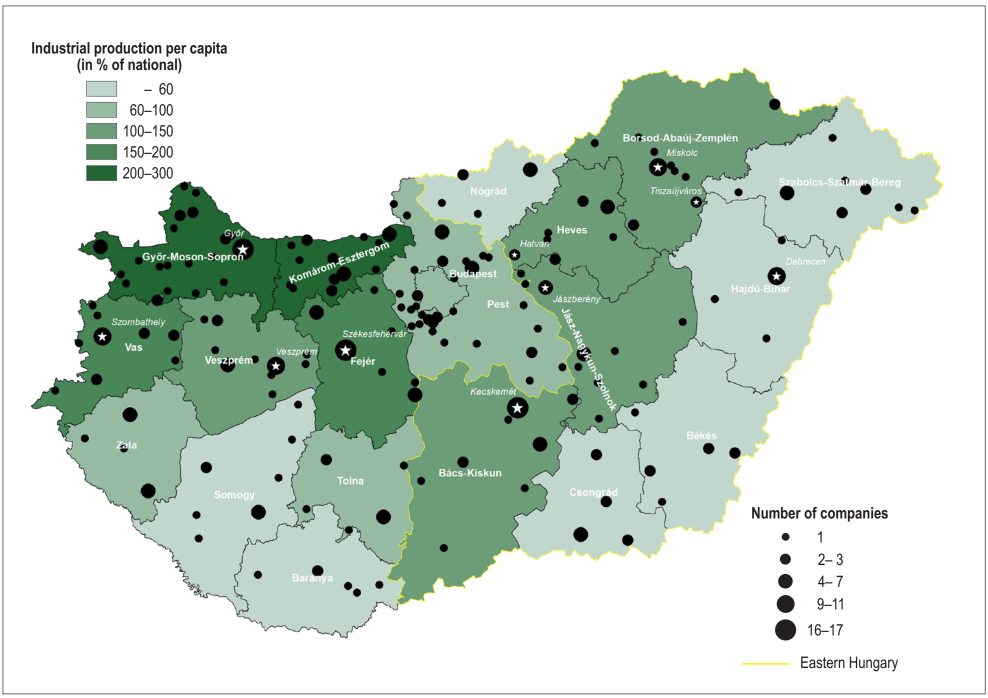

Fig. 1. The value of industrial production per county's inhabitant in per cent of the country's average and the number of manufacturing companies employing at least 250 people by headquarters, 2018. Names of counties (**bold**) and settlements (*italic*) with the most manufacturing companies mentioned in the text are labelled by stars. *Source*: Data of Hungarian Central Statistical Office.

eastern counties, the axis in the foreground of mountains and the proximity of the capital city seem to be the major factors in determining the spatial structure. This is also reflected in the regional differences of the successfullness of industrial parks (Kiss, É. 2013). This shows the resurgence of the north-south differences that have long defined the territorial differences of the Hungarian industry (Barta, Gy. *et al.* 2008; Kiss, É. 2010), which also suggests the role of inherited conditions in shaping the future (Molnár, E. and Lengyel, I.M. 2015). Major characteristics of the studied region are demonstrated in a table illustrating well its position within the country *(Table 1).*

Re-industrialisation also means industrial structural change. With a stronger presence of large foreign companies in more dynamic counties – regardless of geographical location – the dominance of capital-intensive, more value added mechanical engineering (possibly chemical industry) is typical (Barta, Gy. *et al.* 2008). In relation to upgrading of Hungary considering factor intensity, the regions that have been re-industrialised later do not start from the same point and seem to be taking similar development paths in less time than their predecessors re-industrialised in the 1990s, as demonstrated by the faster change of activity structures and embedding of some corporations (Józsa, V. 2019). In value chains managed by foreign parent companies, the role of the limited character of functional upgrading in blocking re-industrialised regions and, at the same time, (quality) functions beyond production detectable in the East re-industrialised late fade differences between the old and new industrial areas, e.g. in automotive industry (Molnár, E. *et al.* 2020).

Methodology and sample

This research is based on company interviews, designed to collect economic geographically relevant questions related to Industry 4.0 and to outline the possibilities for interpreting correlations in a semi-peripheral economy with dual characteristics. Qualitative methods were applied creating abundant information, flexible conversation, enabling the interviewer to learn continuously and correct the protocol in situ, to reveal causation and to collect information (Babbie, E. 2008; Liu, C.L. and Zhang, Y. 2014; Müller, J.M. *et al.* 2018).

The semi-structured in-depth interviews were conducted between September and

Table 1. Some data of the industry of Eastern Hungary and Hungary, 2018

Denomination	Re-industrialising counties of Eastern Hungary*	Other counties of Eastern Hungary**	Hungary
Number of active industrial enterprises per 1,000 inhabitants	4.7	3.8	5.1
Industrial production per inhabitant, 1,000 HUF	4,568	1,659	3,270
Industrial employment, number of employees per 1,000 inhabitants	84	59	80
Industrial productivity, industrial production per one industrial employee, 1,000 HUF	54,697	28,334	40,889
Number of industrial enterprises employing at least 250 people per 100,000 inhabitants	4.7	3.5	4.8
Employment in mechanical engineering, number of employees per 1,000 inhabitants	34	10	27

*Borsod-Abaúj-Zemplén, Heves, Jász-Nagykun-Szolnok and Bács-Kiskun county (based on Nemes Nagy, J. and Lőcsei, H. 2015; Lengyel, I. and Varga, A. 2018). ** Nógrád, Szabolcs-Szatmár-Bereg, Hajdú-Bihar, Békés and Csongrád county. *Source*: Data of Hungarian Central Statistical Office.

December 2019. In line with the exploratory nature of the research, open-ended questions were asked, leaving room for interviewees to interpret them, and gave way to their thoughts depending on the time frame of the conversations (1–3 hours). Like the investigation of Szalavetz, A. and Somosi, S. (2019), what had been said in the conversations was interpreted as a weak signal. In some areas facts were asked, however, opinions regarding certain questions in relation to possible spatial trends were also recorded.

The companies interviewed in Eastern Hungary were selected on the basis of the recommendations of professionals and entrepreneurs who had been visited before. Different industries, region and settlement types are represented in the study, and the size and ownership of the involved companies reflect the dual structure of the economy. Therefore, in the logic of targeted sample selection, the principles of easy accessibility, experts selection, snowball method and quota sampling are mixed (Babbie, E. 2008). Competent companies are targeted for interviewing in the topic at which some elements or signs of Industry 4.0 have already appeared. Therefore, the sample is not representative of the area's industry.

Composing the question the aim was to obtain experience in practice in relation to the occurrence and possibilities of the fourth industrial revolution in Hungary and to survey the related attitude and strategies of the decision makers. Gathering information on the role of Industry 4.0 in transforming spatial relations, on the assessment of the relevant advantages and disadvantages of the studied region was also important. Naturally, before the interviews available materials (e.g., website, financial reports) were used to obtain information on the companies. After the companies are presented, results are discussed in accordance with the theme of the interview question series, but in a structure with a slightly different logic, reflecting duality and minimising overlaps:

– The occurrence of Industry 4.0 and global economic change at company level are analysed first taking strategy, technology proliferation, process transformation and competencies into account. First, the general trends, then the characteristics of foreign corporations and Hungarian medium-sized enterprises are presented. This is followed by a section where some of the unique characteristics of each company are demonstrated.
– In the second part, locality, the environment, spatiality aspects come to the front, where the role of human resources, suppliers and other relationships is important. Again the analysis follows a route from general trends to the specifics of the two groups of companies *(Table 2).*

The 10 studied companies include five foreign-owned corporations (subsidiaries) and five Hungarian-owned medium-sized companies located east of the Danube between 80 and 240 kilometres from the capital city. Subsidiaries have long operated at their locations, showing a gradual expansion in terms of size, production and functionality. Stable Hungarian management leads all companies. The beginning of the career of the Hungarian ones can be related to the period of the regime change: they started small and grew gradually, but even today they operate on a family basis.

The gap between multinational corporations and smaller Hungarian businesses was a recurring motif in the discussions (for both types) despite the fact that otherwise respectable innovativeness and competence were experienced at medium-sized enterprises as well. Since experience from both literature and field is consistent with the role of the dual economic structure in space influencing the adaptation of Industry 4.0 innovations, the replies are presented along this policy principle. It is important to emphasize that all interviewees were well-informed about Industry 4.0 and that they were addressing the potential of innovation. At the same time, most of them regard the adaptation of innovations a part of an organic and reasonable development process and – regardless of the upheaval around Industry 4.0 – focus on solving specific problems.

Table 2. The main characteristics of the studied enterprises, 2019

Nr.*	Ownership	Size category of employment, 2018	Income, mEUR, 2018	Sales	Industry	Activity	Settlement**
1.	Foreign	1,500–3,000	200–300	Mainly export	Motor vehicle industry	Supplying modules	City
2.		1,000–1,500	30–50		Mechanical engineering	Supplying metal parts for the motor vehicle industry	
3.		1,000–1,500	150–200		Electronics	Hardware, software, SSC (Shared Service Centre)	
4.		1,500–3,000	150–200		Mechanical engineering	Mainly end product manufacturing	
5.		500–1,000	20–30		Light industry	Supply for the motor vehicle industry	
6.	Hungarian	50–100	3–5	Mainly domestic	Wood industry	Packaging	Small town
7.		50–100	3–5		Plastics industry	Household, some contract manufacturing	City
8.		50–100	5–8		Metal industry	Supply for the motor vehicle industry and own products	City and small town
9.		50–100	2–3		Paper industry	Packaging	City
10.		150–250	2–3	Mainly export	Electrical engineering	Contract manufacturing	Small town

*The number means how the given enterprise is referred in the text. **Cities are county seats with more than 100,000 inhabitants hosting major higher education institutions. Small towns with 10,000 to 20,000 inhabitants are not located in the agglomeration of cities. *Source:* Creditreform Ltd. and companies' webpages.

Results of empirical research

Industry 4.0 at companies

According to the interviews – similarly to the study of Tjahjono, B. *et al.* (2017) – the most frequently identified strategic goals regarding the adaptation of Industry 4.0 are productivity growth, efficiency, competitiveness, cost and time optimisation and flexibility. Improvements in labour productivity generate growth for most (1, 2, 4, 8) and the workforce freed up by automation and optimisation is redeployed within the company: technology-based capacity expansion, diversification, headcount-neutral transformation are the goals. Solutions offered by Industry 4.0 are not exclusive and generally not competitive with traditional series production optimised for a single product. Automating with linear-driven target machines is cheaper than robotics, but robots are easier to reuse.

Enterprise resource planning systems considered the foundations of Industry 4.0 are present almost everywhere. The strong influence of the German enterprise culture is also demonstrated by the fact that the SAP system is most widespread (at companies 1, 2, 4, 6). This reflects the management's desire to better understand the processes. Since the modernisation of production infrastructure is not a prerequisite for enterprise resource planning (ERP) systems, only the price of software hinders their spread. However, for its effective operation, it is essential that the necessary information is included as soon as possible, which requires well-organised processes. One corporate leader declared the recipe of Industry 4.0: lean → data collection → autonomous systems. Principles of lean production representing the demand-driven product organisation logic were mentioned in several companies (4, 5, 9) in accordance with the results of Tortorella, G. L. and Fetterman, D. (2017).

In all cases, the development of corporate Industry 4.0 background competencies was motivated by the relative cheapness and accessibility of own resources, as opposed to the solutions offered by external companies.

There have also been several cases of worker assistance and improvement of working conditions: on the one hand, the replacement of physically demanding work (2, 6) and, on the other hand, reduction of the complexity of tasks in order to create safe operation conditions for both humans and machinery in the form of so called poka-yoke solutions (4, 5). Predictive maintenance was mentioned only in two cases (2, 4), meanwhile scheduled programs are widespread.

A common speciality of foreign subsidiaries is that they do not make decisions independently. While product development is typically the responsibility of headquarters, production design and sustain engineering are largely subsidiary competences. Due to the dominant production function of the companies, efficiency and cost optimisation are top priority. Hungarian management is more successful due to the lack of cultural and linguistic barriers, providing more leeway, as does the fact if a plant is the sole producer of a product. Local developments are typically generated not by high command, but by keeping the cost level, solving current problems, or the ambitions of local management with limited leeway, as Szalavetz, A. (2016) has experienced.

The technological superiority of subsidiaries is also an important difference. Examples of a working Manufacturing Execution System (MES) and simulation applied in development and lower-level optimisation have only been seen at corporations. 3D printers were used in prototyping (1, 4) and indirectly in tool manufacturing (2's supplier). Industry 4.0 provides an opportunity for premises to become a competence centre in certain fields: two automotive suppliers (1, 2) for example, in MES, and a third in lean and production support software (5). Two companies have significant robotics and production line building competences for the smooth production (1, 4). Product-related services and integration are quite widespread (1, 3, 4). In terms of quality assurance, increasing traceability stands out *(Table 3).*

A common feature of Hungarian medium-sized enterprises is that they form a strategy based on several, not only economic, but e.g. individual, family objectives. Owner-executives have full decision-making power. In addition to the underdevelopment of organisations, limited resources are the biggest barrier to Industry 4.0 innovations. All managers cited the lack of time in management as an obstacle to development and strategic thinking. There is relevant knowledge in several places, but typically management itself is the intellectual capacity for designing and implementing developments (6, 7, 8). Many feel that young people, the second generation of corporate governance, are able to break away from their daily routine and deal with strategy and development (Müller, J.M. *et al.* 2018; Czél, B. 2019).

All of the asked medium-sized company leaders were concerned about Industry 4.0 in Hungary, while in Czechia 3/4 of the studied companies did not feel Industry 4.0 relevant to them at all, which is of course more the result of targeted selection than the difference between the two countries (Kopp, J. and

Table 3. Some important technologies at the companies interviewed, 2019

Denomination of technology*	Foreign corporations	Hungarian medium-sized companies
Manufacturing Execution System	1, 2, 4, 5	–
Radio Frequency Identification	1, 5	–
Augmented Reality, Virtual Reality	1 (in education)	–
Enterprise Resource Planning	1, 2, 3, 4, 5	6, 7, 8, 9
Simulation	1, 3, 4	–
Robot	1, 2, 4	6, 8
3D printer	1, (2), 4	6

*Not all technologies are closely related to Industry 4.0, but they are essential elements. *Source*: Company interviews, 2019.

Basl, J. 2017). Trends in the specific cases were rather variable. MES (Manufacturing Execution System) or similar ideas have occurred as future plans in several cases (7, 8, 9). They are weaker in data collection and processing: efficiency indicators are often not used, however, they want to improve in this field (in accordance with the experience of Müller, J.M. *et al.* [2018], and Nick, G. [2018]). The outdated and heterogeneous production infrastructure also often hinders development (7, 8, 10).

Individual subsidiary examples indicate further practices in the application of Industry 4.0 innovations. Corporation 1 works hard on process innovations besides dynamically changing activities of its manufacturing premises, placing a significant emphasis. According to the manager interviewed, they are gradually moving from low-cost to high-cost location.

Corporation 2 produces low-value products in large quantities, therefore reducing the cost of production and that of material share is particularly important for it. Practicaly all of their machines have been equipped with a monitoring system that enables predictive maintenance and supports quality assurance. They also test robots, which can help in visual inspection during quality control.

Corporation 3 carries out highly diversifiable, high value added (75–80%), R&D intensive (nearly 20%) activities: in addition to hardware manufacturing, software development and system integration takes place and has significant shared service centre (SSC) functions (IT, law, financial service provider, customer service). Nearly half of the employees have diploma. At the same time, their high mix low volume production covers thousands of product variants, which hinders the introduction of the MES. Robots are not considered suitable for fine operations, or to correct minor defects, moreover they receive no support for the modernisation of their production system from the centre.

Corporation 4 also has a high mix low volume product group. To produce this, a special "Industry 4.0 line" has been created that is capable of producing single-piece series, has machine-level interconnectedness, automatically checks the qualification of operators, issues work instructions, has (not visualized) digital twin and provides a one-way material flow in logistics. Deep learning is planned with the help of big data collected with sensors in welding. As a means of limiting the autonomy of the subsidiary, the size of the technical department is limited.

In the case of corporation 5, the barrier to automation is the individuality of the natural raw material, and that of flexible organisation is quality assurance (their safety-sensitive automotive products should only be manufactured using lines designed specifically for the particular product, to be resampled in the event of modifications, approved by car manufacturers). Lean and kaizen approaches dominate in the corporation and it follows self-control and null error strategy. MES works at a low level the corporation uses a less-known, well-customised ERP, however, they are under pressure to switch to SAP.

Individual medium-sized company examples also offer a variety of relevant experiences. The progressive executive of company 6 held back growth and focuses on downsizing developments. It has a robot (and plan to purchase another one) programming of which is carried out by his sons and the robotic arms are 3D-printed. This company was among the first in its size category to purchase a corporate governance system (SAP) in Hungary in order to connect with its customers. This is how it supports delivery scheduling.

Company 7 works primarily with its own product designs. Plastic is difficult to plan and simulate. Due to the tool requirements of injection moulding, the company works with a local supplier, and small series are not profitable. A 3D printer is planned for prototyping. The company also aims to give workers instructions on tablets. In order to track deliveries a mobile app is used and orders are planned to be automated. The company carries out R&D co-operation with the university of another city.

As the development of the automotive supplier business is costly, company 8 focuses more on the own product division. Following the modernisation of the production line (welding robot cell) it plans to expand the related services and integrator functions. For reasons of cost-effectiveness, it developed machinery and ERP together with Hungarian companies; the ERP is well customized to the needs of the firm, however, not sold on the market by the software company. Multiply retrievable data improved their bargaining power and the executive's son has also developed an online price calculator.

Company 9 works with a number of product variants, often small series, on which many operations are carried out. One of the main obstacles to development is that the company cannot change from point production to line production. The ERP of the company is outdated, however, due to high prices no new software has been bought yet. Improvements are supported by a lean engineer.

Company 10 works as a custom manufacturer with small profits that hinders development. Dispersed production on more locations hamper the integration of ERP and the main customer is not partner in interconnection either.

Relationship with the environment of companies

The spatial effects of Industry 4.0 can be interpreted in two dimensions. On the one hand, it is manifested as the unequal spread of innovations maintaining/re-creating competitiveness (keeping or removing those involved) and, on the other hand, as the effects of the production and value-chain division of labour transformed by Industry 4.0 on spatial relations.

One of the most obvious consequences of Industry 4.0 accompanied with spatial effects is the change in the demand for labour. The role of industrial qualification is diminishing as a result of Industry 4.0, while the need for digital competencies and for the ability to manage complexity is increasing. Some are dissatisfied with the digital competencies of older people (9) and others are dissatisfied with the digital competencies of manual workers (2). Others believe that this is not a problem of the blue-collar workers, but rather important for the white-collar ones (8). Most leaders emphasized the role of education and training within companies. There is a general agreement on the importance of major developments in the education system, often the knowledge of teachers is not adequate. Recruitment becoming hard is felt everywhere, especially in terms of highly qualified workforce. Nevertheless, the region's relative advantage over other parts of the country can be seen. According to the head of the company (8), present in both a city and a town, recruitment is becoming more difficult in both areas, however, it is slightly easier in the small town, which was explained by the workforce released due to the closure of a local foreign company.

In relation to supplier networks critical for the reasons discussed earlier, experts emphasise co-operation with multiple partners (companies, institutions), the flow of information and transparency as the basis for development (Tjahjano, B. *et al.* 2017; Müller, J.M. *et al*. 2018). In our interviews, the role of corporate governance systems has occurred repeatedly (5, 6, 10), as well as, the Achilles heel of automotive industry supply: quality assurance (5, 7, 8). The leader of one corporation and that of a medium-sized company set the criteria for fast and flexible communication at a distance of 100 km (2, 9). One corporate leader missed "medium-sized" businesses with hundreds of employees in Hungary (4) who could have the ability to function as stable partners.

R&D cooperation – regardless whether foreign-owned subsidiary or a Hungarian medium-sized company – occurs only at companies in cities (e.g. machine testing, material science), although it is also planned in small towns (6, 10). The availability of tender resources is a general advantage of the region. The positive impact of the development of the main road network on accessibility and flexibility was also mentioned (6, 8). The non-optimal functioning of professional organisations (4, 6, 8) was raised as a problem.

The foreign subsidiaries usually have large labour market catchment areas, with one of them having employees from 100 km, across the border (4). In most cases, the share of non-manual workers (20–30%) is much smaller than that of manual workers. The ratio of those with a diploma is not very high. The ratio is generally improving and in some cases this has been linked to Industry 4.0, the expansion of development and IT functions, but this has not always been clear. Where possible, they also make themselves more attractive by remote working or the possibility of home office. In order to have human resources supply, most corporations are actively involved in secondary and higher education, offering dual training. Considering higher education, in addition to technical training (1, 2, 4), companies are sometimes active in economics (4), however, opinions are divided on whether students should be educated by the companies from the beginning or not. Nevertheless, dual training is an excellent opportunity to attract young talent, i.e. a competitive advantage that requires an accessible (relevant) higher education institute. At secondary school level experiences are generally not very good.

For the foreign subsidiaries, the local supply network offers flexibility, just in sequence organisation, reduced logistical costs and closer co-operation. They themselves are often suppliers therefore the entire chain logically contributes to concentration and spatial specialisation. The supply network is a critical issue for companies with a high material proportion. However, local co-operation is also advisable in the case of tools and services. Most companies (1, 2, 4, 5) strive to improve the local supplier network (mentoring, on-site consultancy, strategic consultations, even joint development), but none of them reported breakthrough successes. They often carry out the task themselves cheaper than a local operator. Some have no Hungarian supplier at all (3), while others talked about Germans in 90 per cent (5) or about suppliers mostly from the Far East (2).

Several multinational corporates appreciated and took advantage of the university and research institute opportunities in their city (1, 2, 3, 4), some reported improved attitudes and conditions in Hungarian institutions that have traditionally not been very open to the market (2, 4), others were dissatisfied (3). Co-operation does not necessarily take place with (only) the local institution. They usually take steps to improve their local embedding, and they have good relationship with local political forces. Several corporates trust in the benefits of industrial agglomeration in the field of institutional networking, services and industrial advocacy. Regarding the infrastructure of the location (industrial park), major companies formulated expansion needs at most (4).

Medium-sized companies typically attract no workers from far away and are characterised by a particularly low rate (<10%) of workers with a diploma. They seem to accept the fact that they cannot compete for non-manual workers with multinational corporations. Effective steps are not taken to attract a highly qualified workforce (e.g. teleworking, educational co-operation), the management, the family typically try to solve everything themselves.

In general, there is a low level of cooperation, businesses rely on themselves and government supports, and there is no question of co-operation with competitors. Several companies are involved in the circulation of the global industry as suppliers or custom manufacturers, while they also have suppliers. Several companies consider that the entrepreneurial and supplier culture around the city Győr is more advanced. Pushing down prices and poor bargaining power are the main problems in custom work (7, 10). In the life of medium-sized enterprises, personal contacts and soft information play a significant role both towards external businesses (9) and in their internal operation (7). The resulting agility and benefits may become threatened by Industry 4.0. Similar concerns were also raised during the investigation of Müller, J.M. *et al.* (2018).

In the case of Hungarian medium-sized enterprises, the relationship with the local environment is ambivalent. In small towns and periphery areas transport management may cause problems (6, 8). The role of proximity to the consumer market is indicated by the fact that one of the companies (otherwise in a city) maintains a sales office in Budapest (9). Some did not perceive a constructive attitude from local leaders and businesses (6), others felt that their embedding in the local market was poor (9). Many medium-sized companies (6, 7, 8, 9, 10) participate in an Industry 4.0 state programme, in which the Industry 4.0 preparedness of companies is assessed, forerunner factories and training are visited, and finally prepare a development plan. Eventually selected companies will receive customized, professional advice. Such a programme would be truly constructive if development resources were also allocated, therefore grounded decisions customized to individual cases could be made at the time of allocation.

Discussion of empirical experiences

Based on the Eastern Hungarian experiences it has become obvious that companies are dealing with the Industry 4.0 issue, but the fourth industrial revolution is mostly ahead of us. According to different points of view there are smaller or larger similarities and differences among the companies studied. They are in the different phase of Industry 4.0 *(Table 4).*

With the transformation of the human resources needs of production adapting Industry 4.0 innovations, it would be logical to consider the reshoring of manufacturing formerly relocated on cost basis to the mainland or near major consumer markets. Relocation of foreign investments is continuous, in Eastern Hungary examples can also be found for activities relocated to or from Hungary, although typically more for the former. Based on automation, however, mass reshoring seems not like. Probably because this

Table 4. *Companies in Eastern Hungary from different aspects in relation to Industry 4.0*

Aspect analysed	Common features	Foreign corporation	Hungarian medium-sized company
Activity	Manufacturing, production	Product design, optimisation, sustain engineering	Generally development of own product as well
Strategic goals	Growth, diversification with stagnant workforce	Dependent state, priority of efficiency, keeping cost level an important goal	Single-person, multi-factor decision-making
Grounds	Frequently principles of lean	Development of production infrastructure is relatively uniform	Heterogeneous, underdeveloped infrastructure
Technologies	ERP, availability of information in company management	Superiority, harmonised developments, emphasis on process optimisation (MES)	Diverse, sporadic, developments
Attracting human resources	Acquisition of labour becomes harder	Focus is on attracting (skilled) workforce	Not attractive
Qualification	Digital and soft abilities become more important	Higher ratio of graduates from higher education, educational co-operation	Low ratio of graduates from higher education
Supply	Local partnerships become more important, low standard level	Efforts to develop the local network are not successful	Untapped potential due to the lack of resources and intent
R&D	Only in cities	Frequent co-operation	Rare co-operation
Local environment	Aspects: availability, tender sources, human resources	Positive attitude, strong desire for co-operation	Ambivalent attitude, little co-operation

Source: Company interviews, 2019.

would not be a solution to the socio-economic problems of the parent country, since the lack of highly qualified workforce is the problem there as well, and autonomous production systems require less low and medium-skilled workers. At the same time, considering capacities in the Far East, even a more peripheral region in the EU provides more flexibility as location (nearshoring). The activities of the subsidiaries of multinational corporations diversifying due to the integration of production support, IT and service activities may even prove to be a retaining force.

The opportunities and effects of function expansion due to Industry 4.0 are only partially realised in Hungary, and the changes do not seem to be so remarkable therefore it can be declared that they represent relative progress and upgrading compared to the competitive environment in the world economy. The preparedness of potential suppliers can play an important role in attracting foreign capital. It is also in the interest of Hungarian businesses to be linked to the system with the highest possible level of activity, as this involves greater knowledge transfer (Szanyi, M. 2010). The need for the growing amount and diversity of knowledge not only underlines the importance of education, but also is a guide for its organisation. Education needs to move forward from the previous uniform and static paradigm towards a model aiming for diversity and supporting continuous learning, a basic condition of which is the internal motivation of participants because of flexibility. It is no surprise that the issue of education has concerned almost all of our interviewees.

New technological opportunities give subsidiaries such features (flexibility, efficient information flow, decentralisation, availability, presence) that have previously been the most important competitive advantages of smaller companies. Since there is no effective own organic development model for SMEs at present, it is necessary to create the possibility of financing for learning and development of the smaller ones that can only be achieved through cooperation and ecosystem thinking (Müller, J.M. *et al.* 2018; Rouhamaa, H. *et al.* 2018). A competitive advantage could be gained by pooling separate, sporadic developments in a resource-efficient way and eliminating duplication, but this would require a properly functioning network of institutions, an entrepreneurial culture and trust. There is institutional practice for continuous training and for the acquisition of highly qualified professionals at corporations. In contrast, SMEs are not able to cover these needs from their own resources therefore co-operation in this field is also necessary. It is a disadvantage that the employment of highly qualified workers is not emphasized enough at medium-sized enterprises, where the development of the organisational culture is important.

The interviews also confirmed that knowledge and corporate culture essentially spread through people, therefore the support for (Hungarian) smaller companies at system level should be considered by highly qualified employees who possibly obtained experience at multinational corporations. Without the above steps, it is feared that Industry 4.0 will not be a possibility for medium-sized enterprises, but – due to the cumulative, interdependent character of innovations – the inherited disadvantages will be strengthened, further increasing the gap between the competitiveness of corporates and medium-sized companies.

The capital and technology intensity of Industry 4.0, its sector dependence, the central role of multinational corporations, the integration of supply networks, the importance of personal relationships in knowledge generation all point to the fact that the more developed industrial districts or clusters and cities can gain additional benefits. As discussed above, the possibilities of Industry 4.0 can be strongly influenced by the characteristics of manufactured products and raw materials used. This includes two possibilities regarding the development of the spatial structure: on the one hand, areas specialised in industries where the achievements of Industry 4.0 can be applied more easily and thus developed and optimised (the automotive industry seems to be, for the time being, the most dynamic in terms of Industry 4.0 – see Molnár, E. *et al.* 2020) and, on the other hand, it may conserve less dynamically developing, labour-intensive activities in less developed areas.

In the evolution of the spatial structure of the Hungarian industry, the trends suggest broadly the relative prosperity of the Northern Transdanubia region with a one-sided automotive profile, with a more established relationship system, and that of Budapest and its wider environment with the greatest knowledge and consumer market. In Eastern Hungary, the major cities hosting universities may be mostly the winners of the fourth industrial revolution, while the disadvantage of small towns and rural areas may increase further. It may be encouraging that the respondents considered the suppliers within a 100–200 km radius to be local, however, nothing indicated that the developments would boost beyond the boundaries of cities and districts.

Conclusions

The present study provided a few examples to reveal similarities, differences and potential explanations for Industry 4.0 in an economy with dualistic character, highlighting issues with economic geographical relevance to the semi-peripheral Eastern Hungary. The results point to the fact that the spatial structure outlined over the last decades would not change significantly, the areas that have been thriving are expected to retain their advantage in Hungary and the further concentration of value-producing processes in corporations and around cities is likely. It also has to emphasize that we have to prepare for global processes both nationally and locally, and this requires primarily the renewal of the education system, the development of the Hungarian medium-sized enterprises and the strengthening of the institutional framework for co-operation. Even with these measures, it is questionable whether the country can move forward in the absence of internationally competitive, innovative Hungarian businesses.

There are several options for continuing the research. One of the most important is the extension of empirical studies. This is necessary, on the one hand, because the conclusions based on interviews reflect only those experienced in the case of a few companies, which, however, certainly provided decisive information to Industry 4.0 on processes in a semi-peripheral region. On the other hand, investigations should also be continued to control the primary results and to reveal new connections between Industry 4.0 and the economic geography of companies. Another research direction may be to explore what characterises businesses at a disadvantage as a result of the expansion of Industry 4.0. These all together will enable a more detailed and complete picture of the realisation of Industry 4.0 in Hungary and of its economic geographical context.

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A 54-year record of changes at Chalaati and Zopkhito glaciers, Georgian Caucasus, observed from archival maps, satellite imagery, drone survey, and ground-based investigation

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Abstract

Individual glacier changes are still poorly documented in the Georgian Caucasus. In this paper, the change of Chalaati and Zopkhito glaciers in Georgian Caucasus has been studied between 1960 and 2014. Glacier geometries are reconstructed from archival topographic maps, Corona and Landsat images, along with modern field surveys. For the first time in the Georgian Caucasus aerial photogrammetric survey of both glacier termini was performed (2014) using a drone or Unmanned Aerial Vehicle, where high-resolution orthomosaics and digital elevation models were produced. We show that both glaciers have experienced area loss since 1960: 16.2±4.9 per cent for Chalaati Glacier and 14.6±5.1 per cent for Zopkhito Glacier with corresponding respective terminus retreat by ~675 m and ~720 m. These were accompanied by a rise in the equilibrium line altitudes of ~35 m and ~30 m, respectively. The glacier changes are a response to regional warming in surface air temperature over the last half century. We used a long-term temperature record from the town of Mestia and short-term meteorological observations at Chalaati and Zopkhito glaciers to estimate a longer-term air temperature record for both glaciers. This analysis suggests an increase in the duration of the melt season over the 54-year period, indicating the importance of summertime air temperature trends in controlling glacier loss in the Georgian Caucasus. We also observed supra-glacial debris cover increase for both glaciers over the last half century: from 6.16±6.9 per cent to 8.01±6.8 per cent for Chalaati Glacier and from 2.80±6.3 per cent to 8.53±5.7 per cent for Zopkhito Glacier.

Keywords: glacier change, glacier monitoring, supra-glacial debris cover, climate change, Greater Caucasus, drone survey, Chalaati Glacier, Zopkhito Glacier

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Introduction

Climate change is causing nearly all of the world's mountain glaciers to lose mass (Vaughan, D.G. *et al.* 2013) which now accounts for about one third of the cryosphere's total contribution to global sea level rise (Gardner, A.S. *et al.* 2013). Mountain glaciers also play an important role in the regional hydrological cycle by modulating the storage and release of freshwater, so as they retreat, the availability of runoff for irrigation and hydro-power generation is altered (Kaltenborn, B.P. *et al.* 2010) and there are potential impacts on ecosystem health (Jacobsen, D. *et al.* 2012).

The most important resource provided by glaciers for Georgia is freshwater. Many rivers in the mountain regions are fed by the

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melting of glaciers and snow. The largest glaciers in the Georgian Caucasus (2014) such as Lekhziri (~23 km^2), Tsaneri (~12 km^2), and Chalaati (~ 10 km^2), feed the Enguri River which itself is the most important source of freshwater and hydropower in Georgia. Electricity is generated by a hydroelectric power plant and dam along the Enguri, which is the third highest concrete arch dam in the world with a height of 271.5 metres (Blatter, J. and Ingram, H.M. 2001). A continued retreat of Georgian glaciers could lead to considerable changes in glacier runoff, with implications for regional water resources. Therefore, continued monitoring of glacier behaviour across Georgia is necessary.

After the dissolution of the Soviet Union, most glaciological monitoring programs stopped in the Caucasus region and the initiation of new monitoring sites was difficult. Even though some important information on recent glacier change (mainly focused on glacier mapping) has become available for the Georgian Caucasus (Stokes, C.R. *et al.* 2006; Lambrecht, A. *et al.* 2011; Shahgedanova, M. *et al.* 2014; Tielidze, L.G. 2016; Tielidze, L.G. and Wheate, R.D. 2018; Tielidze, L.G. *et al.* 2020), the status of individual glaciers is poorly documented. In this paper, we use the same approach as we have applied on glacier change at a regional scale (Tielidze, L.G. and Wheate, R.D. 2018; Tielidze, L.G. *et al.* 2020) along with limited drone survey and ground-based observations, such as ablation tracking, temperature observations, and terminus surveying.

The Chalaati (GLIMS ID – G042713E43130N) and Zopkhito (GLIMS ID – G043422E42884N) glaciers were chosen because modern ground-based measurements are not yet available from any other glaciers in the Georgian Caucasus. The goals of our paper are:

i) to reconstruct the dynamics of Chalaati and Zopkhito glaciers over the last half century, by estimating the length and area changes, and to compare the observed changes to those of glaciers from the northern side of the Greater Caucasus and other mountain regions (e.g. European Alps, Middle East, Western Himalaya);

ii) to reconstruct the longer-term air temperature record for both glaciers in 1960–2014; to observe the length of the melt season (defined as temperatures above 0 °C) during the same time, and to estimate the change of equilibrium line altitude (ELA);

iii) to assess the alteration of the supra-glacial debris cover for both glaciers over the last half century.

Study area

The Greater Caucasus is one of the major mountain systems in Eurasia, stretching ~1,300 km from the Black Sea in the West to the Caspian Sea in the East. A recently published inventory lists ~2,000 glaciers with ~1,200 km^2 total area (Tielidze, L.G. and Wheate, R.D. 2018).

The main mountain range exerts a moderating influence on the climate of Georgia by protecting it against the penetration of cold air masses from the North. Most moisture-bearing weather systems arrive from the West having passed over the Black Sea. Orographic lifting of convergent air masses in western Georgia creates favourable conditions for snowfall at any time of the year in the high mountains. In contrast, a secondary pattern of weather systems originates in the drier continental climate to the East of the Caspian Sea. These meteorological conditions give rise to a strong West–East gradient in precipitation, reflected in annual snowfalls of several metres in the western parts of the Greater Caucasus and less than a metre in the East (Jincharadze, Z. 2011).

An analysis of meteorological observations collected over the period 1957–2006 shows mean annual air temperatures have increased 0.2 °C in western Georgia and 0.3 °C in eastern Georgia (Jincharadze, Z. 2011), with spring and summer months representing the most rapid warming. There has also been a modest increase in precipitation in western Georgia. Given the observed changes in climate, there is considerable interest in understanding their net effect on glaciers on the southern slopes of the Greater Caucasus.

The central Greater Caucasus (Svaneti-Racha section) is the highest part of the main mountain range in morphometry. The relief of the Svaneti-Racha section is mainly constructed from Proterozoic and Lower Paleozoic plagiogranites, plagiogneisses, quartz diorites and crystalline slates. Lower Jurassic clay slates, schists, sandstones, aleurolites, gravelites, basal conglomerates, and quartzites stretch along the intrusives as a narrow strip in the south. The morphology of the watershed range of the central Greater Caucasus is formed as a result of modern snow-glaciers influence, intense physical weathering, excaration action of Late Pleistocene glaciers and river erosion (Tielidze, L.G. *et al.* 2019a, b).

We focus on two glaciers in the central part of the Greater Caucasus *(Figure 1,* a*).* Chalaati Glacier is located at the headwaters of the Enguri River, the main river for hydroelectric power generation in Georgia (Svaneti region). Zopkhito Glacier is in the Rioni River basin, approximately 60 km to the south-east of Chalaati Glacier (Racha region).

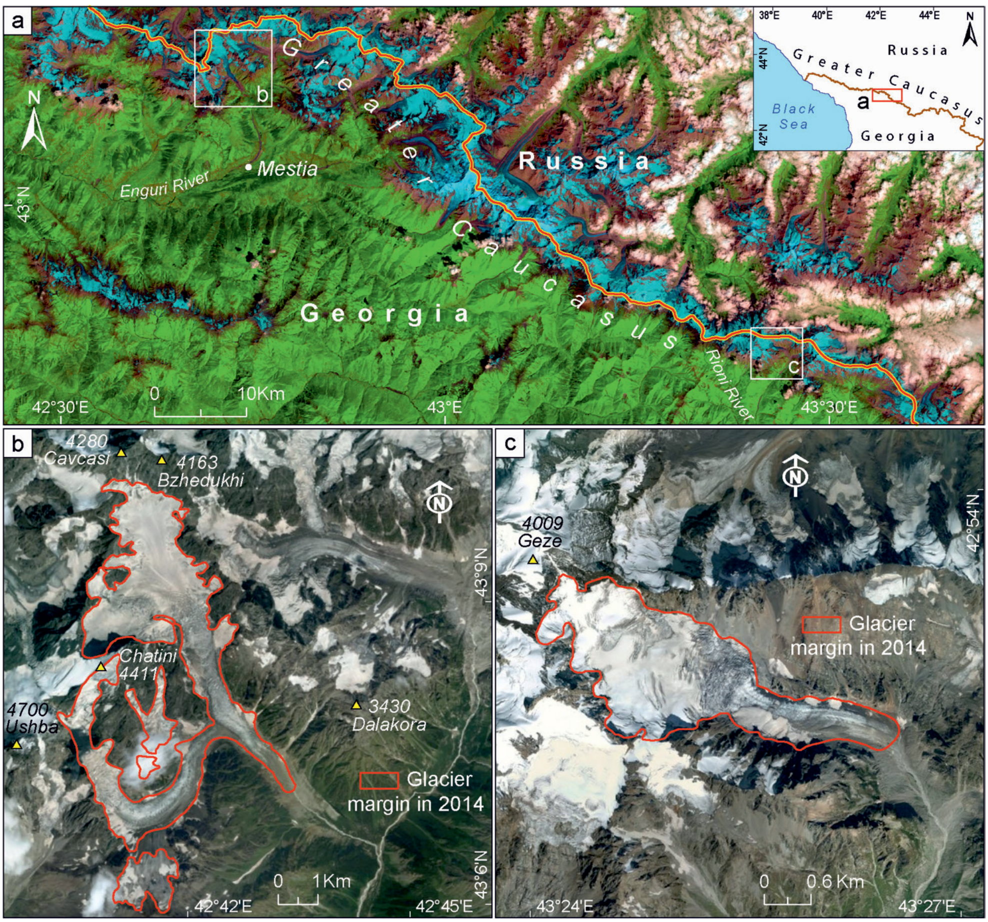

Fig. 1. Study area in the central part of the Greater Caucasus. – a = the location of Chalaati and Zopkhito glaciers and Mestia weather station. Blue colour corresponds to the glaciers, green to the forest zone, and brown to te bedrock. Landsat 8 OLI (03/08/2014) is used as the background; b = Chalaati Glacier; c = Zopkhito Glacier location with surrounding area in close view. Note: GeoEye (2012) are used as the background.

Chalaati Glacier consists of two tributary glaciers which are fed by snowfall from the 4,000 m peaks: Ushba, Chatini, Cavcasi and Bzhedukhi *(Figure 1,* b*)*. Its main channel (the eastern tributary) is about 6.8 km long, and the glacier terminus intrudes into the forest zone at an elevation of 1,960 m above sea level (a.s.l.), making it the lowest-elevation terminus on the southern slopes of the Greater Caucasus. The glacier has a total surface area of 10.73±0.53 km^2 and its lower reaches are covered by ~0.1–0.3 m thick debris (in 2014).

Zopkhito Glacier is a simple valley glacier beginning on the south-eastern slopes of Geze peak (4,009 m) *(Figure 1,* c*)*. It is ~3.6 km long with an area of 2.46±0.12 km^2. The ice surface of the cirque sits at an elevation of approximately 3,000 m a.s.l., and the ice tongue ends at 2,605 m.

Data and methods

Dataset

We seek to reconstruct the extents of Chalaati and Zopkhito glaciers using archival and modern datasets. Baseline data are from 1:50,000 military topographic maps drawn in the 1960s and co-registered by Tielidze, L.G. and Wheate, R.D. (2018).

The modern sequence of glacier terminus positions is established using cloud-free Corona (20/09/1971), Landsat 5 TM (6/08/1986), Landsat 7 ETM+ (09/09/2000), and Landsat 8 OLI (03/08/2014) images *(Table 1)*. The images were orthorectified prior to distribution using the ASTER Global Digital Elevation Model (GDEM, 17/11/2011). All images and GDEM were supplied by the US Geological Survey's Earth Resources Observation and Science (EROS) Center and downloaded using the EarthExplorer tool (http://earthexplorer.usgs.gov/). The images have been co-registered to each other using the August 2014 Landsat image as master; registration uncertainties are 1 pixel (30 m).

Glacier mapping

Landsat images have a pixel resolution of 30 m for the bands used in this study. To facilitate mapping the glacier boundaries, we produced a colour-composite scene for each acquisition date, using the short-wave infrared, near infrared, and blue bands. Each glacier boundary was manually digitized by a single operator. Manual digitizing by an experienced analyst is usually more accurate than automated methods for glaciers with debris cover (Raup, B.H. *et al.* 2007), such as Chalaati and Zopkhito. Combining the images with topographic maps allows us to estimate the variability of Chalaati and Zopkhito glaciers over four periods corresponding to 1960–1971, 1971–1986, 1986–2000, and 2000–2014.

We map the equilibrium line altitude from Landsat 8 OLI image (03/08/2014), towards the end of the ablation season in August, for comparison with equilibrium line altitude in 1960 mapped by Gobejishvili, R.G. (1995). Terminus measurements were conducted by using the glacier outlines for each date, along the ice front – perpendicular to the flow.

Table 1. Topographic maps, satellite/ortho images and digital elevation model used in this study

Date	Map/Sensor	Resolution	Scene ID
1960	1:50,000 topographic map	5 m	k_38_26_v k_38_39_b
20/09/1971	Corona	2 m	DS1115-2154DF070_d DS1115-2154DA079
06/08/1986	Landsat 5 TM	30 m	LT51710301986218XXX02
05/09/2000	Landsat 7 ETM+	15/30 m	LE71710302000249SGS00
03/08/2014	Landsat 8 OLI	15/30 m	LC81710302014215LGN00
Sept. 2014	Orthomosaics	20 cm	UAV_DJI Phantom 4_Chalaati_Zophito
17/11/2011	ASTER GDEM	30 m	ASTGTM2_N43E042/E043_DEM

Terminus measurement by Unmanned Aerial Vehicle

Using the Unmanned Aerial Vehicle (UAV) DJI Phantom 4 pro quadcopter, we performed a limited (terminus only) aerial survey (2014) of the Chalaati and Zopkhito glaciers. Flight planning for the UAV was completed in the office using mission planner software and Google Earth. The UAV was capable of operating at elevation ~3,000 m a.s.l. Total weight including camera and battery was ~1.4 kgs. The maximum flight time for the platform at 3,000 m a.s.l. was around 20 min on a single 5,870 mAh battery. Ground station control was managed by a field tablet running APM Mission Planner for Android. The maximum length of an individual flight line was 0.4 km from the take-off point. The UAV images were processed using the Pix4D software. A dense point cloud was generated from the sparse point cloud model. The DEMs were generated at 20 cm pixel resolution and RGB orthomosaics were created at 20 cm pixel resolution *(Figure 2).* The uncertainty between terminus by Landsat image (2014) and drone survey from the same year was ±20 m.

Mapping of supra-glacial debris cover and uncertainty assessment

Supra-glacial debris cover area clearly visible on the 1960s topographic map and Corona

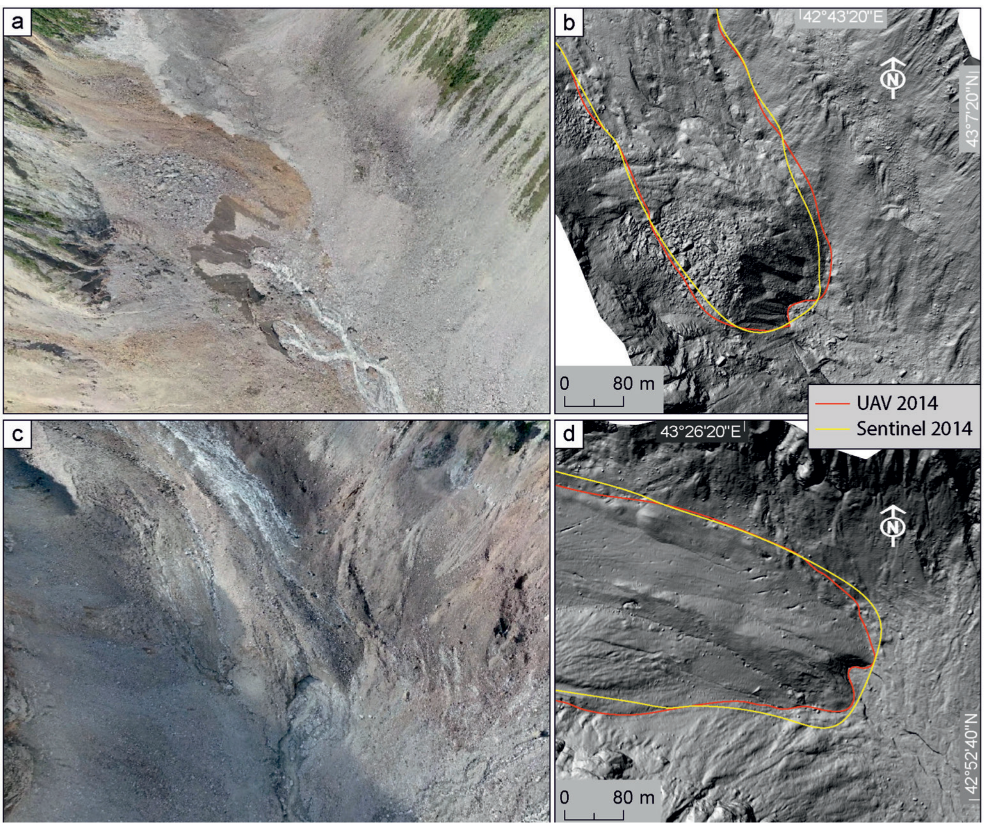

Fig. 2. An example of high resolution (20 cm) orthomosaics and hillshade (generated by 20 cm DEMs) for the Chalaati (a-b) and Zopkhito (c-d) glaciers.

images from 1971 allowed us to map it manually. For the Landsat images the band ratio segmentation method (RED/SWIR; with a threshold of ≥2.0) was used as the first step in delineating clean-ice outlines (Bolch, T. *et al.* 2010; Paul, F. *et al.* 2013), and then intensive manual improvements were performed (removal of misclassified areas, e.g. snow, shadows), hereafter called the semi-automated method. In the next step, similar to Tielidze, L.G. *et al.* (2020), supra-glacial debris cover was classified as the residual between semi-automatically derived clean-ice outlines and manually mapped glacier extent outlines. For clean ice uncertainty estimation we used a 15 m (1/2 pixel) buffer (Bolch, T. *et al.* 2010) and for debris-covered parts 60 m (two pixels) (Frey, H. *et al.* 2012). This generated an average uncertainty for the clean-ice/debris-covered areas of 4.9%/6.6% for 1960, 5.0%/6.5% for 1971, 4.7%/6.4% for 1986, 4.7%/6.3% for 2000, and 4.9%/6.4% for 2014. The uncertainty estimates for all Caucasus glaciers are described in previous studies (Tielidze, L.G. 2016; Tielidze, L.G. and Wheate, R.D. 2018; Tielidze, L.G. *et al.* 2020).

As an independent assessment of the uncertainty estimates, Zopkhito Glacier outlines from Landsat OLI 8 (03/08/14) (including clean-ice and debris-covered parts) were imported into Google Earth and manually adjusted using the available high-resolution Quickbird images (19/09/11) superimposed upon the SRTM3 topography (Raup, B.H. *et al.* 2014). These glacier outlines were then compared with original outlines from the Landsat 8 image (03/08/14). The area differences between the two resulting sets of outlines were ±5.9 per cent for supra-glacial debris cover and ±3.8 per cent for clean-ice. We were not able to use Google Earth software for Chalaati Glacier due to lack of cloud-free images, however, we used high-resolution GeoEye image from DigitalGlobe (ArcGlobe 10.6.1 software) as proposed by Paul, F. *et al.* (2013). We calculated the area uncertainty in a similar way for the Chalaati Glacier. The area differences between the two datasets were ±5.7 per cent for supra-glacial debris cover and ±3.5 per cent for clean-ice which confirms our uncertainty estimate based on the buffer method.

An additional uncertainty assessment was performed using GPS (Garmin 62stc) measurements of glacier margins (~230 points) obtained during field investigations in 2014. The horizontal accuracy of these measurements varied from ±4 to ±10 m. Upper part of *Figure 3* ('a' and 'b') shows the results of comparison between GPS measurements and Landsat based supra-glacial debris cover outlines. The average accuracy based on both Chalaati and Zopkhito glaciers measurements was ±30 m for supra-glacial debris cover, hence again confirming the suitability of the selected buffer method.

Ground-based investigation

We carried out a limited amount of field work on each glacier. During a three-month period in 2011 (June-August), hourly air temperature observations were made at an elevation of 2,140 m on Chalaati Glacier using a Campbell CR21 data logger. We also tracked ablation by measuring exposed stake heights at several locations across the glacier every 7–10 days *(Figure 3,* c*)*. During a brief follow-up field visit on August 16, 2014, we surveyed the terminus using global positioning system (GPS) methods.

Similar observations including the Automatic Weather Station (AWS) installation at an elevation of 2,700 m were carried out on Zopkhito Glacier during the months of July and August in the summers of 2007–2010, and August 2014 *(Figure 3,* d*)*.

Results and discussion

Chalaati Glacier

Over the study period, Chalaati Glacier area decreased by ~2.08±0.10 km^2, equivalent to ~0.04 km^2/yr. Rates of area loss have been variable *(Table 2* and *3)*, with the fastest rate (~0.42% yr^{-1}) occurring between 1960 and 1971. During the

Fig. 3. Example of glacier mapping. – a = Chalaati Glacier – GeoEye (2012) image is used as the background; b = Zopkhito Glacier – Google Earth (19/09/11) image is used as the background; c = Ablation stake installation onto the Chalaati Glacier; d = Automatic Weather Station (AWS) installation onto the Zopkhito Glacier

next 15-year period (1971–1986), the rate of area loss was still higher (~0.39% yr^{-1}). The lowest decrease rate occurred in 2000–2014 (~0.18% yr^{-1}). In contrast to area decrease, supra-glacial debris cover area has increased from 6.16±6.9 per cent to 8.01±6.8 per cent over the study-period, mostly in 2000–2014 *(Figure 4).*

In addition to area changes, we also mapped linear retreat of the terminus since 1960. The fastest rates of retreat occurred during the first measurement period (1960–1971) while the lowest was measured in 1986–2000 *(Table 4).* This might be due to a minor 15 m re-advance of the terminus between 1990 and 1993 as evidenced by small terminal moraines (Gobejishvili, R.G. 1995).

The equilibrium line altitude on Chalaati Glacier was located at 3,155 m a.s.l. in 2014. The cirque extended to 3,800 m and covered an area of 5.01±0.25 km^2. Between 1960 and 2014, the elevation of the equilibrium line rose by ~35 metres, resulting in a decrease in the accumulation zone of ~0.44 km^2 over the 54-year period. Using the measured areas, we calculated the accumulation-area ratio (AAR) *(Table 5).* Chalaati Glacier total area has decreased at a faster rate than the accumulation area, so the AAR has actually increased over the study period, although

Table 2. Terminus position, area, and supra-glacial debris cover change since 1960 for Chalaati and Zopkhito glaciers

Year	Chalaati				Zopkhito			
	Terminus, m a.s.l.	Total area, km²	Clean ice area, km²	Debris covered area, km²	Terminus, m a.s.l.	Total area, km²	Clean ice area, km²	Debris covered area, km²
1960	1,800	12.81±0.64	12.02±0.59	0.79±0.050	2,435	2.88±0.14	2.80±0.13	0.08±0.005
1971	1,860	12.31±0.62	11.51±0.57	0.80±0.050	2,475	2.81±0.14	2.71±0.13	0.10±0.006
1986	1,900	11.59±0.56	10.81±0.51	0.78±0.050	2,525	2.72±0.13	2.63±0.12	0.10±0.006
2000	1,920	11.09±0.54	10.34±0.49	0.75±0.050	2,550	2.64±0.13	2.52±0.12	0.12±0.007
2014	1,960	10.73±0.53	9.87±0.48	0.86±0.050	2,605	2.46±0.12	2.25±0.11	0.21±0.012

Table 3. Chalaati and Zopkhito glaciers area change between 1960 and 2014

Year	Chalaati			Zopkhito		
	Decrease, ~ km²	Annual decrease, ~ km²	Annual decrease, ~ % yr⁻¹	Decrease, ~ km²	Annual decrease, ~ km²	Annual decrease, ~ % yr⁻¹
1960–1971	0.60	0.05	0.42	0.07	0.006	0.22
1971–1986	0.72	0.05	0.39	0.09	0.006	0.22
1986–2000	0.50	0.04	0.30	0.08	0.005	0.21
2000–2014	0.36	0.03	0.18	0.18	0.120	0.48
1960–2014	2.08	0.04	0.30	0.42	0.007	0.28

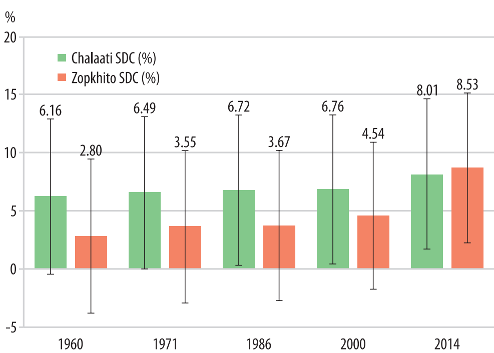

Fig. 4. Supra-glacial debris covered (SDC) area in percentage of total glacier area for Chalaati and Zopkhito glaciers between 1960 and 2014.

*Table 4. Linear retreat rate of Chalaati and Zopkhito glaciers since 1960**

Time periods	Chalaati		Zopkhito	
	Retreat of glacier terminus		Retreat of glacier terminus	
	m	m yr⁻¹	m	m yr⁻¹
1960–1971	270	24.5	190	17.3
1971–1986	135	9.6	180	12.0
1986–2000	80	5.7	120	8.6
2000–2014	190	13.6	230	16.4
1960–2014	675	12.5	720	13.3

*The average uncertainty for length change are ±15 m.

the estimated uncertainty is comparable to the obtained relative changes.

The comparison of the photos of the glacier terminus in 1970 and in 2011 clearly shows the retreat of the Chalaati Glacier over the last half century *(Photo 1).*

Zopkhito Glacier

Over the study period, the area of Zopkhito Glacier decreased from 2.88±0.14 km² (1960) to 2.46±0.12 km² (2014), equivalent to a rate of ~0.007 km²/yr. The rate of area loss was the fastest during the most recent part of the record (~0.48% yr⁻¹ between 2000 and 2014) (see *Table* 2 and 3). Most of the area loss occurred in the ablation area of the glacier, where there was a steady retreat of the Zopkhito Glacier terminus, from 2,435 m a.s.l. (1960) to 2,605 m a.s.l. (2014). This led to a ~720 m reduction in the length of the glacier since 1960 (see *Table* 4).

In contrast to total area decrease, supra-glacial debris covered area increased from 2.80±6.3 per cent to 8.53±5.7 per cent for the Zopkhito Glacier in 1960–2014. The highest increase rate occurred in the period 2000–2014 (see *Figure* 4).

Table 5. Accumulation-area ratio (AAR) change for Chalaati and Zopkhito glaciers between 1960 and 2014

Years	Chalaati		Zopkhito		AAR	
	Accumulation (firn) area, km²	Total area, km²	Accumulation (firn) area, km²	Total area, km²	Chalaati	Zopkhito
1960	5.01±0.25	12.81±0.64	1.69±0.08	2.88±0.14	0.39±0.44	0.58±0.11
1971	4.95±0.25	12.31±0.62	1.66±0.08	2.81±0.14	0.40±0.43	0.59±0.11
1986	4.72±0.22	11.59±0.56	1.61±0.07	2.72±0.13	0.40±0.39	0.59±0.10
2000	4.54±0.21	11.09±0.54	1.60±0.07	2.64±0.13	0.40±0.38	0.60±0.10
2014	4.57±0.22	10.73±0.53	1.38±0.06	2.46±0.12	0.42±0.38	0.56±0.09


Photo 1. Chalaati Glacier terminus in 1975 (left) and in 2011 (right). Photos by Gobejishvili, R.G. (1975), and by Tielidze, L.G. (2011).

In 2014, the equilibrium line on Zopkhito Glacier was located at 3,080 m a.s.l. and encompassed cirque basin of an area of 1.69±0.08 km², extending to 3,800 m elevation a.s.l. There was a ~30 m rise in the elevation of the equilibrium line between 1960 and 2014, resulting in a decrease in the accumulation zone of ~0.31 km² over the 54-year period. Using the measured areas of snow accumulation and ablation, we calculate the accumulation-area ratio (AAR) which shows that Zopkhito Glacier's total area decreased at a slightly faster rate than the accumulation area (see *Table 5*). We note, that this insignificant changes of the AAR remain within uncertainties, which means that AAR remained unchanged during the study-period. The comparison of the photos of the glacier terminus shows the change of Zopkhito Glacier over the last half century *(Photo 2).*

Temperature

Our study shows that both glaciers are experiencing constant retreat, except for a short period of re-advance of the Chalaati Glacier. We examine these changes in the context of regional air temperature conditions. The hourly temperature measurements only exist for occasional short (2–3 months) periods at Chalaati (summer 2011) and Zopkhito glaciers (summers 2008–2009), but detailed records are available for the weather station in the settlement of Mestia, located ~7 km down-valley from the terminus of Chalaati

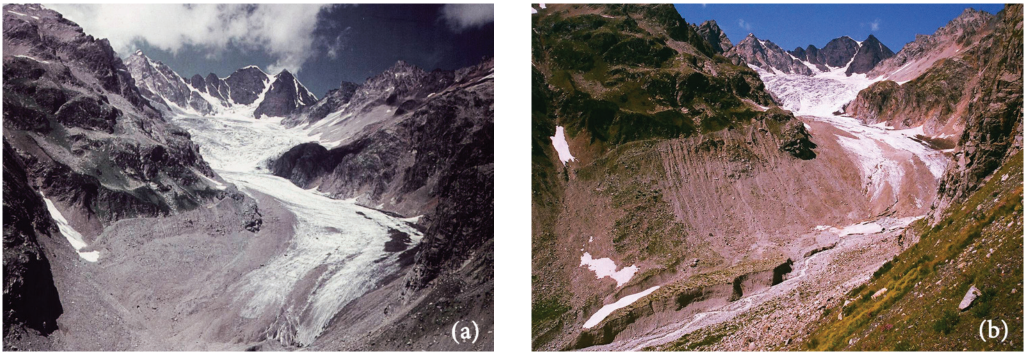

Photo 2. Zopkhito Glacier terminus in 1966 (a), and in 2010 (b). Photos by Inashvili, Sh. (1966), and by Svanadze, D. (2010).

Glacier (~60 km from Zopkhito Glacier), at an elevation of 1,440 m a.s.l. (see location on *Figure 1*). Observations are available for the period between 1960 and 2014.

The summertime hourly temperature measurements at both glaciers are in agreement with the temperature records at Mestia and enable us to compute the empirical lapse rate for the region (-9.8 °C/km between Mestia and Chalaati, and -7.8 °C/km between Mestia and Zopkhito). They also allow us to establish a transfer function that can extend the record of air temperatures at each glacier back to 1960. For the transfer function, we need to confirm that temperatures at both sites are well correlated. A linear regression yields a correlation coefficient of 0.89 between Mestia and Chalaati, and 0.82 between Mestia and Zopkhito *(Figure 5)*, showing a significant correlation between both glacier records and Mestia weather station.

The estimated mean annual temperatures at both glaciers are below to the 0 °C for the entire record. Zopkhito Glacier is colder than Chalaati, as would be expected from its higher elevation terminus (~650 m higher, than Chalaati). In general, the warmest temperatures occur in July *(Figure 6)*, and the melt season (defined as temperatures above 0 °C) lasts an average of 184 days at Chalaati and 145 days at Zopkhito. There has been an increase in the length of the melt season at both glaciers *(Figure 7)*. The in-

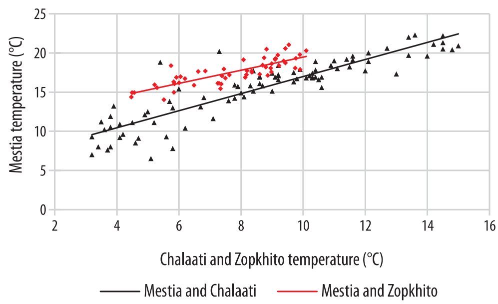

Fig. 5. Correlation between summertime hourly temperature observations at Mestia weather station (1,440 m a.s.l.) in 1960–2014, and local hourly temperatures measured at Chalaati (2,140 m a.s.l.), and Zopkhito (2,700 m a.s.l.) glaciers during the same time.

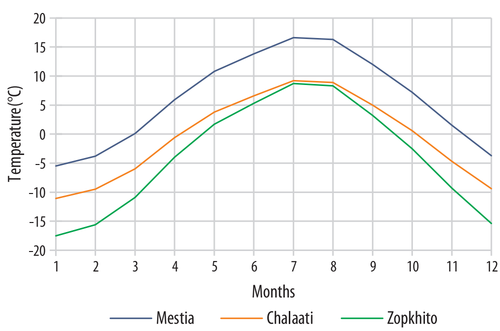

Fig. 6. Average summertime monthly air temperatures (1960–2014) at Mestia weather station (1,440 m a.s.l.), and estimated values at Chalaati (2,140 m a.s.l.), and Zopkhito (2,700 m a.s.l.) glaciers

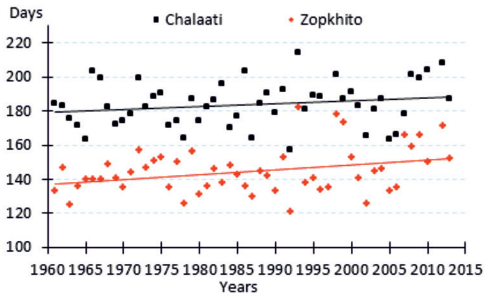

Fig. 7. Duration of melt season for Chalaati and Zopkhito glaciers in 1960–2014 and linear trends.

creasing length of the melt season is consistent with a general trend of warming air temperatures over the period 1960–2014 *(Figure 8)*. We note that because of the very limited observation time, this has to be considered as a tentative estimate of the air temperatures at the glaciers.

Equilibrium Line Altitude

For estimating the equilibrium line altitude (ELA) it is appropriate to use at least two variables, precipitation, and temperature, which represent the effects of accumulation and ablation, respectively (Ohmura, A. *et al.* 1992). Often, the annual mean 0 °C isotherm is also used as the ELA (Källén, E. *et al.* 1979; Oerlemans, J. and Van der Veen, C.J. 1984). For this purpose, we use the Mestia temperature record with calculated empirical lapse rate to estimate the height of the summer (June, July, August) 0 °C isotherm for comparison with the observed (by satellite imagery, 2014) ELA. For Chalaati Glacier, the estimated 0 °C isotherm height is 3,052 m a.s.l., which is ~100 m lower than the observed ELA elevation of 3,155 m a.s.l. For Zopkhito Glacier, the estimated 0 °C isotherm occurs at 3,465 m a.s.l., which is ~400 m higher than the observed ELA at 3,080 m a.s.l. Surface air temperatures are not the sole control on snow line altitude, but lacking information on regional precipitation characteristics, we are unable to fully explain the difference in equilibrium line and summertime 0 °C isotherm altitudes. However, we postulate that the respective aspect of each glacier contributes to the difference in offset between the equilibrium line altitude and the height of the 0 °C isotherm. Chalaati Glacier has a predominantly south-facing aspect, which might mean solar radiation is able to drive additional melting and raise the equilibrium line altitude to above the summertime freezing isotherm. In contrast, Zopkhito Glacier faces predominantly east and is shaded from the sun by a steep ridge, which might allow snow to survive to an altitude below the regional 0 °C isotherm height.

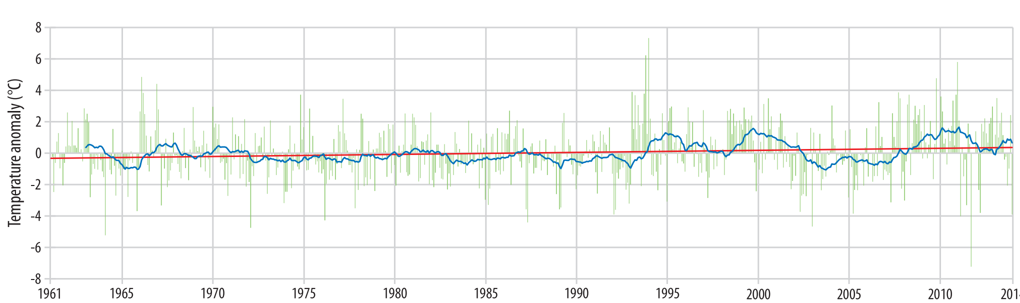

Fig. 8. Time series of monthly air temperature anomalies at Mestia weather station with respect to the 1960–2014 average. A 24 month smoothed anomaly is shown by the thick blue line. The red line is the trend showing a modest increase in warm anomalies with time.

Ablation

Field observations at both glaciers of stake heights exposed by the ablation allow us to examine the role of air temperature on ablation. On the basis of the derived lapse rates, we can use the Mestia temperature record to produce a 'local' temperature record for each stake location and compute the cumulative positive degree days (PDD) for each site (Hock, R. 1999).

The stake observations for Chalaati Glacier were made in summer 2011 at an elevation of 2,040 m a.s.l. The sum of air temperatures and observed ablation in July exceed the same indicators for August. For a 27-day period from July 4 to July 31, the sum of PDDs is 298.8 °C, and measured ablation was 172.5 cm, yielding an ablation rate of ~0.6 cm/PDD. Over a 31-day period from July 31 until August 31, PDDs summed to 289.7 °C, and observed melting was 129.0 cm, corresponding to an ablation rate of ~0.4 cm/PDD. Repeating the analysis for Zopkhito Glacier using observations from 2008 for a stake at 2,700 m a.s.l. yields an ablation rate of ~0.6 cm/PDD in July, and ~0.5 cm/PDD in August. A partial explanation for the difference in derived melt rates is solar angle, which in July is farther above the horizon than in August and, thus, supplies a greater amount of incoming radiation to melt the glacier surface.

Comparison with other studies

Direct comparisons of glacier change with previous investigations in the Greater Caucasus are difficult because most of them do not deal with individual glaciers. Therefore, our rates (0.2–0.3% yr^{-1}) are much lower than other regional studies of glacier changes in the Greater Caucasus; e.g. Tielidze, L.G. and Wheate, R.D. (2018) found generally higher rates of glacier shrinkage for south-facing glaciers during the same investigation period (0.69% yr^{-1}). This high rate can be explained by the disappearance of small glaciers (<0.5 km^2) from the regional study by Tielidze, L.G. and Wheate, R.D. (2018) in 1960–2014.

Comparison to Mount Ararat glaciers (39.70°N, 44.30°E) in the Middle East, show that our rates are significantly higher. The glacier area of Mount Ararat has decreased from 7.98±0.80 km^2 to 5.66±0.57 km^2, equivalent to 29 per cent area loss (or 0.83% yr^{-1}) between 1976 and 2011 (Sarikaya, M.A. 2012). This can partly be explained by the warm and dry climate in the Middle East versus the Greater Caucasus.

The continued existence of glaciers, like Chalaati and Zopkhito, at elevations above the summertime 0 °C isotherm altitude is probably due to their topographic setting (Grunewald, K. and Scheithauer. J. 2010) in which surrounding high peaks and steep slopes promote snow accumulation through avalanching and wind-driven processes. Little is known about accumulation and precipitation patterns in Georgian Caucasus, but any future decrease in precipitation might lead to increased rates of glacier loss as regional temperatures continue to warm.

Since the glacier snout recession is a more sensitive indicator of changes at decadal timescale than area change (Bhambri, R. *et al.* 2012; Leclercq, P.W. *et al.* 2014), we compared Chalaati and Zopkhito glaciers cumulative length changes with other similar types of glaciers from the northern Greater Caucasus. The comparison shows that both glaciers experienced higher retreat rates than the northern counterparts *(Figure 9)*, which is in agreement with other studies suggesting that southern facing glaciers are melting faster than northern ones (Shahgedanova, M. *et al.* 2014; Tielidze, L.G. and Wheate, R.D. 2018). This might be explained by relatively high radiation input in the southern slopes.

Comparison with glaciers from the European Alps shows that Greater Caucasus glaciers are retreating more steadily while the glaciers from the European Alps experience several advancing stages during the same time. Chalaati and Zopkhito glaciers' retreat was also similar in comparison with Sonapari Glacier from Western Himalaya in 1970–2000 period, while it was different in 2000–2016, when Sonapari Glacier experi-

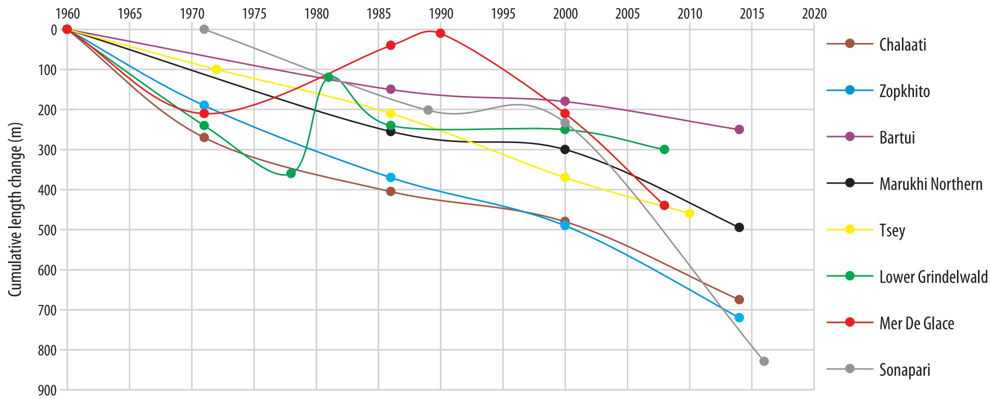

Fig. 9. Cumulative curves of glacier retreat for Chalaati and Zopkhito compared to glaciers from northern slope of the Greater Caucasus (Bartui, Marukhi Northern, Tsey – Solomina, O. *et al.* 2016; Tielidze, L.G. and Wheate, R.D. 2018); European Alps (Lower Grindelwald and Mer de Glace – Zumbühl, H.J. *et al.* 2008); and Western Himalaya (Sonapari – Majeed, Z. *et al.* 2020).

enced its highest retreat rate (~37.3 m yr^{-1}) (Majeed, Z. *et al.* 2020) (see *Figure 9*). These differences can be attributed to different meteorological conditions, orographic units, and morphological types of glaciers between these mountain regions.

Conclusions

We observed a substantial loss in the area of two of the largest glaciers on the southern slope of the central Greater Caucasus, Georgia, between 1960 and 2014 based on an analysis of archival maps, modern satellite imagery, drone survey, and ground-based measurement. The main findings are as follows:

i) Chalaati Glacier lost 16.2±4.9 per cent (~0.30% yr^{-1}) of its area since 1960, while Zopkhito Glacier lost 14.6±5.1 per cent (~0.27% yr^{-1}) over the same period. A slightly greater change in area of Chalaati Glacier might be due to its terminus extending to lower elevations than Zopkhito Glacier.

ii) Chalaati Glacier experienced a terminus retreat rate of ~12.5 m yr^{-1} during the years 1960–2014 with highest retreat rate in 1960–1971 (~24.5 m yr^{-1}), while the Zopkhito Glacier retreat rate was ~13.3 m yr^{-1} over the last half century, with highest rate in 1960–1971 (~17.3 m yr^{-1}).

iii) The equilibrium line altitude has risen by ~35 metres for Chalaati Glacier (from 3,120 m to 3,155 m a.s.l.), and ~30 metres for Zopkhito Glacier (from 3,050 m to 3,080 m a.s.l.) resulting in a decrease in the accumulation zone for both glaciers over the 54-year period.

iv) There has been an increase in the estimated length of the melt season at both glaciers (defined as temperatures above 0 °C) lasting an average of 184 days at Chalaati, and 145 days at Zopkhito.

v) The observed glacier loss is consistent with a 0.2 °C regional rise in near-surface annual air temperature over the last half century period as recorded at a weather station close to both glaciers. An increase in the mean summer temperature (June, July, August) appears to be a particularly important factor in glacier shrinkage, as shown by an increase in the duration of the melt season over the study period.

Glaciers on the southern slopes of the Greater Caucasus are expected to continue their retreat as regional air temperatures rise. This deglaciation will have important consequences for the management of water resources and hydropower generation in Georgia. Further work should focus on more detailed field observations of climatic elements, and instrumental recording of glacier processes such as ablation and supra-glacial debris cover dynamics as well as ELA definition.

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Access to urban green spaces and environmental inequality in post-socialist cities

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Abstract

Access to urban green spaces and environmental inequalities are increasingly on the agenda in contemporary cities due to increasing density of people, widening social inequalities, and limited access to Urban Green Spaces (UGS). This is even so in post-socialist cities where recent urban sprawl and suburbanisation could be strongly linked to the scarcity of adequate green spaces in the inner-parts of cities. This paper examines the provision and accessibility of public green spaces in Debrecen, a second tier city in post-socialist Hungary, with applying a walking distance approach. Using GIS technology and socio-demographic data of residents the study assesses the availability and accessibility of green spaces in the city, and their social equity. According to research results the geographical distribution of UGS is very uneven in the city, some neighbourhoods lack public green spaces, while others are well-supplied. This is partly due to the natural environment and the post-WWII development of the city. Research findings show that the quality of residential green spaces is generally poor or very poor. Research also confirmed the widening environmental inequalities within the local society. New upmarket residential areas, where the wealthiest section of population reside are rich in high-quality (private) green spaces. Other lower-status neighbourhoods, including some of the socialist housing estates, suffer from the lack of good quality green spaces. Authors argue that environmental justice should be a core concept of city-planning considering not only the officially designated public green spaces, but also other forms of urban green (institutional, private etc.).

Keywords: urban green spaces, post-socialist city, accessibility, residential well-being, environmental inequality, environmental justice, fixed walking distance.

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Introduction

Urbanisation has been witnessing an unprecedented growth rate over the last decades. According to the United Nations (2018), 55 per cent of the global population live in cities today, and urban ratio is expected to increase to 68 per cent by 2050 (UN 2018). (Over)urbanisation creates many problems due to increasing density of people, widening social inequalities, limited access to public amenities, and relative disregard for environmental aspects which altogether threaten the liveability of cities. According to the WHO (2017), green spaces and other nature-based solutions offer innovative approaches to increase the quality of urban settings, enhance local resilience, promote sustainable lifestyles, and improve both the health and the social well-being of residents.

Urban green spaces (UGS) comprise different types of vegetated spaces in urban areas, both natural and semi-natural, irrespective of

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their size, ownership and function. The most typical forms are forests, public parks and gardens, institutional green spaces, playgrounds, sport fields, street trees, nature conservation areas, garden walls, cemeteries, but also community and private gardens (Saelens, B.E. and Handy, S.L. 2008; Wolch, J.R. *et al*. 2014; Cvejić, R. *et al.* 2015). The magnitude of the positive environmental effects and the complexity of the ecosystem services provided by urban green spaces are highly influenced by their physical parameters (e.g. the size of the area, the dominant vegetation type), their basic functions (street trees, playgrounds, etc.) and geographical location within cities.

When considering the relevance of urban green for human well-being we should take into account both environmental and social effects. A growing body of literature suggests that UGS positively contribute to healthy environment in urban areas by improving air quality and reducing the urban heat island effect (Yang, P. *et al.* 2016; Yu, Z. *et al*. 2018; Aram, F. *et al.* 2019). Green spaces absorb a significant amount of hazardous substances from the air as leaves act as a kind of natural filter. A United States study, as cited by Cicea, C. and Pîrlogea, C. (2011), estimated that dust levels in an urban park in the State of Georgia were 60 per cent lower than outside the park. In addition, urban green spaces (primarily parks) contribute to the reduction of sound emission generated by road traffic (Brambilla, G. *et al*. 2013; Hong, J.Y. and Jeon, J.Y. 2013). UGS also have an important ecological role (Li, H. *et al*. 2015), as they contribute to biodiversity preservation by providing habitats for great number of plants and animals (Threlfall, C.G. *et al*. 2017; Lv, Z. *et al*. 2019).

In addition, one of the most important ecosystem services of urban green spaces is that they provide recreational opportunities for residents, and facilitate social interaction and cohesion (Vargas-Hernández, J.G. *et al*. 2018; Biedenweg, K. *et al*. 2019; Iraegui, E. *et al.* 2020). In our (over)urbanised world, the regular use of urban green spaces stimulates cognitive, emotional, and psycho-sociological benefits, contributing to the reduction of constant stress and mental tiredness and the improvement of attention and memory (Ulrich, R.S. *et al*. 1991; Hartig, T. *et al.* 2003; Berto, R. 2005; Berman, M.G. *et al*. 2008; Hedblom, M. *et al*. 2019). Some urban green spaces, primarily parks, provide not only aesthetic experience but also allow people to participate in sports and other physical activities, children to use playgrounds, and older people to relax. A large body of literature has highlighted the positive effects of green spaces for mental and physical health conditions (Bedimo-Rung, A.L. *et al*. 2005; Cohen, D.A. *et al*. 2007; Kaczynski, A.T. and Henderson, K.A. 2007), enforcing healthy living and reducing the rate of chronic diseases and mortality (Wolch, J.R. *et al*. 2014). By the beginning of the 21st century, the ecosystem services provided by UGS have become an extremely significant factor in the liveability of cities (McCormack, G.R. *et al*. 2010; De Valck, J. *et al*. 2016; Larson, C.L. *et al*. 2018; Lu, Y. 2019) and a cornerstone of current urban planning debates (Haaland, C. and van den Bosch, C.K. 2015; Littke, H. 2015; Anguluri, R. and Narayanan, P. 2017).

Obviously, not every type of green space is capable of providing the above services and functions in a complex way, or even partially (Mexia, T. *et al*. 2018). For example, street trees are primarily responsible for providing shade and filtering air pollution and sound generated by road traffic but are less suitable for providing recreational opportunities, and a grass-covered green space is less effective at reducing the urban heat island effect than a forest. Planners strive to ensure urban green spaces that are capable of providing complex ecosystem services (Bolund, P. and Hunhammar, S. 1999; Xu, L. *et al*. 2016; Chang, J. *et al*. 2017).

Access to urban green is a key question when it comes residential well-being all over the world and it is even so in former state-socialist countries. New housing construction during state-socialism concentrated predominantly in high-rise housing estates on empty spaces within city limits maintaining a compact urban form as opposed to capitalist cities (Sýkora, L. 2009). However, in the 1970s and 80s during the mass-production of uniform pre-fab dwellings little attention was paid to the proper provision of infrastructure and services, including green spaces (Benkő, M. 2016). After 1990 post-socialist urban transition could be characterized by dynamic changes of urban spatial structure. The compact physical morphology of former socialist cities started to vanish quickly due to urban sprawl (Bičík, I. and Jeleček, L. 2009; Tammaru, T. *et al.* 2009; Slaev, A.D. *et al*. 2018; Kovács, Z. *et al*. 2019). Urban sprawl has been enabled by several factors, including the privatization of land, the decentralisation of planning rights, the increasing car ownership and the growing desire of people to live in single-family homes at peri-urban locations (Szemző, H. and Tosics, I. 2005; Pichler-Milanović, N. *et al*. 2008). However, as recent findings of Koprowska, K. *et al*. (2020) demonstrated urban sprawl in post-socialist cities could also be strongly linked to the scarcity of adequate green spaces in the inner-parts of cities. Hence, if post-socialist cities want to successfully cope with urban sprawl, planners and city administrators should pay more attention to the development of urban green spaces.

The aim of this paper is to examine the accessibility of public green spaces in Debrecen, the second largest city in Hungary with over 200 thousand inhabitants, by employing a walking distance approach. The main aim is to analyse the availability and accessibility of the city's public and other green spaces, and to assess their social equity. The specific objectives of the research are as follows:

Firstly, we want to define the UGS of the city, with special attention to residential and institutional green spaces that are not defined as 'public green spaces' by the Zoning Plan of the city, although, regarding their physical appearance and services they can be considered equivalent to public green spaces.

Secondly, we would like to analyse the accessibility of urban green spaces (including residential and institutional green spaces) by the walking distance approach.

Thirdly, we aim to analyse the socio-economic and demographic profile of residents living in the catchment areas of green spaces.

Accessibility of urban green spaces: a literature review

The importance of urban green spaces and their accessibility has been widely recognised by researchers, urban planners and decision-makers (EC–UN-Habitat 2016; Poelman, H. 2016; Kolcsár, R.A. and Szilassi, P. 2017). Next to the general access to urban green spaces a growing body of literature investigates the question whether urban green is equitably distributed in relation to socio-economic status of residents. Thus, the provision of urban green is increasingly recognised as an environmental justice issue which has necessarily brought about the refinement of methodology (Wolch, J.R. *et al.* 2014).

There are several approaches to measure accessibility of urban green. One of the most popular accessibility models is based upon the fixed distance approach, which adopts a fixed distance from assumed origins and counts the number of destinations that can be reached (Reyes, M. *et al*. 2014). To express accessibility more adequately, it is necessary to transform walking time into walking distance. For instance, Smoyer-Tomic, K.E. *et al*. (2004), Hoffimann, E. *et al*. (2017), and Wei, F. (2017) employed a walking distance of 800 metres as the equivalent of 10 minutes walking time. In contrast, Barbosa, O. *et al*. (2007) adopted the recommendation of the European Environment Agency (EEA) according to which green spaces should be accessible within 15 minutes walking time, and applied walking distance thresholds of 300 and 900 metres. Moreover, the WHO recommends that green spaces should be located within 5 minutes walking time, that is, within a walking distance of 300 metres (WHO 2017).

The same distance appears in the Accessible Natural Green Space Standard (ANGSt) being applied in the United Kingdom. The ANGSt suggests that public parks lying within a walking distance of 300 metres must have at least 2 hectares in terms of area (the larger the park in terms of area, the longer the walking distance can be) (Balfour, R. and Allen, J. 2014). Similarly, Cömertler, S. (2017) investigated the green infrastructure of European capital cities by using an accessibility distance of 300 metres, and Grunewald, K. *et al*. (2017) employed two specific distances based on different approaches: a straight-line distance of 300 metres and a path distance of 500 metres. Boone, C.G. *et al*. (2009) used a walking distance of 400 metres to determine park accessibility when exploring environmental justice in Baltimore, Maryland. Iraegui, E. *et al.* (2020) argue that the size of green space matters when measuring its capability to host adult physical activity, therefore, they propose 5 hierarchical categories according to the functional level, maximum walking distance and minimum size of UGS.

Chen, J. and Chang, Z. (2015) cited the Hong Kong Planning Standards and Guidelines published by the Hong Kong Planning Department, which recommends that local open spaces should be located within a short walking distance from the residents, preferably within a radius of fewer than 500 metres. To investigate environmental justice in different geographical environments, De Sousa Silva, C. *et al*. (2018) chose two contrasting cities as case studies: a post-communist city (Tartu, Estonia) and a Mediterranean city (Faro, Portugal). When outlining the buffer zone of those cities, walking distances of 300 metres (i.e. a walking time of 4 minutes) and 500 metres (i.e. a walking time of 7 minutes) were applied. Schipperijn, J. *et al*. (2010) carried out a survey to obtain information on the relative importance of factors influencing park users in Odense, Denmark, and they chose 600 metres to be a reasonable accessibility distance.

Kaczynski, A.T. *et al*. (2009) investigated how the number and the size of parks within 1,000 metres from residents' homes as well as distance to the closest park are associated with moderate-to-strenuous physical activity. Similarly, Paquet, C. *et al*. (2013) used a walking distance of 1,000 metres to examine the accessibility of green spaces, and in their opinion this distance equates to an estimated walking time of 12 minutes (at a walking pace of approximately 5 km/h). Furthermore, Lu, Y. (2018) applied a buffer zone with a radius of 1,000 metres to reveal the connection between street greenery and physical activity. In contrast, Dempsey, S. *et al*. (2018) investigated the relationship between green space accessibility and obesity in older people and chose 1,600 metres as a reasonable walking distance (associated with a walking time of 20 minutes). In their pioneering work Wüstemann, H. *et al*. (2017) defined "walking distance" as a maximum distance of 500 m in their analysis on access to urban green spaces and environmental inequalities in German major cities by merging geo-coded household data from the German Socio-Economic Panel (GSOEP) and Population Census Data with land use data from European Urban Atlas. Finally, Reyes, M. *et al*. (2014) examined the aspects of green space accessibility of children in Montreal, applying an accessibility time of 15 minutes by making it equivalent to a walking distance ranging from 810 metres to 1,350 metres.

As it has been demonstrated the definition of walking distance is influenced by several factors, including a reasonable walking time (ranging from 4 to 15 minutes in the cited papers) being transformed to distance, the size of the green space in terms of area, the dominant ecosystem services the green space provides, the type of the vegetation coverage, the transport mode used to approach the green space (e.g. walking, cycling, public transport), and the age characteristics of users (e.g., children, young adults, older people).

Data and method

The definition of 'urban green spaces'

In Hungary, 'public green space' is a legally defined and regulated zoning category; consequently, each public green space located in a given municipality must be included in the Zoning Plan. Accordingly, the National Urban Planning and Building Requirements (NUPBR) regulates the fundamental features, physical parameters, and ecosystem services of public green spaces. The NUPBR classifies public green spaces into two subcategories: the public park and the public garden. According to the description of the NUPBR, public green spaces (both public parks and public gardens) are public open spaces permanently covered by vegetation with the goal to improve the climatic conditions, protect the ecological system of settlements, and provide opportunities for inhabitants to relax and participate in sports and physical activities.

Unlike public parks and gardens, residential and institutional green spaces are not recognised and mapped in the Zoning Plan. They comprise 'residential areas' and 'institutional areas' covered by green, regardless of how large they are or how they are frequented by daily green space users. Common feature of these spaces is that they do not qualify as public spaces, because they are owned by either a community (residential estate) or an institution. In addition, some residential green spaces do not meet the planning criteria of the NUPBR (their built-up ratio exceed the maximum limit as indicated in the NUPBR). However, they are freely available to anyone most of the time, therefore, we decided to consider them during the analysis. In this study, we consider 'public', 'residential' and 'institutional' green spaces together as '*urban green spaces*'. During the research a total number of 99 urban green spaces were identified in Debrecen. The geographical location of the inner urban UGS is highly concentrated, as the vast majority of them are located in the northern, north-western, and south-western districts of the city *(Figure 1).* In contrast, the eastern, south-eastern, and southern parts of the city host few public green spaces.

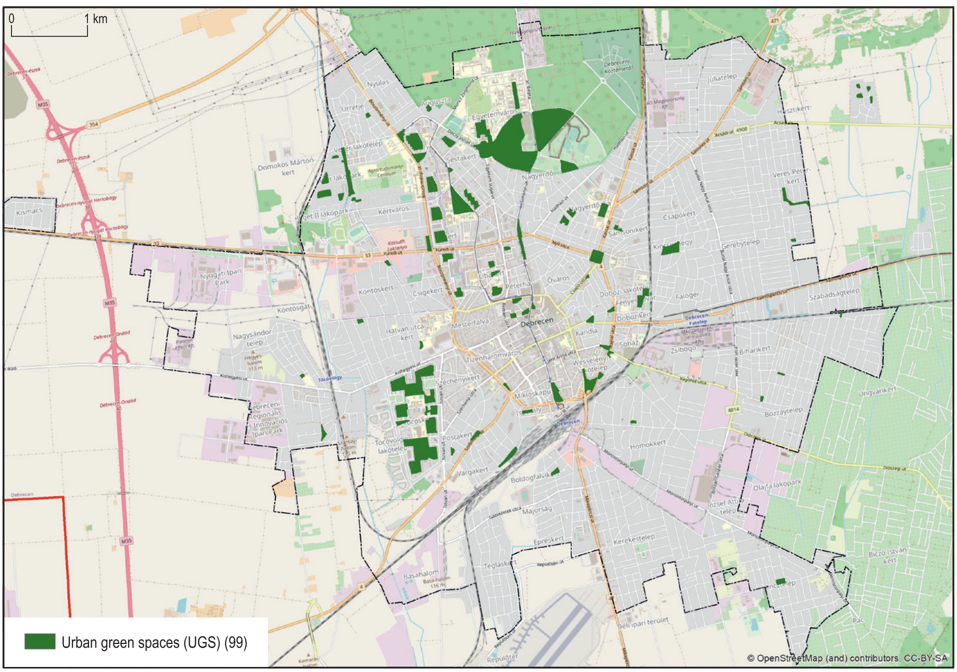

Fig. 1. The geographical location of urban green spaces in Debrecen, Hungary. *Source*: Own survey, 2020.

The assessment of urban green space accessibility by walking distance

In this research a walking distance of 300 metres has been applied as a fixed distance. This can be justified by two factors. First, Debrecen is one of the largest municipalities in Hungary by size: its administrative area covers 461.58 km^2. However, the inner urban area, being home to 92.78 per cent of the local population, is as small as 70.49 km^2. Furthermore, the East–West diameter of the inner urban area is 9.72 km, and the North–South diameter is 7.80 km. Given the relatively small and compact inner urban area of the city, it is reasonable to employ a shorter walking distance. For example, Smoyer-Tomic, K.E. *et al.* (2004) applied a walking distance of 800 metres in the case of Edmonton, Alberta; However, the built-up area of the Canadian city is 572 km^2 (i.e. eight times larger than that of Debrecen). Second, the average size of urban green spaces in the city is relatively small: 1.46 hectares per green space and only 1.05 hectares without the area of the largest city-park called 'Nagyerdő', located in the North.

Primary and secondary datasets

The UGS of Debrecen (as we understand it) are not properly designated and mapped by the planning documents of the city. Therefore, it was necessary to identify them by using satellite images from Google Maps and then investigate them via fieldwork. After compiling an inventory of green spaces in the city, each area was visualised by using Google My Maps. To map the accessibility area of green spaces, a fixed distance of 300 metres was measured on each street and road heading towards the green space. After measuring and fixing each border vertex lying 300 metres from the perimeter points of the green space, the border vertices were linked, and the accessibility polygon was created.

To explore the quality and functions of urban green spaces, each of them was explored individually. During the fieldwork, the functions of each UGS were determined and classified into the following categories: none, passive, active, playground and the combination of these. Also, a detailed photo documentation containing approximately 1,500 photos was performed. Both the photo documentation and the description of the UGS have been uploaded to the Google Maps profile of that green space.

The assessment of UGS was based on the examination of their physical appearance, the quality of the vegetation and that of the infrastructure. In addition, when investigating the quality of UGS we also considered whether they were maintained and cleaned properly. Based on the outcome of the quality assessment we classified UGS into five quality categories which are as follows: 1) very poor, 2) poor, 3) medium, 4) good, and 5) very good. Some UGS, particularly those being surrounded by block-like buildings, are currently under revitalization. We marked these UGS with "R".

In addition to the primary survey data, we used the 100 x 100 m purchasing power database issued by GeoX Limited. This is a grid-based dataset in WGS84 coordinate system, which covers the inhabited area of Debrecen. Each grid cell has 29 attribute data assigned to it, which represent territorial identification data, demographic and social indicators, or special traffic indexes. We also used ArcMagyarország, Open Street Map and ESRI aerial imagery as basemap layers in our analysis.

Methods of GIS and statistical analysis

For detailed geographical analysis, the polygons of the UGS and their 300 metres accessibility zones were imported to ArcGIS. The data connection of green spaces and 300 metres buffer zones with demographic and social indicators was a two-step process: 1) we generated centroid points for each grid cell, 2) the centroid points were connected to each UGS and buffer zones based on spatial location (ArcGIS-Spatial Join function).

To determine the broader 'service area' of UGS, we used the 'Thiessen polygon' and the

'Near' functions of ArcGIS. The former converts points coverage (centroids of UGS) to Thiessen (Voronoi) proximal polygons while the latter calculates the geodesic distance of each grid cell centroid to the nearest buffer zone. The results of these give us quasi accessibility indication for the areas outside of the 300 metres accessibility zones.

We also carried out spatial autocorrelation of mean income to map their spatial clusters in the study area. In the first step, we used the Global Moran's I function of ArcGIS to examine whether they form spatial clusters. Next, we carried out an incremental analysis to determine the optimal cut off distance. Finally, we mapped the clusters and outliers with the Anselin Local Moran's I function of ArcGIS. As a result, five clusters were defined:

1. high-high clusters: 100 x 100 m cells characterized by high values and surrounded by cells with similarly high values;
2. high-low outlier: cells with high values surrounded by cells with low values;
3. low-high outlier: cells producing low values surrounded by cells with high values;
4. low-low clusters: cells producing low values surrounded by cells with similarly low values;
5. not significant: the cell pattern does not fit into any cluster.

When doing so, we investigated the relationship between the quality of UGS and the mean income of people living in the 300 metres accessibility zones.

Finally, we carried out a Spearman's rank-order correlation analysis in SPSS to reveal the connection between the population density of the 300 metres buffer zones and the quality of UGS. To match green space quality ranks, we used the 'Natural Breaks' method of ArcGIS classification engine to classify the accessibility zones by their population density into five classes.

Results

Accessibility of urban green spaces

Using the 300-metre walking distance method we can say that the catchment areas of UGS are highly concentrated, as most of them are located in the central part of the inner urban area of Debrecen *(Figure 2).*

The cumulative accessibility area covers only 21.6 per cent of the inner urban area, but hosts 45.9 per cent of the city's population. If the 300 m catchment area is extended by 200 m, we find that almost two-thirds (66.2%) of the city's population live within a 500 m distance from an UGS. However, from the Northeast to the South, the inner urban area is encircled by outskirts being home to approximately 16.3 per cent of the city's population (32,400 people) for whom there is no single accessible UGS within 1,000 metres or more (see *Fig. 2* and *Table 1*).

Based on the Thiessen polygon scheme we can conclude that green spaces being located on the edge of the inner urban area are the closest green spaces for people living in the outskirts. This approach clearly demonstrates the enormous spatial inequalities regarding the location of urban green spaces in Debrecen. On

Table 1. Main features of accessibility categories

Distance to green space, m	Number of households	Percentage of households	Number of population	Percentage of population
0– 300	39,365	51.60	91,526	45.93
301– 500	15,572	20.41	40,536	20.34
501–1,000	11,485	15.06	34,793	17.46
1,001–1,500	3,981	5.22	13,551	6.80
1,501–7,199	5,880	7.71	18,881	9.47
Total, 0–7,199	*76,283*	*100.00*	*199,287*	*100.00*

Source: Own calculations based on survey and GeoX database, 2020.

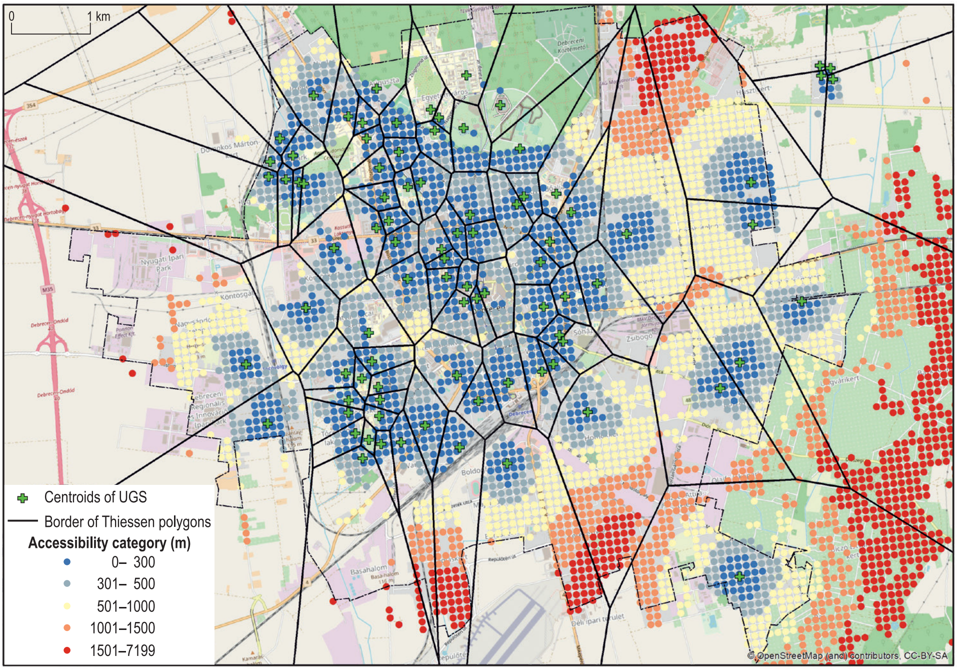

Fig. 2. The geographical pattern of accessibility of UGS and Thiessen polygon scheme. *Source*: Own calculations based on GeoX database, 2020.

the one hand, the 'Nagyerdő Park', being the largest urban green space in the northern part of the city, and covering 42.0 hectares, it is the closest UGS only for 750 people according to the Thiessen polygons. It means, that the ratio of the area of 'Nagyerdő Park' and the number of park users for whom it is the closest UGS is only 18 people/hectare. On the other hand, the 'Tócóskert' neighbourhood with high-rise buildings is the most populous residential area in Debrecen being home to approximately 17 thousand people. However, the Thiessen polygon scheme suggests that the UGS located in 'Tócóskert' satisfy the needs of almost 23,500 people. This neighbourhood, however, hosts two urban parks and several larger green spaces which have a total area of 27.57 hectares. Due to this fact, the relative number of green space users in Tócóskert is nearly 50 times higher (i.e. 850 people/hectare) compared to 'Nagyerdő Park', but still rather low compared to the eastern belt of the compact city. In the eastern neighbourhoods of Debrecen, the total area of nine UGS is only 5.86 hectares, and they are the closest UGS for 52,895 people, most of whom live in low-rise outskirts. We can note, that reaching 9,026 people/hectare, the relative number of green space users is extremely high in the eastern sector of the city.

The differences of green space accessibility of people living in particular neighbourhoods also confirm robust spatial inequalities. *Figure 3* shows that in the central part of the inner urban area, residents have more than one options to access an UGS within 300 metres. Those residential areas that were established in the socialist era and contain high-rise buildings of 4–10 storeys, particularly the 'Tócóskert' housing estate, offer the greatest number of options for people to access UGS. The north-western residential quarters with single-family homes inhabited by affluent people are also relatively well-supplied by green spaces.

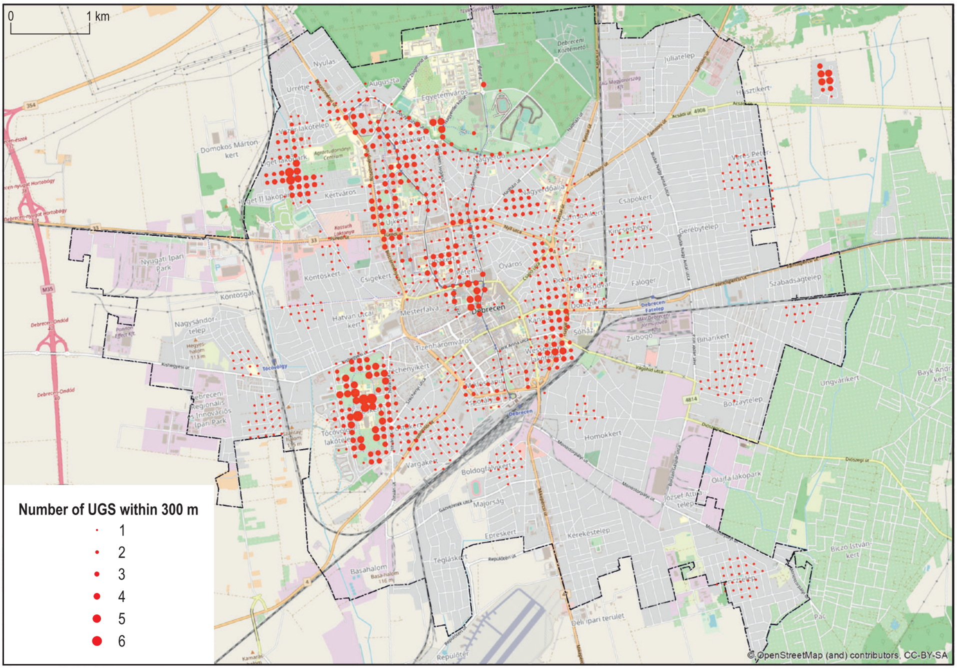

Fig. 3. Accessibility options in terms of the number of urban green spaces available for people living in particular neighbourhoods. *Source:* Own calculations based on GeoX database, 2020.

Sharp differences can be observed regarding the socio-economic characteristics of people living in particular accessibility categories. As *Table 2* demonstrates, those people who live closest to UGS (i.e. within 500 metres), are generally more educated. In addition, the ratio of elderly (i.e. people over 63) is the highest in these areas, whereas the ratio of young people (i.e. people below 18) is the lowest. In contrast, those people who live in the outskirts, particularly those who live 1,500 metres or more from UGS, are the least educated. Furthermore, the age structure of people living in the outskirts is quite the opposite as among those people living in 300 and 500 metres distance from UG: the ratio of children is high and that of old people is rather low. *Table 2* shows that there is

Table 2. Socio-economic characteristics of accessibility categories

Distance to green space, m	Mean income, HUF/year	Percentage of college graduates	Percentage of people aged	
			below 18	over 63
0– 300	1,368,353	26.0	15.81	23.83
301– 500	1,368,009	30.3	18.24	22.36
501–1,000	1,301,545	25.2	18.92	20.72
1,001–1,500	1,316,755	19.5	20.86	18.84
1,501–7,199	1,322,700	14.3	20.22	17.03
Mean value	*1,348,786*	*25.2*	*17.61*	*22.01*

Source: Own calculations based on survey and GeoX database, 2020.

no significant difference between the mean income of people located closest to UGS and those living in the outskirts.

Relationship between the quality of urban green spaces and their socio-economic environment

It is an important objective of this study to find out whether there is any relationship between the quality of UGS and the socio-economic background of their potential users. According to *Table 3* most UGS in Debrecen fall in the categories of medium and poor based on their quality. The total area of medium quality UGS is the largest, however, for the majority of people, only poor quality UGS are available within 300 metres. The total area of UGS with very good quality is less than 10 hectares, and they provide easy accessibility only for very few people (i.e. 3.14% of the population) within 300 m distance.

Considering the UGS-quality vs. socio-economic environment, we first examined the relationship between the quality of UGS and the mean income of people living nearby by using spatial autocorrelation clusters.

As can be seen in *Table 4*, the majority of Debrecen's population lives in high-high clusters (42.66%) and low-low clusters (23.73%). Thus, the city is highly polarised. The mean income in high-high clusters is 17 per cent higher than in low-low clusters. In addition, the high-high clusters host more educated people than the low-low clusters.

If we examine the spatial distribution of UGS by cluster types, it can be seen that the western part of the inner urban area of Debrecen is characterized by high-high clusters and low-high outliers *(Figure 4).* These clusters host most of the UGS. The north-western neighbourhoods particularly belong to high-high clusters (i.e. people residing in these neighbourhoods have high mean in-

Table 3. The quality classification of UGS and relevant data

Quality of UGS	Number of UGS*	Total area of UGS, ha	Number of households	Number of people
			living within 300 m*	
Very poor	4	1.84	1,086	2,749
Poor	26	40.33	30,906	74,315
Medium	32	47.97	19,164	44,318
Good	20	38.08	9,433	21,229
Very good	12	9.60	2,608	6,248
Under revitalization	5	6.42	7,088	14,760

*Due to overlaps, a person can be assigned to more than one UGS. *Source*: Own calculations based on survey and GeoX database, 2020.

Table 4. Summary statistics of clusters in terms of mean income

Clusters	Mean income, HUF/year	Number of households	Population number	Mean population density, people/km²	Percentage of graduates	Mean UGS quality
High-high	1,429,689	37,221	85,007	7,657.70	29.3	3.00
High-low	1,383,998	3,988	11,967	2,750.82	22.8	3.59
Low-high	1,278,626	8,599	21,814	7,058.99	26.5	2.75
Low-low	1,230,668	15,956	47,287	2,836.43	21.9	3.19
Not significant	1,343,281	10,519	33,212	1,890.12	25.2	2.87

Source: Own calculations based on survey and GeoX database, 2020.

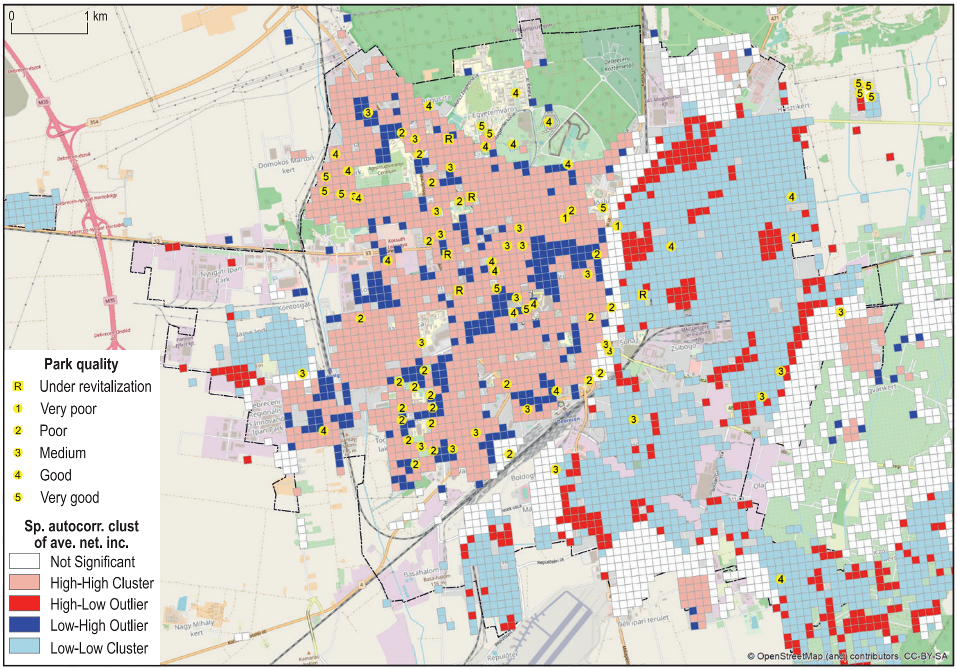

Fig. 4. The quality of UGS and the geographical pattern of clusters regarding mean income. *Source*: Own calculations based on GeoX database, 2020.

come), and these neighbourhoods host the best quality UGS as well. As an opposite, the eastern and the south-eastern parts of Debrecen are dominated by low-low clusters. In these neighbourhoods there is only a few UGS with medium quality.

In the study, the relationship between population density of the 300 m accessibility zones and the quality of UGS was also examined *(Table 5)*. To explore this aspect, a Spearman's rank-order correlation was performed, which showed a moderate negative correlation between the two variables, which is statistically significant (r_s = -.450, $p < 0.01$).

Considering data in *Table 5*, we can conclude that UGS with the poorest quality are located in areas with higher population density. It is assumed that this reflects an over-

Table 5. Population density classes vs. UGS quality

Population density categories of 300 m accessibility zones	Number of UGS*	Mean population density, people/km^2	Minimum	Maximum	Mean UGS quality
			population density		
Low	23	1,197.0	399.7	2,221.0	3.7
Below average	29	3,447.5	2,566.2	4,979.6	3.3
Average	15	7,046.6	5,331.8	8,608.8	2.7
Above average	11	11,008.2	9,158.4	12,634.3	2.5
High	16	16,701.1	14,343.8	19,975.3	2.6

*Without those UGS which are under revitalization. *Source*: Own calculations based on survey and GeoX database, 2020.

use of UGS being located in densely inhabited areas. In addition, if examining data in *Table 4*, a relationship between the quality of UGS and the mean income of people around the UGS can be observed. In the case of high-high clusters in terms of mean income an overall medium UGS quality can be seen, whereas, irrespective of the lower population density, the low-high outliers produce an UGS quality below the mean level. These results suggest that high income people living in the north-western part of Debrecen are provided with better quality UGS as compared to those living in the less wealthy neighbourhoods (see *Figure 4*). Surprisingly, the low-low cluster hosts better quality UGS than the high-high cluster (i.e. the cluster where wealthier people reside) because, due to the low population density characterizing the low-low cluster, the negative effect of overuse is less significant.

Discussion and conclusions

In this study, the analysis of accessibility and the qualitative assessment of urban green spaces (UGS) in Debrecen allowed us to reveal both some specific features for the city, and some generalisations for post-socialist cities.

Considering the case-study of Debrecen the role of physical geographical features and historical pathway of urban development can be emphasised in the contemporary provision of UGS. The city is lying at the boundary of two distinct physical geographical regions: Hajdúság with fertile chernozem soil in the West, and Nyírség covered by sandy soil in the East. Historically, the eastern periphery of the city has been covered by afforested areas mixed with lakes and pasture, whereas the western peri-urban zone has been traditionally used for crop production. When the city started to grow in the post-WWII period most of the major housing development projects were concentrated in the western half of the city, in the form of high-rise housing estates. Given the high concentration of new residents these housing estates had to be supplied with green spaces to satisfy the needs of people. However, green areas developed during state-socialism were mostly 'residential' and 'institutional' green spaces and were not qualified as public green spaces. At the same time, the eastern half of the city, with low-density housing, became neglected regarding green surface development. In this part of the city only a few UGS are available even today in a reasonable walking distance. For most of the people living in the eastern and southern outskirts there is no UGS within 1,000 m or more, and the closest ones are typically small-sized playgrounds with hardly any amenities. Research also showed that the 'Nagyerdő Park', the largest public green space of Debrecen, located on the northern edge of the inner urban area is not accessible for the majority of residents on foot.

Based on research findings we can conclude that in the future planning and development of green spaces in Debrecen should focus on the eastern and southern outskirts of the city in order to reduce the spatial inequalities of UGS. The accessibility of UGS for all the people living in the city should be in line with the principles of spatial justice, a concept that has emerged recently and is of high importance in contemporary urban planning (Soja, E.W. 2010). In addition, greater emphasis should be placed on improving the accessibility of the 'Nagyerdő Park' by public transportation and bicycle.

Looking beyond the Debrecen-specific findings, we can also conclude some generalisations for post-socialist cities in Hungary and Central and Eastern Europe. The development of Debrecen's residential areas clearly reflects social polarization that has emerged since the early 1990s (the geographical context of social polarization is examined by, e.g. Hamnett, C. 1994; Wessel, T. 2000; Lemanski, C. 2007; Modai-Snir, T. and van Ham, M. 2018). A significant proportion (ca. 30%) of the local population lives in neighbourhoods characterized by high-rise housing estates built in the socialist era, whereas a much smaller group of residents lives in upmarket residential compounds protected by fences, and gates. The former zones contain poor-quality UGS surrounded by rows of 4 to 10-storey buildings and are characterized by high population density *(Figure 5).* These neighbourhoods are generally overcrowded with cars due to the limited number of parking spaces. The most typical example of this type is the 'Tócóskert', the largest and most populous housing estate in Debrecen.

New upmarket residential areas, however, are home to the wealthiest section of population in Debrecen, who live in newly built villas, row houses and gated compounds with high-quality (private) UGS in the centre of the neighbourhoods, equipped with tennis courts and playgrounds *(Figure 6).* In Hungary and other post-socialist countries, gated communities have emerged since the early 1990s and they are particularly typical in capital cities (e.g. Budapest and its agglomeration) as well as in other rapidly growing second-rank cities in the countryside (e.g. Debrecen, Győr, and Kecskemét) (Hegedűs, G. 2009; Kovács, Z. and Hegedűs, G. 2014). In the case of Debrecen, gated communities have been established on the edge of the inner urban area, increasing the size of the city's built-up area; however, since the late 1990s they have been fully incorporated into the city. In addition, some newly created suburban gated communities are located 5–10 kilometres from the inner urban area, predicting the directions of the city's future expansion.

In the future urban planners in Hungary (and in other post-socialist countries) should seriously consider challenges of spatial inequalities of UGS. Environmental justice should be a core concept of city-planning considering not only the officially designated public green spaces, but also other forms of urban green (institutional, residential, private etc.). Planners should strive to make fair balance among different types of neighbourhoods and their residents regarding the sup-

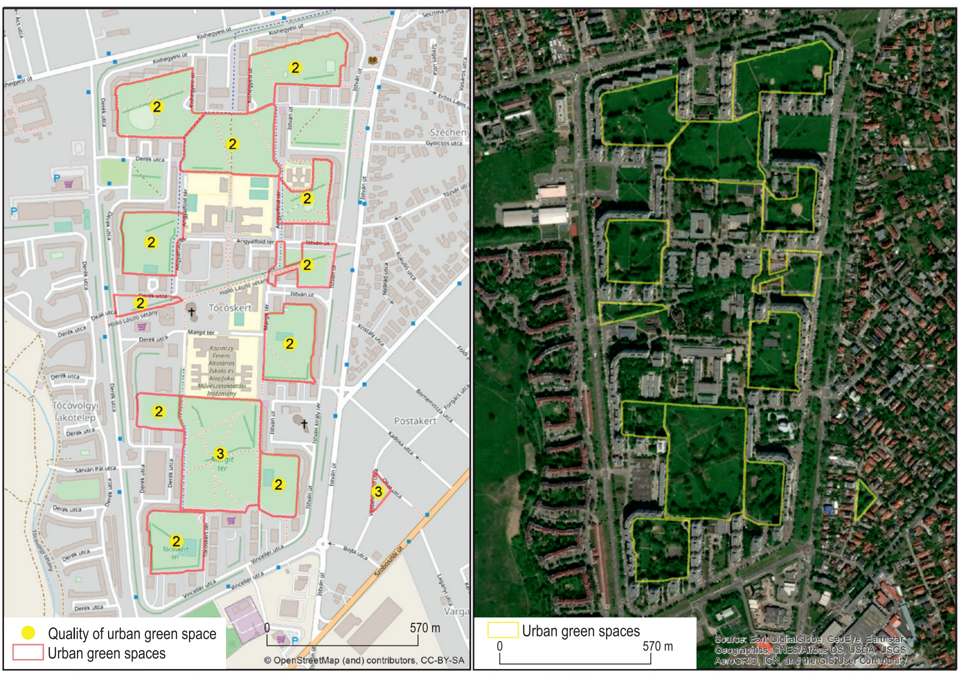

Fig. 5. The 'Tócóskert' neighbourhood, a high-rise housing estate with pre-fab buildings of 4- to 10-storeys and poor quality urban green spaces. *Source*: Own design using Google My Maps.

Fig. 6. A gated community for the wealthiest section of the population with high quality urban green spaces in Debrecen. *Source*: Own design using Google My Maps.

ply, accessibility and quality of green spaces. To support the planning process of environmentally more equitable cities the walking distance approach combined with socio-demographic data analysis can be a useful tool.

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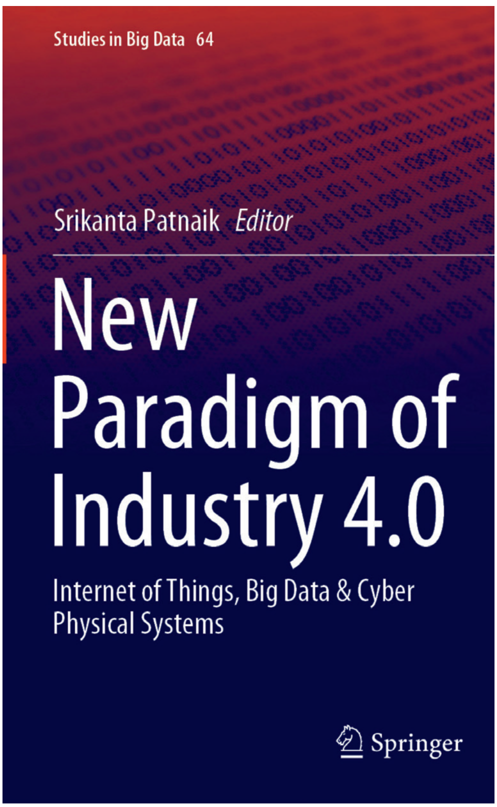
BOOK REVIEW SECTION

Patnaik, S. (ed.): New Paradigm of Industry 4.0: Internet of Things, Big Data & Cyber Physical Systems. Bhubaneswar, Springer, 2020. 180 p.

Are we going fast enough to cope? This is the most frequent question that has been asked over the companies since 2011. It was the year that has introduced the fourth industrial revolution to our lives that became one of the biggest debates among companies, politicians, scholars, and even the primary school teachers. So, are we going in the right direction to cope with this revolution in our life? This is a big question, which needs a bigger answer. However, with the uncertainty that we have in our life caused by natural disasters as well as human-made disasters, are we able to cope with this revolution in the sake of managing the unforeseen and to promote a better life for human beings? This book is an attempt to give an overview of the issues that organisations are facing in adopting Industry 4.0, now and later. For sure, it cannot answer the whole question, but discusses a wide range of Industry 4.0 related issues, future models and the development of a set of sustainable management tools to cope with this revolution to close the gap between academic investigations and actual feasibility.



The book editor, Professor Srikanta Patnaik has already written several publications in connection with the new technological revolution. The book has eight chapters, and each of them discusses a certain issue to cover some of the managerial challenges and the decision-making framework in the Industry 4.0, as well as certain areas of manufacturing and education techniques that can be adopted in the upcoming period. It also goes beyond, investigating how the new IT systems can support sustainability in firms hiring Artificial Intelligence (AI) in the manufacturing and inspection, and it discusses some technical matters of Industry 4.0 too.

Many books can promote further research on Industry 4.0. This volume is one of them, even if the topic is hard to be covered in one book. However, after reading the book I have chosen only two chapters (first and third) for a more detailed review, because these are more closely connected to Industry 4.0 in a way that has explicit relevance for those working in the field of geography, particularly in the disaster and crises management.

The first chapter discusses "one effective way to the risk factors integrating Machine Learning (ML) into Industry 4.0 applications" (p. 1). Here is a direct example of applying ML in Industry 4.0 to introduce geographical information systems to the decision-making process to manage natural disasters and, more broadly, to manage risks. The third chapter is related to the education gap that has been caused by Industry 4.0, where lack of training and education is one of the biggest obstacles (beyond low infrastructural development) to use Industry 4.0 applications not only in GIS and disaster management, but in many other fields as well. Another obstacle for education is scarce financial means due to which we need open-source software to teach how can deal with Industry 4.0 applications.

The first chapter considers the field of ML techniques to be integrated into the Industry 4.0 applications to manage risks as the main subject. The authors have categorised risks into four main groups: Volatility, Uncertainty, Complexity and Ambiguity

(VUCA) according to the old classifications of US Army War College from 1991. The authors also brought some information about the background of Industry 4.0 based on AI, Big Data, Internet of Things (IoT), Cyber Physical Systems (CPS), Information and Communication Technology (ICT) and Radio Frequency Identification (RFID), these applications had their foundations laid during the third industrial revolution. It is interesting to note that every industrial revolution has its own sides of risks. This chapter proposes a way of managing risks using ML, taking into consideration that ML is a subset of AI. ML can be defined in a same way as any data processing. It uses algorithms that are adopted and analytically formed to train the identified and tested database. The steps of any data process are the followings: 1. data collection, 2. data pre-processing, 3. model building, 4. model training and testing, 5. performance evaluation and model prediction of desired results. ML algorithms were classified into three major groups: supervised, unsupervised and reinforcement learning. ML applied techniques have been used to manage VUCA, starting from the late 19th century not only in commercial crises management but also in natural and human-made disasters. They also classified many parameters of risks, developing algorithms for each parameter to improve ML process in risk management. Moreover, the authors started to highlight the role of some ML techniques used for managing risks that can occur within industrial platforms. This chapter also explains ML algorithms, and after each explanation, a series of recent studies gives examples for the applications of each ML type.

One such application is in food production, which is highly volatile and uncertain depending on the customer's expectations and needs. It is also affected by traffic conditions. Increasing traffic and traffic jams due to increasing number of vehicles can endanger the quality of products (e.g. dairy products), and this can lead to less customer satisfaction and financial losses. ML is a good solution for the traffic condition forecasting. It analyses the historic data of roads and gives predictions about their conditions and traffic for example on Google maps.

The second one of the ML applications is the Role of Logistic Regression. It is also supervised by ML algorithm that can be applied in the weather forecasting and in many other fields (healthcare system, voting etc.). A rich literature review about the different applications is also available here for readers.

Of the application methods, The Role of Forest (RF) is also worth mentioning. In this chapter the authors also demonstrate a well submitted literature review to provide real life examples using ML techniques. One ML method employed by Wang, Z. *et al.* (2015) was mentioned as an example for the use of ML in geographical and decision support systems for disaster management. This case was a novel approach to flood hazard risk assessment, using RF as a method and Support Vector Machine Learning (SVM) as a risk assessment comparison to solve a non-linear problem. Based on four previous floods in the Chinese Dongjiang River Basin, five thousand samples of eleven risk indicators were taken into consideration. This river is the primary water source of six highly populated and developed cities: Ganzhou, Heyuan, Huizhou, Dongguan, Guangzhou, Shenzhen and Hong Kong. However, after applying RF and SVM they were able to produce spatial distributions and assessment maps showing the place and frequency of each risk indicator. In consequence, ML techniques based on the RF classifier were able to exclude six out of eleven indicators with different importance. Taken as a whole, this was a great way to employ ML to identify risks and reduce time and efforts (Wang, Z. *et al.* 2015).

Before discussing how we can use the Industry 4.0 applications in disaster management using the Big Data and IoT in GIS, it is worth to retrospect. The use of GIS in disaster and crises management has been known from 1849 when John Snow traced the source place of cholera in London (Snow, J. 1991). In the 1960s its usage started to be wide, but at that time it was only a few terabytes. However, with the extraction of social media data, crowdsource data and remote sensing data (using open-source satellites systems), not to forget higher resolutions, high definition layers, and the big number of drones and cellular phones that have been in use as well, the amount of GIS data has grown bigger than ever. European Space Agency (ESA) by itself generates tens of terabytes per day. IoT in this matter generates huge geo-coded temporal, and real-time data (Azaz, L. 2011). This means that it can be too big for too many users to download and (or to) process, therefore the solution was to link it to space using the Cloud Computing. This allows data sets to be overlaid to the algorithms of ML (Klein, L.J. *et al.* 2015). However, several software can be used to manage this kind of Big Data, one of them is PAIRS Geoscope. This software can be used for Physical Analytics Integrated Data and Repository Services. It has been made to handle the complexity and size of geospatial-temporal data. This software with the use of Industry 4.0 concepts can also use other technologies like Geomesa and Geowave, which are open-sources for geospatial-temporal indexing big databases (Albrecht, C.M. *et al.* 2020). This software also allows us to be connected through the usage of IoT and historical imagery stored in it. In this way we can draw many of post disasters scenarios, to help us in the lesson (De Perez, E.C. *et al.* 2014).

Geospatial information is one of the most important information that can be used in Disaster Management (DM). Big Data and cloud computing have made it easier to use this information. The major elements of the DM cycle are the followings: preparedness, response, mitigation, and recovery (Thomas, D.S.K. 2018). The real-life example shows how the sensor's information was used during and after an earthquake from a ground-based sensor like the seismic sensor network operated by the U.S. Geological Survey (USGS) and The Global Seismic Sensor Network. This was used in Lombok (Indonesia) disaster where a 6.8-magnitude earthquake happened on August 5, 2018. Just hours after the disaster, the analysis of earth surface displacements was available. Using the Synthetic Aperture Radar (SAR) and the signals acquired by the European Space Agency was also an effective way to reach infrastructure analysis after disasters (Albrecht, C.M. *et al.* 2020). In the mitigation phase of the DM, evacuation, rescue and relief have to be taken immediately after the disaster to reduce its impacts (Risk Reduction). Using Big Data and Cloud Computing we can reach lots of people and houses, and also the critical infrastructure that may be affected within the area. Then this information can be directed to the first-response teams and it can help in the search and rescue operations (He, L. and Yue, P. 2019). We can also process the remote sensing images and drones quickly to be integrated into geophysical models to assess the damage (Flesch, R. 2007).

Not only in case of earthquakes, but in many other cases as well (e.g. wildfire disasters), we can use modelling that is highly dependent on geospatial temporal data to know the soil, humidity, temperature and many parameters that can determine the spread of the fire. We can also determine the right way to dispatch the response teams using these data sets, like the European Union system and the National Aeronautics and Space Administration system, which provide operational data for wildfire tracking using Landsat with resolution reaching up to 10 metres (Albrecht, C.M. *et al.* 2020). Dealing with these systems that are using the Industry 4.0 applications needs a software to code and decode programming languages. One of the most popular programming languages is Python (Klein, L.J. *et al.* 2015), which is open source with no hidden costs.

Chapter 3 discusses a very important field in the era of Industry 4.0 which is education using a low-cost open-source hands-on Industry 4.0 education software, a recommendation of Python as the ideal tool for laboratories. To cover most of Industry 4.0 skills gap that it's affecting the implementing process where the largest gap is the skills in the field of Big Data. This chapter went to all the hands-on ways of education to prepare the young as well as the experienced workforce. It gives examples from many countries on how they set up their laboratories, also in terms of software. We can see the Turkish-German University (Istanbul, Turkey) and Graz University (Austria) here as good examples. But they are expensive ones as well, so the author is focusing on low-cost software that can be afforded. The author describes this software as "the glue or the bridge between all the systems" (p. 39.), providing a comparison among five such kinds of software. The focus is here on Python, which is for free (open source). Taken as a whole, the chapter does not give an exact answer how to fill the gap of skills.

After summarising the book, I would say that it has ups and downs if we focus on Industry 4.0, the central topic of the book according to its title. Yet, it can be the starting point for many researches. Overall, it is a good read, but it does not give a good overview on Industry 4.0 compared to other pieces of literature. In spite of this, I would recommend this book primarily for those who are working in disaster management and who are geospatial information specialists in disaster management. The first chapter, which is a most valuable part of the book, will be very useful to them. The book can also be important for those working on filling the skill gap caused by Industry 4.0, for they can get a broader overview of relevant applications. The other parts of the book dealing with different industries (e.g. furniture, textile) and environmental issues could be more insightful if they handled Industry 4.0 as a solution to help, but not to replace, the workforce in the textile industry of India. However, these parts of the book can be useful for decision makers, who can read about many ways for improved decision making when it comes to green supply chains and the use of statistical methods to improve their decisions. The volume can also be a useful starting point to read about the fourth industrial revolution, for some chapters help the reader better understand the technical formation of Industry 4.0.

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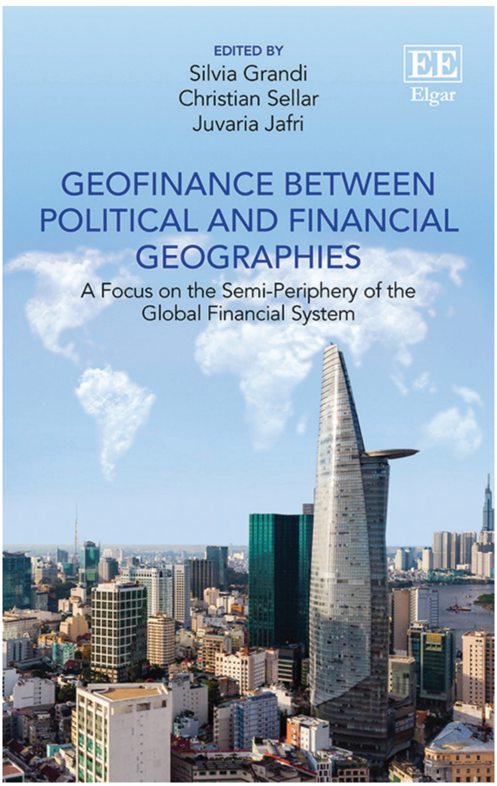
Grandi, S., Sellar, Ch. and Jafri, J. (eds.): Geofinance between Political and Financial Geographies: A Focus on the Semi-Periphery of the Global Financial System. Cheltenham–Northampton, Edward Elgar, 2019. 264 p.

Since the early 2000s, debates revolving around the global economy focused on powerful processes of the reorganisation of production processes and the emerging new global division of labour, the complexity of social relations underpinning those, the rise of new economic cores, and the unfolding variegated landscape of the current capitalist regime (Hudson, R. 2016; Peck, J. 2016). Financialisation shifted in the score of such discourses due to the enhanced scale of capital flows and transactions between national and regional markets, the apparent role of financial capital in driving globally organised production, and the penetration of global financial processes in all realms of social relations and everyday life. Accordingly, inquiries on financialisation were extended spatially and focused not only on national institutional-regulative contexts and the interplay local markets and global capital flows, but endeavoured to grasp the multi-scalar and relational nature of financialisation (Dymsky, G.A. 2018). The 2008/9 financial crisis exhibited the multiplicity of agencies in financial processes and the need to relate processes inside and outside financial markets, such as the power of global financial centres, insular financial practices, structural imbalances in global trade, the growing power of financial media, and cultural-institutional dimensions of national market – to understand financial linkages as social relations (Aalbers, M. 2009; Sokol, M. 2017).



The 2008/2009 crisis and its consequences revealed the complexity and versatility of socio-spatial relations of the current regime of capitalism, and also challenged core economy-focused theorisations of financialisation. The latter emerged not only as a powerful subject to academic inquiry, but also as a lens through which socio-spatial processes of financial capitalism could be grasped. This inevitably led to theoretical debates that challenged dominant discourses rooted in general equilibrium that drives the allocation of resources in the most efficient way, thus, had no explanation to financial crisis either at macro-, or micro-scale (the latter were limited to decision failures, asymmetry of information flow and moral hazard problems) (Dymsky, G.A. 2018; Hadjimichalis, C. 2018). Alternative concepts that relied on heterodox economics, e.g. on demand-side explanations of macro-processes and critical political economy, argued for cross-disciplinary approaches, linked the economic and the political in the inquiry, and introduced spatiality as inherent to all social relations of financial capitalism (Sheppard, E. 2018; Wójcek, D. 2018; Coe, N. and Yeung, H. 2018). Current debates on financialisation embrace powerful problems that reflect on the unfolding new global financial order and also on the changing context of knowledge production on that, such as innovations in the financial systems and its socio-spatial consequences, global financial centres as source of growth and/or instability, homogeneity vs. variegated nature of global finance, the mechanisms of exploitation, and the unevenness and core bias of knowledge production on financialisation.

The edited volume 'Geofinance between Political and Financial Geographies: A Focus on the Semi-Periphery of the Global Financial System' is an interdisciplinary endeavour to address the last three topics, i.e. to reveal how strategies and practices of various social agents, such as people, firms, and state institutions acting in various socio-spatial contexts are related and entangled outside the financial core of the global economy. Writing from a semi-peripheral context, the authors enrich our knowledge on financialisation as a diverse real-world process, and by doing so, reveal mechanisms of unequal development and its variegated nature in the current regime of capitalism.

The book is meant to address two plus one major gaps in studies of financialisation as a spatial process. One is understanding financialisation as a political process, i.e. how state regulations, institutional practices and political discourses drive financial processes, moreover, how financial processes and agents impact upon state policies and politics, and through those, drive the allocation of capital shaping local and regional development. The editors mobilise the concept of state power as "the result of the interactions between the territorially framed institutions and the social forces operating within and around these institutions" (p. 19). This is very much in the heart of current debates on state spaces, and the book is a valuable contribution to those by relating financialisation and the organisation of state power. This entails a relational (cross-sectoral and cross-scalar) approach that encompassed the authors of case studies and contributed to the coherence of the volume.

Secondly, the book is devoted to reveal the processes in the financial 'semi-periphery' of the global economy, embracing established or emerging industrial economies with substantial and structured domestic financial service sector, and clear state policies toward financing firms and households by the definition of the editors. This is consistent with Wallerstein's concept of semi-periphery in a sense that it places the dominance of agents of the financial core (in innovation, assets, information monopoly, institutional practices, etc.) and the dependent nature of financial(ised) relations in the focus. Nevertheless, it challenged the authors and the editors to go beyond macro-scale and national contexts, and grasp the essentials of the semi-peripherality along with the multiplicity agency beyond the state and powerful agents of finance.

Finally, semi-periphery is identified also as an epistemological context, a position from which core-focused ('Western'/'Eurocentric') theories could be challenged also in the current regime of capitalism. Thus, case studies from outside the global financial core are to reveal not only the vulnerabilities stemming from dependent financial position of agents in semi-peripheral economies, but to discuss the latter as "place for experimentation for the politics of finance" (p. 25), thus, a source of knowledge on how global finance unfolds at subnational scale and how it is (how it could be) counteracted to/responded by less powerful agents.

For geographers researching socio-spatial inequalities in and from the European (semi-)periphery, the book raised a number of questions that are related to debates on current processes of uneven development and financialisation as a powerful mechanism propelling it. Here I group them and structure the review as it follows: (1) What political agencies, strategies and social relations drive the integration of non-core economies in global finance? How did the entanglement of such agencies produce unevenness and (semi)peripheralisation at subnational scale and within the global semi/periphery? (2) In what way does this volume contribute to reconceptualising semi-periphery in the era of financial capitalism? Is semi-periphery a relevant spatial concept to explain uneven development despite its heterogeneity rooted in diverse economic-financial historical trajectories? How to grasp the mechanisms and relations that manifest financial semi/peripheral position? Could we challenge the binary logic of dominant discourses on economic development from the (semi)periphery?

Multiscalar agencies and relations of financialisation driving uneven development

The volume is focused on the relations of various agents of financialisation acting at various spatial levels and in diverse sociocultural contexts, nevertheless, the studies are organised along a scalar logic. The first section is devoted to discussing how powerful *global agents* drove uneven development in the post-crisis (2008-) era. The authors explain how actual *geopolitical contexts,* discourses and struggles are inscribed in the spatial organisation, memberships and practices of international financial institutions, how national political and economic interests are mediated by those contributing to the rise of new centralities and dependencies (semi/peripheralities) at macro-regional and global scale (Chapter 2 by Grandi, S.; Chapter 4 by Rosati, U.). They also highlight the mechanisms that emerged to get rid of national regulations and political interests to enhance the scope of agents of the financial system. Those include the unfolding '*shadow banking*', a financial model that rests on pooling and securitisation of financial vehicles to seek investment opportunities, and to which borrowers are only instrumental; thus, how model could be destructive to regional and national economies (particularly, those in peripheral position) and destabilise the global economy (Chapter 3 by Battisti, G.). *Offshore financial centres* are discussed as building blocks of such mechanisms, as they offer non-binding legislative frameworks, skilled labour and high-quality communication networks and transportation services, and a dense network of social relations (a cluster of firms related to finance) linking them to global financial centres. They manifest national (regulative) strategies for economic development, and also the mutually constitutive nature of local embedding and global power – a process identified as semi-peripheralisation exhibiting structural change, dense (inter)dependent relations to global financial centres, and socio-spatial polarisation stemming from agglomerative effects of the rising financial sector (Chapter 4 by Rosati, U.).

The second section (relying on case studies form Brazil, Russia, Italy, Bulgaria and Vietnam) reveals the diversity of national financial systems and provides an insight in internal and external relations that reflect and also reproduce the 'semi-peripheral' position and institutional responses of the discussed economies. The macro (national) scale focus is justified by the powerful agency of the nation state as driver of regulative-structural changes stimulated by global financial crises. The discussed models of state interventions bifurcated, paving the way either (1) for neoliberal policies (deregulation-liberalisation) to manage structural crises, or (2) for a top-down state controlled reforms.

(1) The former is exhibited by Bulgaria and Brazil where growing external control over the domestic financial market increased the vulnerability of the national economy to global crises due to the enhanced mobility of capital (Chapter 8 by Stavrova, E.; Chapter 6 by Sellar, C.). Neoliberal schemes, even those accompanied by national development programmes (such as in Brazil) stimulated organisational and spatial centralisation in domestic financial systems that fuelled uneven development by directing capital flows from peripheries to economic cores (Chapter 5 by Contel, F.B.; Chapter 8 by Stavrova, E.).

(2) State control over domestic economies and finance also entailed highly uneven socio-spatial processes. In such regimes, the power of political elites is anchored in domestic financial systems through which they control key industries, manage risks, and mitigate the consequences of external crises. Major state banks that hold monopolistic position in domestic markets are instrumental to run such systems, while smaller regional banks have to rely on households' and SMEs' savings and enter transactions that have higher costs and carry more risks (Chapter 7 by Ageeva, S. and Mishura, A.; Chapter 9 by Lim, G. and Nguyen, T.T.). The five case studies suggest that unevenness in the financial semi-periphery is stemming from dependent market relations, and also from non-transparent social relations and bargaining processes in domestic finance, in which national states have multiple roles. The diversity of state policies, institutional configurations, market relations and strategies revealed, how diverse mechanisms are at work outside global financial cores producing unequal power relations and spatial inequalities—a lesson to learn and go beyond binary thinking and economic reductionism in financialisation studies.

Section three does not have a clear scalar focus; the studies analyse the mechanisms of social restructuring related to financialisation, thus, give a deep insight in the production of inequalities at *subnational scale*. Studies written by Yilmaz, E. (Chapter 10) and Jafri, J. (Chapter 12) revealed *how subjectivity is produced* through the mechanisms of lending. In Turkey, post-crisis economic recovery rested upon *household consumption.* That was fuelled by extensive lending of banks that linked globalised financial market and the realms of social reproduction through their sourcing strategies; thus, households and individuals were instrumental to maintain growth, profitability, and political power exploited by the coalition of banks and the political elite. A more pronounced differentiation of subjectivities has been produced in Pakistan, where the commercialisation, global embedding and growing reliance on ICT of the *microcredit system* (that was established to support more inclusive lending and, thus, counteract social polarisation) led to increasingly selective institutional practices that confined the poor to *'shadow citizenship'* with limited access to finance at a higher cost. Finally, going beyond the scale of individuals and households, Percoco, M. (Chapter 11) discussed, how locally embedded business relations could be sources of growth and also of instability in the regime of financial capitalism, and highlighted the role of relations of various forms of capital in regional development in the context of Italy (thus, could be considered as complementary to Sellar's insight).

The studies included in the volume added a lot to our understanding on the mechanisms of the unfolding post-crisis financial order, such as how spatially differentiated structures of markets and institutions and practices are related and combined, what new power relations unfolded and how they produced new dependencies and socio-spatial inequalities across scales in the post-crisis (2008-) era. Non-core contexts exhibited institutional diversity in which global processes could be played out, and also revealed the political nature of financialisation and its complex roles in restructuring social relations, challenging simplified, economistic and binary approaches to current socio-spatial processes.

Grasping semi-periphery in the current regime of financial capitalism

Semi-periphery is a conceptual tier of the World System Theory (WST) and as such, defined as a transitory category to explain social relations that drive the expansion and highly uneven spatial organisation of capitalist regimes (Wallerstein, I. 2010). It was developed and later mobilised as an analytical category by many to research the diversity and the socio-spatial dynamics of capitalism critically, moreover, as a source of criticising dominant discourses and institutional practices in politics and academia. Nevertheless, semi-periphery was scrutinised as an undertheorised element of the WST; criticism was articulated due to its functional definition (as a stabiliser of capitalist regimes), and as part of this theory, economic reductionism and macro-scale bias (Massey, D. 2005; Peet, R. and Hartwick, E. 2009).

The authors of the book mobilised the concept of semi-periphery by going back to Wallerstein's seminal work (Wallerstein, I. 1974) to reveal how politics and finance are entangled in the current financial system that is fundamental to understand the processes, relations an underlying structures of the current regime of capitalism. The adoption of semi-periphery as a subject to study and also as an analytical tool raised the problem of recursive argumentation, such as the relation of *explanandum* (the grasp what financial semi-periphery is) and explanatory factors (agencies, processes and mechanisms that emerged in the contexts identified as semi-periphery in the introduction). Since the problem remained implicit (the book is not focused explicitly on defining semi-peripherality), I relied on the lessons of the case studies and discussed only their lessons to grasp the relevance of this concept.

Discussing financialisation and geopolitics in a semi-peripheral context is justified by the scope, multiplicity and diversity of state interventions, an attribute of such transitory spaces in the financialised world system. The authors of the volume mobilised and also enhanced the explanatory power of the concept by approaching to finance and geopolitics relationally, focusing on key agents, their strategies and relations; thus, they revealed the mechanisms (adopting dominantly an institutional focus) producing unevenness, and got rid of functionalism (a source of critique toward WST). Case studies also explained, how power relations are played out in global financial institutional practices, how new dependencies manifest in lending practices, and how emerging offshore centres as financial semi-peripheries (defined so by Rosati, U.) put forward and reproduce such relations. By doing so, the authors placed current processes in a historical perspective, revealing diversity in national financial systems, state policies and related discourses, and also powerful mechanisms that limited agencies and produced new ones operating at national and subnational scales. Thus, the authors contributed to grasp semi-periphery as a scene to constant experimentation (as proposed in the editors' introduction) to capture values from differences in regulative contexts, and also to the subjection of the society to the mechanisms of financialisation as means of exploitation and dispossession by global and also by domestic agents (see Ginelli, Z. 2017; Hajdimichalis, C. 2018; Gerőcs, T. and Pinkasz, A. 2018 on the European context). Finally, semi-periphery is identified as a source of risk and instability stemming from the dependent embedding of such economies/agents in global finance, but also a context from which new strategies and policies could emanate addressing economic crisis and social inequalities. Nevertheless, the latter offer remedies (from inclusive micro-credit systems to locally embedded banking, discussed by Jafri, J., Sellar, C. and Percoco, M.) that are sooner or later get controlled by powerful market agents, thus, produce new risks and unevenness—that is also a manifestation of semi-peripherality in the current regime of capitalism.

Returning to the original concept of WST, that placed multiplicity of agents and their relations in the explanation of inequalities (Wallerstein, I. 2010), and also addressing the criticism on the economistic approach of the WST, case studies discussed, how the re/production of political power and the financialisation of non-core economies are related. The value added of the book is (a) focusing explicitly on the mechanisms through which global power relations are played out at national, regional, or local scale, enforcing externally-driven institutional strategies, that supported the subjection of the society; moreover, (b) how global financial relations are mobilised by national elites to enhance their power, i.e. how diverse yet neatly tied political structures are supporting the regime of financial capitalism.

Discussing financialisation from a semi-peripheral context is conceptual tier for the book that was guiding the selection of case studies and also the argumentation of the authors to highlight unequal power relations and mechanisms of subjection in discourses and institutional practices. It is consistent with the World System Theory that introduced an alternative epistemology of researching social change, challenging dominant (Eurocentric/core-biased) approach to social sciences. To emancipate the subjected from the discursive position of the 'other' in the context of financial capitalism is an issue that should be in the heart of critical social inquiry to counteract ongoing exploitation and social polarisation. Semi-periphery as an analytical category could be instrumental to such an intellectual and political endeavour, as it exhibits the complex dependencies of core and non-core agents and spaces, the class-biased and externally driven nature of state interventions, and the thorough changes in local societies (Arrighi, G. 2010; Wallerstein, I. 2010). Understanding such processes as part of different historical trajectories we could reveal how diversity is incorporated in the current regime and why anti-systemic responses and movements failed (Peet, R. and Hartwick, E. 2009). Nevertheless, discussing alternative approaches and practical solutions to tackle crises and social conflicts stemming from semi-peripheral positions make such spaces 'visible' in international debates (Boatca, M. 2006), and the lessons of those could support the rise of new responses at local, national and also global scale. This volume contributed to such processes by enhancing our knowledge on financial semi-peripheries, and also by politicising financialisation studies.

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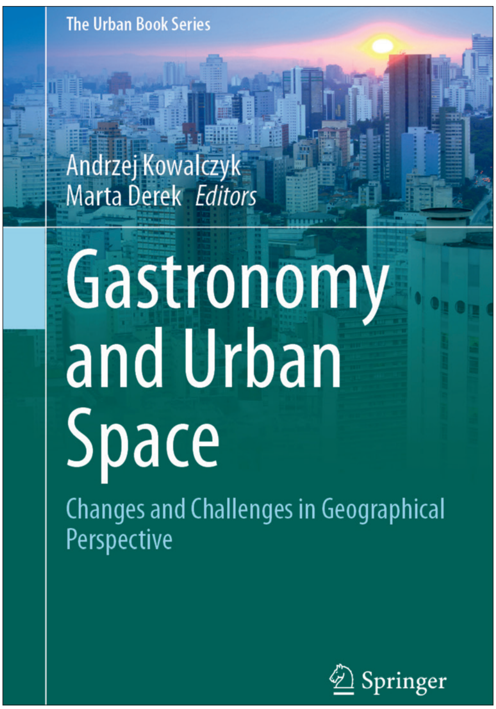
Kowalczyk, A. and Derek, M. (eds.): Gastronomy and Urban Space. Changes and Challenges in Geographical Perspective. Cham, Springer, 2020. 345 p.

When I started reading the volume in early February 2020, I was sitting in a café on campus, packed with students chatting over double shot tamarind lattes, a Viennese melange or sipping a pumpkin spice ice coffee from a trendy repurposed jar. A mundane scene symbolized the zealous enthusiasm towards gastronomy in the last decades worldwide. Besides *what* to eat, customers have become more conscious about *where* to consume. The generation called Millennials, many of them university students these days, is especially engaged in experimenting with food and drink as well as documenting and thus trending catering places on social media (Howe, N. 2017). Consequently, the book, edited by Andrzej Kowalczyk and Marta Derek, might be appealing to its target audience: university students and non-academics who are interested in the "spatial aspects of eating facilities" (p. XVIII).

Since gastronomy is studied by various disciplines and the term itself is used in everyday conversations, the Preface provides definition of gastronomy and urban space as these are understood in the volume. It clarifies that the aim of the book is to present problems related to the geographical location of restaurants, bars,



cafés (etc.) in urban areas. As the authors note, they are aware of the social, cultural, economic or health related issues of gastronomy in urban space, but in their view these topics are in lesser extent in the domain of socio-economic geography and rather should be studied by sociologists, anthropologists, urban planners, economists, etc. The Preface specifies that the book adopts a positivist approach, which, in their view, better suits the needs of students. Whilst their standpoints can be debated, the sharp demarcation line drawn by the editors helps them clearly circumscribe the place geographical research might occupy among other disciplines engaged in this topic. By narrowing down the scope of issues, and analysing the spatial processes from a positivist approach, the content of the book remained cohesive, albeit the 18 chapters were written by 14 authors.

Gastronomy and Urban Space was written by geographers, mainly affiliated either with the University of Warsaw or the Jagiellonian University in Cracow, but researchers from St. Petersburg and Prague also participated in one chapter. Whereas the authors pay special attention to referring to examples and case studies from all continents, the book (especially Part II and III) has a strong geographical focus on Poland and, in lesser extent, on East-Central Europe. It was a conscious decision of the editors who believe that the book demonstrates that the region "has become an interesting laboratory for exploring the development of gastronomy in urban space, especially as these aspects of geopolitical transformation have not been previously reported in broader studies" (p. 344.). Indeed, one of the most valuable contribution of the book is to draw attention to the spatial processes and specifics of food consumption, catering and supply in this region, so far underrepresented in international literature.

The book is divided into three main parts. Part I serves as a historical and theoretical foundation of the book, whereas Part II and III discuss the main changes and challenges related to gastronomy in contemporary urban space and society. Both Part II and III start with introductory chapters (Chapters 4 and 14) followed by problem-oriented studies (Chapters 5–13 and 15–18).

Part I consists of three chapters. Chapter 1 provides an exciting journey in the history of gastronomy across continents and cultures. The reader can learn about how different catering facilities (restaurants, inns, cafés, etc.) have developed in the urban space in different settings. The chapter is richly illustrated with photos, tables and maps, which visualise and adequately complete the text.

Chapter 2 introduces theories about urban space. Although the models (I presume) are familiar to geography students, explaining and illustrating their implication in studying the spatiality of gastronomy is justifiable. Throughout the book, the authors of each chapter keep referring back to these models when they evaluate the spatial development in gastronomy and food service sector, which further increases the cohesion of the volume.

Chapter 3 addresses issues related to gastronomy in contemporary urban settings. Among others we can read about the role of gastronomy in tourism, urban planning or city marketing; the social dimension of food consumption and place is also addressed. The chapter enlists problems and conflicts related to gastronomy in contemporary city and society, which the author categorises into two main groups: changes and challenges.

Part II is dedicated to the changes. In Chapter 4, Marta Derek suggests that gastronomy should be perceived as a lens through which the social and cultural changes and their manifestation in urban space can be observed. Each chapter is dedicated to a specific topic (in which *change* manifests). The structure of the chapters is as follows. First they offer a brief introduction and literature review (in certain studies the applied methodology is also communicated). Then the authors illustrate the topic with international examples and analyse a case study, in most cases based on an example from Poland, mainly Warsaw and Cracow. Finally, the list of references at the end of each chapter, makes the book ultimately user-friendly. Chapters 5 and 6 are closely related to culinary tourism and the interconnectedness of specific local foods and regional cuisine in creating 'place' in the city.

Chapter 7 explores the geography of gastronomic services in the city centres. The case studies were Warsaw's central district (Śródmieście) and the historic centre of Cracow and St. Petersburg. Based on the spatial and temporal analysis of the distribution of eating facilities, researchers were able to visualise how the density of such places indicate the growth and changes of the city structure (St. Petersburg), or demarcate the central core of cities (Warsaw, Cracow). These findings are complemented with two case studies: Żoliborz in Warsaw and Podskalí in Prague, both situated near the centre. Subchapter 7.5 about Żoliborz is particularly interesting. The author shares fascinating details about the history of the neighbourhood and the way political, economic and urban transformations shape the spatial presence and character of eateries and vice versa. The case study about Podskalí (Subchapter 7.6) concludes that an important factor behind the growing number and density of eateries in this urban neighbourhood (*change*) might be the intention to relieve the pressure on the historic centre of Prague, which is currently suffering from over-tourism.

With the following three chapters, the reader continues moving away from the city centres. Chapter 8 takes us first to three peripheral neighbourhoods of Warsaw (Bródno, Nowodwory and Tarchomin). Similarly to Subchapter 7.5, these subchapters introduce to the history of these neighbourhoods in a nutshell, which is followed by the spatial analysis of eating facilities. The authors found that new restaurants were opened in Bródno after 2000. As the number of residents remained more or less stable, they claim that these new restaurants are signs of the socio-economic and cultural shift induced by the appearance of middle-class dwellers settled in more prestigious new housing. In general, outlets of fast food chains are frequently visited by families with children in these peripheries.

With Chapter 9 we arrive to the suburbs. The authors conducted field work in Piaseczno district, south of Warsaw. Among others, their findings serve as adequate illustration of how gastronomy can be comprehended as a lens through which we can understand and follow socio-cultural changes. Based on their field work conducted in the seven settlements belonging to Piaseczno, the authors point to the importance of social status of inhabitants and tourism that diversifies eating facilities and leads to the spatial concentration of prestigious restaurants in certain parts of the town, whereas low quality facilities are still present elsewhere in the district. They claim that such a diversity in eating facilities reflects the gap in the social status of inhabitants living in Piaseczno.

Chapter 10 endeavours to reveal some aspects of gastronomy and space in smaller towns (500,000 inhabitants and below). The chapter is well grounded and contextualised in international examples and the supposedly tremendous efforts to compile a database of eateries relying on search engines and websites of town halls must also be noted. I found particularly interesting the section about places that were transformed into restaurants or pubs, including a former mine 320 meters below the surface (Subchapter 10.3).

The following three chapters (11-13) address three particular issues related to gastronomy and urban space: the appearance of ethnic cuisine in cities (11), the possible impact of tourist experience on culinary taste and eatery preferences (12), and the specificities of food supply in cities. In Chapter 11, after providing an easy-to-follow history of ethnic cuisine in urban context, the author focuses on two cities: Amsterdam and Warsaw. The study, which is based on the analysis of the location of ethnic restaurants and eateries, found that in the centre of Warsaw (Śródmieście) ethnic cuisine is more concentrated in space than its non-ethnic counterpart. This might be a bit of a surprise, but it also turned out that after the Polish cuisine Japanese is the second most frequently served ethnic-cuisine in central parts of the Polish capital city. This phenomenon can be explained by the popularity of Japanese food globally. Japanese dishes are favoured by geography students of the University of Warsaw who participated in the survey in 2014/15, which is analysed in Chapter 12. This is a rather short chapter, but (I presume) the topic has a potential both in teaching (maybe a research about their habits is appealing to students?) and research. Chapter 13 allows us to look behind the curtains: how the local or exotic ingredients arrive to the city to eventually land on our plate. The chapter uses the case study of a Polish company, but the reader also gains knowledge about the theory of supply chain management and how it functions, for instance, in Indonesia and Canada.

Part III is dedicated to challenges which gastronomy is facing in the 21st century. Such challenges stem from the shifts in society, the changing culture of dining or dietary trends, and they are interlinked with technological developments. From the aspect of urban space, the authors identify four major challenges: food courts (15), green and blue spaces (i.e. parks and waterfront) (16), street food and food trucks (17), and home delivery (18). Following the structure of chapters in Part II, chapters in Part III first provide a general overview of the history of the given form of gastronomy, followed by examples from different cities around the world and, finally, by case studies from Poland (mainly Warsaw). From the historical overview the reader can learn that none of the above catering forms is unprecedented in human history, so one might say that these barely endanger the survival of more traditional facilities, like restaurants. Importantly, the authors illuminate the foreseeable/possible social and spatial consequences if these challenges spread. For instance, the increasing popularity of home-delivery threatens thousands of jobs, while the expansion of dining establishments occupies and/or impacts urban space in a way which creates concerns and conflicts between different users of urban space.

Chapter 16 is particularly informative in this regard. It explores the dining facilities in parks and in the waterfront along the Vistula River. These (open air) dining facilities function as societal hotspots appealing for a diverse clientele, but at the same time, regular park visitors or inhabitants living nearby might complain about the noise or dirt the guests leave behind. The arousing conflicts must be mitigated through the involvement of concerned parties (local government, visitors, inhabitants, street vendors, entrepreneurs) as it has happened in the case of Breakfast Market, a bottom-up initiative rapidly gaining popularity in Warsaw. (Similarly to the authors of this chapter, I also find it important to give the credit to the student, Monika Bartman, who dedicated her BSc degree thesis to the Breakfast Market).

Chapter 17 is not only fascinating because it offers a historiography of food trucks and street food in different regions, but it explains their social context as well. Furthermore, we can learn about what lies behind the popularity of street food (eating healthy, eating local and eating food prepared carefully), and why running a food truck is appealing to many young, educated people. The spatial analysis found a temporal fluctuation in the concentration of food trucks: weekdays they rather show up in the vicinity of offices, but in the weekend they appear closer to parks and waterfronts.

Chapter 18 is dedicated to home delivery. The authors provide a wonderful summary of the history and types of home delivery services, which is followed by the study of a particular food delivery company. Analysing the spatial distribution of restaurants promoted by this company, they found that some type of cuisine can be found in higher concentration in certain neighbourhoods, which also reflects the status of that part of the city. For instance, pricey Japanese restaurants are concentrated in the newly developed business centre in the western part of the inner city of Warsaw, which is considered to be a prestigious one, and eating Japanese cuisine seems to be a symbol of prestige.

The book ends with a few pages long, enviably focused summary (Conclusion), which reviews the major aspects of the relationship between gastronomy and urban space studied in this edited volume.

Gastronomy and Urban Space. Changes and Challenges in Geographical Perspective is an informative, richly illustrated edited volume that broadcasts knowledge in a comprehensible and engaging manner. Besides the maps and photos, the textboxes (separated from the main text with a grey background colour) convey particularly interesting pieces of information. Apart from the literature review and theoretical grounding, the most valuable contributions are the case studies. Based on years of fieldwork, observation, photo documentation, rounds of questionnaire surveys, interviews, analysis of databases, blogs and social media, each chapter testifies the immense work and commitment of participating researchers and the meticulous work of the editors. The book talks about the intersection of gastronomy and urban space in a way which makes it a valuable and enjoyable book to read. Moreover, amid the ongoing coronavirus pandemic, this book attests as a mnemonic of the pre-lockdown 'normality', while some of the concerns and challenges gastronomy is facing in urban space (at least the time of writing this review, in mid-May 2020), sounds prophetic.

Ágnes Erőss[1]

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CHRONICLE

In memoriam Attila Barczi (1964–2020)

In early March a shocking news reached the representatives of Hungarian landscape ecology. One of us, who has been so active in organizing and popularizing this discipline, has left us for good. Attila Barczi, associate professor of the Department for Nature Conservation and Landscape Ecology at Szent István University, Gödöllő, died with tragic suddenness.

He was born in Budapest on 26 April 1964, but he attended primary and secondary school in Siófok. He began with geographical studies at the József Attila University of Szeged, but finally graduated from the Gödöllő Agricultural University as an agricultural engineer and began to work there at the Department of Soil Science and Agrochemistry. After attending postgraduate courses in soil science and agricultural environmental protection, he defended his PhD dissertation in 1997 and became habilitated associate professor in 2004. Recruiting eminent scientists from all fields of landscape study, he undertook a leading role in the organization of the first Department of Landscape Ecology in Hungary and established the journal *Tájökológiai Lapok* (Hungarian Journal of Landscape Ecology). He was active as head of the department and of the Doctoral School of Environmental Sciences, vice-dean of the Faculty, but, first of all, as an enthusiastic and excellent lecturer of soil science and landscape ecology – not only at Gödöllő, but also at other universities. His classroom and field presentations will equally be remembered by the younger generation of soil scientists and geographers.

He had a wide range of research interests: from manuring and composting to soil typology, evaluation, conservation and soil-plant interactions. In paleoecology and paleopedology his investigations of buried soils in tumuli are internationally acknowledged and brought him appreciation in international circles. He won Széchenyi and Bolyai scholarships. He edited a series of full-colour booklets with his professional photos which presented the landscapes of Hungary to the interested public. Only the blind envy and ill-will of his opponents could prevent him from being awarded the title of Doctor of the Hungarian Academy of Sciences, which he would have well deserved.

Attila Barczi will be painfully missed by the community of researchers in landscape ecology and soil science, but through his positive attitude to work, self-confidence in his profession and in the use of the English language, friendly and cheerful personality, incessant helpfulness and readiness for action, we will keep him in good remembrance.

Dénes Lóczy

GUIDELINES FOR AUTHORS

Hungarian Geographical Bulletin (formerly Földrajzi Értesítő) is a double-blind peer-reviewed English-language quarterly journal publishing open access **original scientific works** in the field of physical and human geography, methodology and analyses in geography, GIS, environmental assessment, regional studies, geographical research in Hungary and Central Europe. In the regular and special issues also discussion papers, chronicles and book reviews can be published.

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Books:

Pye, K. 1987. *Aeolian Dust and Dust Deposits.* London, Academic Press.

Book chapters:

Kovács, J. and Varga, Gy. 2013. Loess. In *Encyclopedia of Natural Hazards.* Ed.: Bobrowsky, P., Frankfurt, Springer, 637–638.

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