# INDICATORS FOR BUILT-UP AREA MONITORING – A CASE STUDY OF THE CZECH REPUBLIC AND THE EU*

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The present research is focused on built-up area (BUA) monitoring. The continental landscape is becoming a limited resource in today's world, much the same as some materials and energy resources. The goal was to design simple indicators that are compatible with environmental indicators used in the analysis of material and energy flows. We have consequently proposed the indicators BUA per person and gross domestic product (GDP) demands for total BUA. We have used these indicators to evaluate the development in the Czech Republic and the situation in the EU-27 countries. The development in the Czech Republic shows a moderately smooth decrease in the BUA per person indicator value. The GDP demands for BUA indicator showed that the cessation of economic growth after 2008 slowed the process of decoupling of GDP from the BUA. Despite the low GDP in the Czech Republic, the indicator GDP demands for BUA attains lower values than for Austria or Belgium.

land use changes, land occupation, decoupling

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## INTRODUCTION

The relationship between the environmental and the socio-economic sphere has been the subject of research over several decades (Boulding, 1996; Meadows, 1972). The aim of a sustainable economy is to achieve a situation in which the environmental burden is decreasing and the quality of life is increasing (Jenkins, 2002). So-called decoupling, which monitors the separation of the index curves of the environmental burden and economic growth, is used to evaluate the impact of a state's socio-economic system on the environment. The indicators domestic material consumption (DMC)/gross domestic product (GDP) and Energy demandingness (intensity) of the national economy (Energy/GDP) are commonly used. View of the landscape as a limitless resource that should be utilized effectively, is still missing.

García-Olivares, Solé (2014) have come to the conclusion that world economic growth will encounter insufficient natural resources and world eco-system capacities this century and that new measures for sustaining the current quality of life must be sought. For example, the quality of life should not be conditioned on the consumption of natural resources. A transition from capitalism to a symbiotic economy is consequently appropriate according to the authors.

There are a number of indicators for the quality of life (Glatzer, 2012), and GDP is used to determine decoupling (Kovanda, Hák, 2007). However, GDP is frequently misused and gives a distorted picture of the true quality of life when not used in combination

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with social or environmental indicators (Giannetti, 2015).

Knowledge of material flow indicators, particularly domestic material input – DMI (also recommended by the OECD (OECD, 2002)), is used to express the environmental burden in relation to the consumption of resources, but DMC is also suitable for this purpose (van der Voet et al., 2005). There is a range of indicators for comparing environmental burden in relation to economic growth, which are based on changes in biodiversity, the potential for global climate change, material and energy inputs or pollutant emission outputs (UNEP, 2011; von Weizsäcker et al., 2014). Development of the indicator for environmental burden based on changes in land use is currently in its initial stages and there is insufficient world data for it, in spite of the fact that it would be a very significant indicator (van der Voet et al., 2005). Only the global area of agricultural soil and the European BUA has been established (van der Voet et al., 2005). The only comprehensive European environmental economic analysis based on knowledge of the BUA was realized in Germany and examines changes between the situation in 1993 and 2001. The economic productivity of BUA, which were further divided into individual economic sectors, was examined. The most productive sector was other services with EUR 191 million per $km^2$ of BUA, while the least productive sectors were agriculture, forestry, and fishing (EUR 6 per $km^2$), land transport (EUR 18 per $km^2$) and branch recreational, cultural and sporting services (EUR 28 per $km^2$). The average was EUR 98 per $km^2$ (Schoer et al., 2003). There is already data about the BUA in EU-27 countries for 2009 and 2012. Unfortunately, changes were made to the methodology used to report the BUA in EU countries between 2009 and 2012, so it is not currently possible to compare data from these years (Eurostat, 2014a).

We were guided to propose a new decoupling indicator by the following problematic phenomena linked to the increasing area of build-up in the landscape: (1) the permanent reduction of ecologically valuable areas and the area of agricultural land in EU countries; (2) the growing amount of material stock in the socio-economic system; (3) the high consumption of energy in relation to the operation of buildings.

The first reason for BUA monitoring is a permanent reduction of the area of agricultural land and ecologically valuable areas in the EU. Occupation of land by buildings is usually of a permanent character. Ongoing urbanization and the consequent expansion of infrastructure in the countryside mean permanent loss of farmland in Europe (Stoate et al., 2009). The economic tools and policy for the protection of agricultural land have also been criticised in all American states (Nelson, 1990; Thomson, Prokopy, 2009). Decoupling between the loss of agricultural land and economic growth was analyzed in relation to the area of Beijing in China, where a rapid increase in BUA has occurred. Between 1995 and 2000 there was positive decoupling between economic growth and BUA increase curves, but decoupling of these curves reached negative values between 2000 and 2005. Mainly the actual area of the city had grown until 1995 and the growth of rural settlements was predominant between 1995 and 2000. Non-settlement BUAs, which primarily mean roads, railways, and other infrastructure servicing new development areas, were predominant after 2000. The study also shows that the fact that insufficient infrastructure, which must be constructed subsequently, causes loss of farm land and other negative phenomena linked to development, as well as significant economic losses, must be taken into consideration during the period of growth of settlements and other structures (Song, 2014).

Moreover, the increase in the BUA also has a broad negative impact on the environment. A large percentage of buildings and structures are made up of impermeable surfaces, which negatively affects the hydrogeological regime of landscape (Rougé, Cai, 2014), particularly locally in urbanized areas, such as the area surrounding Prague in the Czech Republic (Dvořák, 2012). Water drainage in densely developed areas is also accelerated by surface water drains in streets (Miller et al., 2014). There is also a clear negative impact on water ecosystems (Alberti et al., 2007; Wenger et al., 2009). Urbanization of areas also has a negative impact on climate change (Kalnay, Cai, 2003).

Material flow analysis (MFA) should include material flow, energy, landscape, information, and live organisms. Soil in particular is a resource which is difficult to renew and landscape area may also be an important resource (Brunner, Rechberger, 2004).

Life-cycle analysis (LCA) includes the quantification of material flows, energy flows, and landscape changes in the system being studied. LCA is very good at expressing the occupation of the landscape (in contrast to changes in the use of the landscape). Occupation is expressed as the area of occupied land multiplied by the period of the land occupation. After finishing the occupation of the landscape, a period of renewal follows. The determination of the impact of changes on the use of the landscape is of significant importance for LCA studies, although there is no unified method, not even on the level of the United Nations Environment Programme (UNEP LCA Initiative). The whole issue is complicated because the impact of anthropogenically caused changes in the landscape is manifested very differently depending on local conditions. It can also be assumed that some changes to the landscape have a negative impact after many years from the time of the intervention (Milà i Canals et al., 2007). The ecosystem damage potential (EDP) indicator is based on the period of soil regeneration.

During occupation of land by buildings and build-ups in a climax forest growth area (e.g. a greater part of Central Europe) this period is determined as a thousand years. During the occupation of agricultural land, this period of renewal is determined as the difference between the duration of succession on such occupied land and the period of 1000 years. It is therefore better to occupy as little of the landscape for the longest possible period rather than to occupy a greater area for a shorter period (Koellner, Scholz, 2008). The repeated use of brownfields, particularly when this concerns former industrial complexes in areas with lower population density, is also another major issue (Frantál et al., 2015).

The second reason for BUA monitoring is the growing amount of material stock in the socio-economic system. The DMC indicator is used most frequently in the EU for the analysis of material flows on national levels. DMC characterizes the environmental burden by the annual consumption of materials. DMC expresses the consumption of all types of material within a country and is composed of domestic applied extraction and the difference between imported and exported goods and material (European Union, 2013). Some of the input material, mainly fossil fuels and biomass, remains in the socio-economic system for a very short period, while other groups include material which can be used over the long-term or repeatedly, particularly metals and non-metallic minerals used in buildings. These long-term utilisable materials make up approximately 40-60% of DMC, in EU countries metal (gross ores) and non-metallic minerals comprise an average of 52% DMC in the EU (European Union, 2013).

Net additions to physical stock (NAS) were approximately 60% in proportion to DMC for the Czech Republic between 1993 and 2000 (Ščasný et al., 2003). Most stock is placed in build-up, which chiefly includes buildings, transport, and other infrastructure (Fishman et al., 2014). Stocks of material in build-up can be executed by two methods: conversion of low-rise buildings into high-rise buildings or the development of a larger landscape area. Total material stock was calculated for Japan and the USA, where it is currently approximately 310 t and 375 t per person, respectively. It can be assumed that total material stock will not increase very much in these countries in the future, because the quantity of material for build-up will remain the same as the amount of material for demolition around the year 2035 (Fishman et al., 2014). Ideally, a large part of the materials should be used long-term and subsequently used repeatedly within a closed material cycle. The average period for which non-metallic minerals remain in the socio-economic system is 50 years (Fishman et al., 2014).

In the case of a sufficiently large amount of stock, non-metallic minerals could remain in the economic system and this would reduce the need for the extraction of new minerals. In the Czech Republic, the cyclical use of non-metallic materials is only 5.28% (Kovanda, 2014), compared to Japan where the cyclical use of non-metallic minerals is 17.76% (Ministry of the Environment – Government of Japan, 2013).

Third reason for BUA monitoring is that operation of buildings usually requires a significant amount of energy. The estimated growth in energy used by residential buildings is increasing and an average increase by 0.6% per year is expected for 2000–2013 in the EU (Capros et al., 2008); residential buildings in the EU have various levels of energy consumption depending on the type of building and local climate. Averages are 144.1 kWh $m^{-2}$ in Denmark, 108.4 kWh $m^{-2}$ in Greece, and 261.1 kWh $m^{-2}$ in Poland (Balaras et al., 2007). Heating makes up nearly 70% of energy consumption, heating hot water 14%, and nearly 12% of energy consumption in households is for lighting (Balaras et al., 2007). Air-conditioning systems in buildings are also a major source of energy consumption in towns. The percentage of air-conditioned buildings in the EU is growing constantly, resulting in rising electricity consumption for air-conditioning (Hitchin et al., 2015). Residential buildings in the EU consume over half the energy, but public buildings also have high energy consumption; in Great Britain the rate is 19% (Gul, Patidar, 2015). A Swiss study seeking links between the age of buildings and energy consumption shows that buildings aged between 40 and 100 years have the highest average energy consumption, new buildings up to 20 years of age and buildings which are approximately 140 years old have the lowest energy consumption (Aksoezen, 2015). A number of studies also point out the link between $CO_2$ production and high $CO_2$ values – the equivalent to energy consumption by buildings (e.g. Junnila, Horvath, 2003; Gaglia et al., 2007; Gustavsson, Joelsson, 2010; Cellura et al., 2013; Radhi, Sharples, 2013).

As is apparent from many sources, it is important to find ways of quantifying landscape occupation and land use changes with methods similar to material and energy flow analysis. New methods for assessing the impact of economic activities on land use change are developed in the life cycle analysis. We see a substantial deficit of scientific interest in macroeconomic analysis at the national level. Indicators for annexation and changing land use the same as appropriate policy measures for landscape protection as part of sustainable development are missing. We believe that future development of knowledge and statistical methods will bring about the possibility to use objective indicators at the national and international levels. Finding methods for assessing the land occupation by construction is therefore the first step.

The goal of this work was a graphic portrayal of the decoupling between economic growth and the environmental burden linked to BUA in the Czech Republic, and, simultaneously, a comparison of the utilization of BUA in individual countries in the European Union. This is the reason for the proposal of suitable indicators which would enable the achievement of the goals above and simultaneously enable monitoring of the issue in the future. It was also necessary to verify whether the EU-27 countries with a greater percentage of BUA had lower economic demands on the BUA and were therefore capable of suitable utilizing their limited free landscape resources. Hypothesis is that countries with a higher proportion of developed areas will have smaller demands of GDP to BUA.

## MATERIAL AND METHODS

### Study area

The development of the situation concerning BUA and the relevant decoupling from economic growth were assessed in the Czech Republic between 2000 and 2012.

Values from the Czech Republic and values from the EU-27 countries were compared for 2012.

### Source data and their processing

Data on the BUA in the Czech Republic were taken from the reports of the State Administration of Land Surveying and Cadastre (2014) compiled by the Czech Environmental Information Agency (CENIA) (CENIA, 2014). The State Administration of Land Surveying and Cadastre obtains data from the registry of areas and detailed cadastral maps. Data on the BUA in the Czech Republic are available from the year 2000, but the methodology used to obtain them was modified in 2005.

Data on the population in the Czech Republic collected by the Czech Statistical Office (CZSO, 2014) and data on the development of the GDP in constant prices in 2010, processed by the Centre for Environmental Issues at Charles University in cooperation with the CENIA (CENIA, 2014) for the purpose of calculating the economic demands of material and energy consumption, were used for analyzing the development in the Czech Republic. Concerning data on the EU countries, data on the BUA were derived from Eurostat (Eurostat, 2014b). The aim of the Land Use/Cover Area frame Survey (LUCAS) is to gather harmonized data on land use/cover and their changes over time. The land cover and the visible land use are classified according to the harmonized LUCAS land cover and land use nomenclatures. The data are supplemented by field survey with over 500 field surveyors on 234 561 points visited *in-situ*. A pilot survey was conducted in 2006, and detailed investigations were carried out in 2009 and 2012. Further information will be available for the year 2015 (Eurostat, 2015). Data on the European population were derived from Eurostat (Eurostat, 2014c).

Data on the GDP calculated according to the purchasing power standard (PPS) in individual countries (Eurostat, 2014d) were used to analyze the situation and make comparisons of the EU-27 countries. The used data from Eurostat are valid for 2012.

### Proposal of indicators

We proposed and tested several options for the calculation of indicators: BUA per person and BUA input per year, and the subsequent graphic portrayal of decoupling BUA from economic growth. Input data for the Czech Republic and the EU are taken from publicly available sources. All procedures can be repeated in the future for the calculation of development indicators.

**BUA per person**. The BUA is expressed in $m^2$ per person to enable monitoring of the development within 2000–2012 in the Czech Republic and make comparisons with the EU-27 countries for 2012. Because CENIA uses a different methodology than Eurostat for determining BUA, the information for the Czech Republic may slightly differ in the comparison of the EU-27 countries.

**BUA input per year**. The land area input for buildings per year in the Czech Republic indicator is expressed as the annual changes in BUA in ha. The period between 2006 and 2012 was chosen because CENIA did not change its methodology for determining BUA during this period. The development of the indicator can be expressed using index values, with the first year representing 100%. The indicator was compared with the development of DMC. It must be mentioned that all BUAs simultaneously enter the total system stock.

**GDP demands for BUA**. The GDP demands for BUA (economic demands for BUA) for the Czech Republic are expressed by means of the total BUA and annual GDP in Czech crowns (CZK) in constant prices for 2010. This is based on the assumption that BUA can be utilized repeatedly. This is a fundamental difference to the method for determining the DMC/GDP indicator, because this only expresses the annual consumption of materials and cannot include stock. The development of decoupling can subsequently be graphically portrayed using index values. The development was expressed for the periods 2006–2012 and 2000–2012. However, this portrayal is encumbered by the modification of the methodology for data compilation by the CENIA Agency. GDP expressed in PPS was used for the international comparison of the EU-27 countries. The unit is $m^2$ per CZK 1000 for the Czech Republic and $m^2$ per 1000 PPS for the EU countries.

Table 1. Annual changes to build-up area

| Year | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| Change in area (ha) | 116 | 380 | 359 | 194 | 239 | 325 | 109 |
| Development of indicators (index 100%=2006) | 100 | 310 | 284 | 161 | 193 | 258 | 88 |

The development of the indicator was graphically expressed using index values, with the first year (2000 or 2006) representing 100%.

## RESULTS

Source data and calculated detailed data on the development in the Czech Republic are shown in Appendix 1 table, while source data and detailed statistics for the EU-27 countries are presented in Appendix 2 table.

**BUA and build-up per person.** In 2012, the BUA in the Czech Republic was approximately 1318 km$^2$. The development of BUA in the Czech Republic is depicted in Fig. 1 (values of the total BUA are shown in Appendix 1). After 2005, the number of inhabitants in the Czech Republic increased more rapidly than the BUA, which is why the BUA per one inhabitant decreased between 2005 and 2012, from 127.5 to 125.5 m$^2$ (Fig. 2).

There was an average of 130 m$^2$ of BUA per person in the EU-27. Values for individual Member States are evident from the graph in Fig. 4, values for total BUA in the EU-27 are shown in Fig. 3 and Appendix 2.

**BUA input per year.** Land area input for build-up per year (annual changes in BUA) fluctuates significantly in the Czech Republic. Between 2006 and 2013 it ranged between 109 and 380 ha (see Table 1). This can be expressed by means of the index value, but, compared to the development of the DMC and GDP index, this method is not evidential, as is clear from the graph in Fig. 5. To calculate the ratio between land area input for build-up per year and GDP consequently makes no sense.

**GDP demands for BUA.** The GDP demands for BUA (economic demands for BUA) were 0.368 m$^2$ per CZK 1000 for the Czech Republic in 2012, which was a worse value than in 2008 (0.360 m$^2$ per CZK 1000). The development of this indicator for the Czech economy is depicted in Fig. 6. Its development from the year 2000 (Fig. 7) can be projected, but it must be taken into account that the methodology for determining the BUA was modified in 2005.

The EU-27 countries had an average GDP demands for BUA value of 5046 m$^2$ per 1000 PPS for 2012. Bulgaria and Cyprus achieved the highest values with 11 708 and 11 450 m$^2$ per 1000 PPS, respectively. Precise numbers for the EU-27 countries are given in Fig. 8. A comparison of individual EU countries shows significant differences in the effective utilization of BUA. This type of indicator is consequently suitable for the international comparison.

The results indicate that even the countries with a high percentage of BUA and consequently limited free landscape resources frequently have high GDP demands for BUA (Fig. 9). Correlation between the share of BUA in the total area of the country and the GDP demands for BUA was not detected ($r = -0.048$).

**Summary results.** In the EU-27 countries, the average BUA per person was 130 m$^2$ for 2012. The BUA per person was below-average in the Czech Republic (118 m$^2$), on level with Germany (114 m$^2$) and Poland (114 m$^2$). An interesting result is that after 2005 the

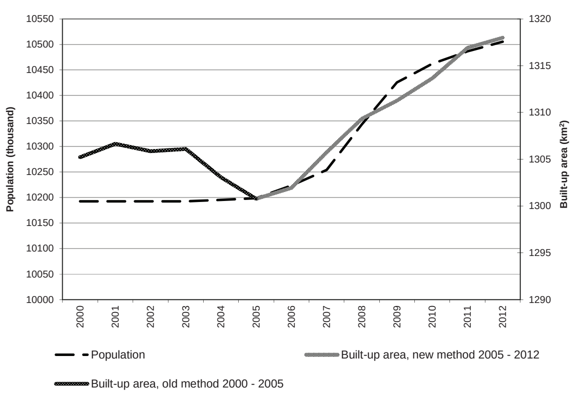



Fig. 1. Development of BUA and population of the Czech Republic

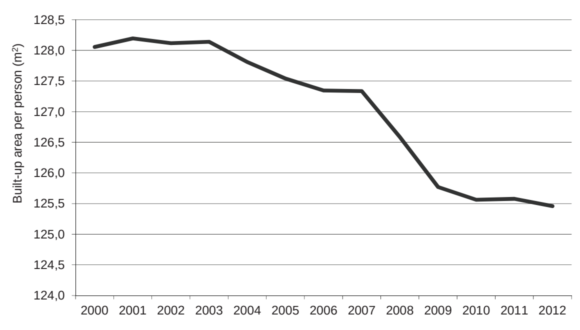



Fig. 2. Development of BUA per person in the Czech Republic

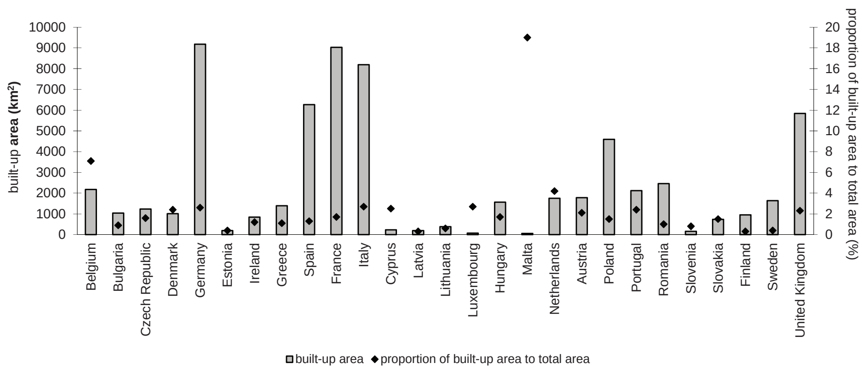



Fig. 3. BUA and proportion of BUA to total area in the EU-27 countries

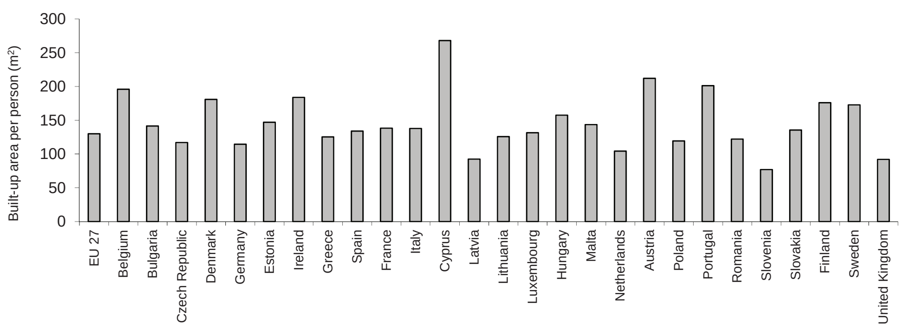



Fig. 4. BUA per person in the EU-27 countries

population in the Czech Republic increased more rapidly than BUA, so the BUA per person actually decreased between 2005 and 2012 by more than 2 m$^2$. The largest BUA per person was in Cyprus (268 m$^2$), Austria (212 m$^2$), Portugal (202 m$^2$), and Belgium (196 m$^2$). The total value of BUA was not significant by Cyprus (231 km$^2$). The smallest BUA per person was in Slovenia (77 m$^2$), the United Kingdom (92 m$^2$), and Latvia (92 m$^2$).

The average GDP demands for BUA in the EU-27 countries for 2012 calculated according to the purchasing power standard (PPS) were 5.05 m$^2$ per PPS. The Czech Republic had above-average GDP demands for BUA (5.66 m$^2$ per PPS). The highest demand values were in relation to Bulgaria (11.71 m$^2$), Cyprus (11.45 m$^2$), and Portugal (10.34 m$^2$). The absolutely lowest GDP demands for BUA were in Luxembourg (1.93 m$^2$), and the following countries had below 4 m$^2$ per PPS: Holland (3.20 m$^2$), the United Kingdom (3.44 m$^2$), Germany (3.56 m$^2$), and Slovenia (3.59 m$^2$). Portugal was among the countries with high values for both indicators (BUA per person and GDP demands for BUA), with the total BUA 2120 km$^2$).

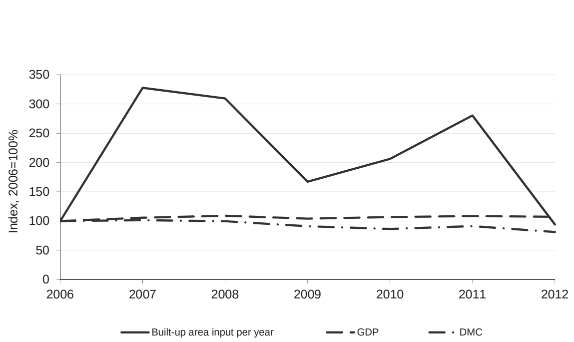



Fig. 5. Development of land area input for build-up per year, domestic material consumption (DMC), and gross domestic product (GDP) indicators

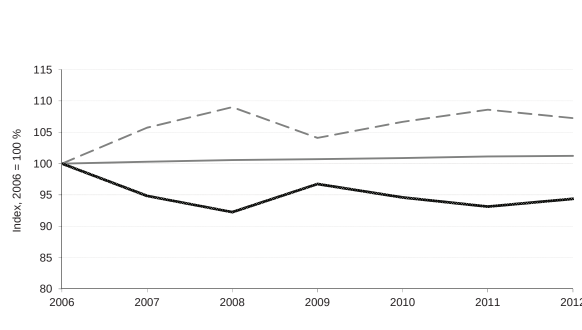



Fig. 6. Development of BUA, gross domestic product (GDP), and GDP demands for BUA in the Czech Republic (2006–2012)

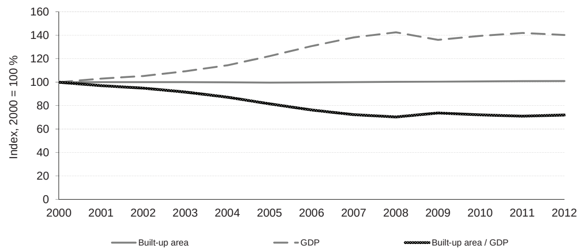



Fig. 7. Development of BUA, gross domestic product (GDP), and GDP demands for BUA in the Czech Republic (2000–2012)

## DISCUSSION

### Interpretation of the results

The growing BUA in the Czech Republic has a major impact on the key ecological function of the landscape. Utilization of the area for build-up and infrastructure may also be considered as the utilization of natural resources.

In spite of the fact that the percentage of the BUA in the total area of the Czech Republic is increasing, development of the BUA per person indicator shows a slump in BUA per person in recent years because the population is growing faster than the BUA. This evidences that the landscape can be considered a natural resource which is being exhausted in relation to the growth of population, not only in the Czech Republic. It is important to mention that the percentage of free areas fulfilling key ecological landscape functions is also falling because of build-up (buildings). The average value of the BUA per person indicator in individual EU-27 countries differs significantly. This indicator can be used to compare the environmental burden resulting from the use of build-up in the same manner like a number of material and energy inputs and also harmful pollutant outputs are compared on the level of the EU today.

Development of the land area input for build-up per year indicator for the Czech Republic shows large year-on-year differences in changes to the BUA. The same methodology was chosen as the methodology used for the evaluation of the now standard annual DMC. There is probably a link between the development of this indicator and the development of the DMC indicator. A significant part of DMC is materials used in build-up.

Development of decoupling between the BUA and GDP using the GDP demands for BUA indicator results in changes to GDP values in particular, while the BUA in the Czech Republic increases constantly at a relatively slow rate. In practice, this means that relative decoupling can only achieve positive values under the condition of a significant GDP growth. An international comparison shows countries which have

Fig. 8. Gross domestic product (GDP) demands for BUA in the EU-27 countries
PPS = purchasing power standard

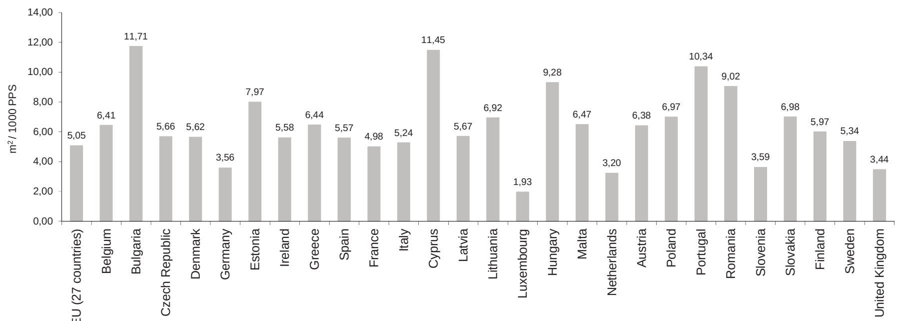
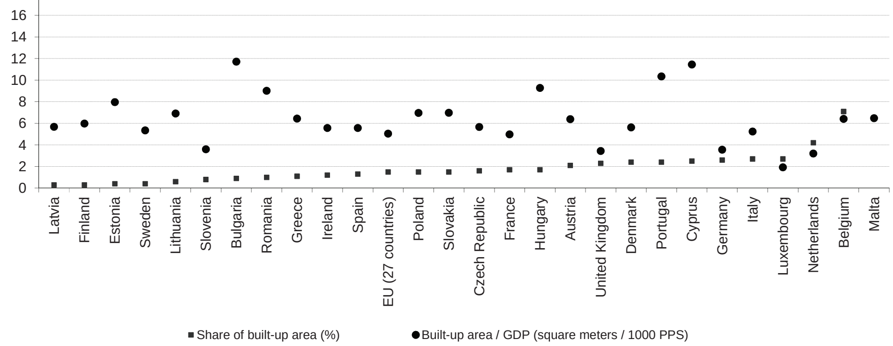



Fig. 9. Share of BUA in the total area of the country and gross domestic product (GDP) demands for BUA
PPS = purchasing power standard



a sustainable BUA. The circumstances of future energy consumption by buildings and infrastructure and the need for repairs and maintenance are also significant. It could be assumed that poorer EU countries with a high percentage of agriculture (e.g. Poland) will have greater BUA per person and greater economic demands for BUA, but the international comparison shows that this does not have to be true. For instance, Poland has a below-average BUA per person and slightly above-average GDP demands for BUA comparable e.g. to Austria, Slovakia, and Belgium. If we consider that Luxembourg has an average BUA per person of 131 $m^2$, it has enormous economic efficiency in relation to the utilization of the BUA. In contrast, on the basis of the values of both indicators, countries such as Bulgaria, Cyprus, and Portugal can expect problems in the future in the field of maintenance of buildings and also energy supply with all the related impact on the landscape and the environment.

**Evaluation of the proposed indicators exploitability**

The results show that the BUA per person indicator is suitable for year-on-year or international comparison and the GDP demands for BUA indicator is suitable for the development of decoupling. In contrast, the land area input for build-up per year indicator has been shown to be unsuitable.

The landscape is a key resource together with materials and energy, however the established method for monitoring the annual material and energy consumption does not seem to be usable in the case of the occupation of land. A certain relationship becomes apparent during the comparison of land area input for build-up per year with development of DMC, for instance the fall in 2008 and 2009 and growth in 2011 and the repeated fall in 2012. In contrast, development of the DMC and land area input for build-up per year indicators differed in 2010. This indicator shows significant fluctuation year-on-year and its curve is very uneven.

We are convinced that the industrial and post-industrial economy in Europe creates a significant percentage of the profits from BUAs, and this is also demonstrated by the aforementioned German BUA Productivity study (Schoer et al., 2003). However, the BUA is used long-term in contrast to some materials comprising DMC (e.g. fossil fuels or biomass). The duration of their use is much longer than the period the actual build-up materials remain in the economy (particularly non-metallic minerals). For this reason we believe that the total BUA, i.e. the GDP demands for BUA indicator, is more suitable for indicating decoupling. Unlike DMC, the total BUA does not decrease during the cessation of economic growth. It is difficult to imagine that buildings and infrastructure would be intentionally demolished during the cessation of economic growth and, furthermore, the removal of buildings from the landscape does not automatically mean a reduction of the environmental burden, as stated by Milà i Canals et al. (2007) and Koellner, Scholz (2008), because the period of restoration of a BUA into a climax condition takes up to 1000 and more years. On the other hand, we are aware of cases from Czechoslovak history when land use and land cover changed significantly, particularly in the Czech border area around the Iron Curtain (Sklenička et al., 2014). The displacement of the German population after the Second World War and the subsequent demolition of settlement structures linked to protection of the border zone around the Iron Curtain (Kovařík, 2009) caused gradual succession at sites and the expansion of the forested area in border mountainous regions (Bičík et al., 2001). We must mention that the abandonment and extinction of settlements and the demolition of buildings was linked to the displacement of a great number of inhabitants, and so this pathological historic phenomenon would not have had a positive effect on the development of the indicators we proposed. The period of succession following BUAs, i.e. 1000 years according to Koellner, Scholz (2008), may, however, be disputable. In spite of the fact that today's landscape in the Czech Sudetenland still bears traces of prior settlement and the growth structures are not consistent with the climax stage, many areas were naturally or artificially re-forested after the removal of structures (Rolková, 2009).

The other aspect of the indication of decoupling – GDP – may also be an issue for discussion. For the purpose of international comparison, we used GDP expressed as so-called purchasing power standard (PPS) as calculated for individual countries by Eurostat (2014e). Even though there are a number of indicators for prosperity other than GDP (Giannetti, 2015), we did not consider their use because research results would not have been compatible with current methods. Another disadvantage in using GDP, particularly for long-term analyses, are changes in currency exchange rates over time and changes to the composition of the consumer basket for determining PPS (Deaton, Dupriez, 2011; Beckmann, 2013).

The disadvantage of the proposed indicators is that they take into account only the BUA. Development of indicators can be expected to include artificial surfaces (buildings, infrastructure and other construction, mining and other areas) and also other minor damage to the landscape in relation to agricultural production.

## CONCLUSION

The present survey results for the Czech Republic show that the BUA is growing constantly in spite of the fact that GDP has been very low in recent years. In spite of falling annual DMC, the environmental burden is increasing in the form of BUA. If this development continues, it would be appropriate to re-evaluate the current soil protection policy before this soil is permanently occupied by build-up.

Suitable methods for the comparison of the environmental burden posed by BUAs are methods utilizing total BUA, because the area is utilized repeatedly and over the long-term. This fact is in conflict with routine methods for evaluating the use of natural resources on the level of the European Union, chiefly material demands for GDP.

We recommend that the indicators BUA per person and GDP demands for a BUA be included among the present Key environmental indicators in group: Soil, landscape and agriculture. The initial hypothesis was not confirmed. It seems that share of BUA in the total area of a country and GDP demands for a BUA are independent.

## REFERENCES


Aksoezen M, Daniel M, Hassler U, Kohler N (2015): Building age as an indicator for energy consumption. Energy and Buildings, 87, 74–86. doi: 10.1016/j.enbuild.2014.10.074.

Alberti M, Booth D, Hill K, Coburn B, Avolio C, Coe S, Spirandelli D (2007): The impact of urban patterns on aquatic ecosystems: an empirical analysis in Puget lowland subbasins. Landscape and Urban Planning, 80, 345–361. doi: 10.1016/j.landurbplan.2006.08.001.

Balaras CA, Gaglia AG, Georgopoulou E, Mirasgedis S, Sarafidis Y, Lalas DP (2007): European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. Building and Environment, 42, 1298–1314. doi: 10.1016/j.buildenv.2005.11.001.

Beckmann J (2013): Nonlinear adjustment, purchasing power parity and the role of nominal exchange rates and prices. The North American Journal of Economics and Finance, 24, 176–190. doi: 10.1016/j.najef.2012.07.005.

Bičík I, Jeleček L, Štěpánek V (2001): Land-use changes and their social driving forces in Czechia in the 19th and 20th centuries. Land Use Policy, 18, 65–73.

Boulding K (1996): The economics of the coming spaceship Earth. In: Lippit V (ed.): Radical political economy. Explorations in alternative economic analysis. M.E. Sharpe, Armonk, 357–367.

Brunner PH, Rechberger H (2004): Practical handbook of material flow analysis. CRC Press, Boca Raton.

Capros P, Mantzos L, Papandreou V, Tasios N (2008): Trends to 2030 – update 2007. European Commission, Directorate General for Energy and Transport. Office for Official Publications of the European Communities, Luxembourg.

Cellura M, Guarino F, Longo S, Mistretta M, Orioli A (2013): The role of the building sector for reducing energy consumption and greenhouse gases: an Italian case study. Renewable Energy, 60, 586–597. doi: 10.1016/j.renene.2013.06.019.

CENIA (2014): Report on the Environment of the Czech Republic 2012. Czech Environmental Information Agency Web. http://www1.cenia.cz/www/node/495. Accessed 6 September, 2014.

CZSO (2014): Population. Czech Statistical Office Web. https://www.czso.cz/csu/czso/population_hd, Accessed 16 September, 2014.

Deaton A, Dupriez O (2011): Purchasing power parity exchange rates for the global poor. American Economic Journal: Applied Economics, 3, 137–166. doi: 10.1257/app.3.2.137.

Dvořák J (2012): The study of water flow Botič basin. In: Maršálek M, Tesařová B, Pecharová E (eds): Insights into the landscape ecology – a collection of professional and scientific work of PhD students. Lesnická práce, Kostelec nad Černými lesy (in Czech).

Eurostat (2014a): Artificial land cover. Eurostat Web. http://ec.europa.eu/eurostat/tgm/table.do?pcode=tsdnr510&language=en Accessed 12 September, 2014.

Eurostat (2014b): Built-up areas. Eurostat Web. http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tsdnr510&plugin=1. Accessed 12 September, 2014.

Eurostat (2014c): Population on 1 January, Eurostat Web. http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tps00001&plugin=1. Accessed 12 September, 2014.

Eurostat (2014d): Gross domestic product at market prices. Eurostat Web. http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=tec00001&language=en. Accessed 12 September, 2014.

Eurostat (2014e): GDP per capita in PPS. Eurostat Web. http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tec00114&plugin=1. Accessed 12 September, 2014.

Eurostat (2015): Land cover and land use, landscape (LUCAS) (lan). Eurostat Web. http://ec.europa.eu/eurostat/cache/metadata/en/lan_esms.htm#stat_process1418758775745. Accessed 12 September, 2014.

European Union (2013): Energy, transport and environment indicators. Publications Office of the European Union, Luxembourg.

Fishman T, Schandl H, Tanikawa H, Walker P, Krausmann F (2014): Accounting for the material stock of nations. Journal of Industrial Ecology, 18, 407–420. doi: 10.1111/jiec.12114.

Frantál B, Greer-Wootten B, Klusáček P, Krejčí T, Kunc J, Martinát S (2015): Exploring spatial patterns of urban brownfields regeneration: The case of Brno, Czech Republic. Cities, 44, 9–18. doi: 10.1016/j.cities.2014.12.007.

Gaglia AG, Balaras CA, Mirasgedis S, Georgopoulou E, Sarafidis Y, Lalas DP (2007): Empirical assessment of the Hellenic non-residential building stock, energy consumption, emissions and potential energy savings. Energy Conversion

and Management, 48, 1160–1175. doi: 10.1016/j.enconman.2006.10.008.
García-Olivares A, Solé J (2014): End of growth and the structural instability of capitalism – from capitalism to a symbiotic economy. Futures, 68, 31–43. doi: 10.1016/j.futures.2014.09.004.
Giannetti BF, Agostinho F, Almeida CMVB, Huisingh D (2015): A review of limitations of GDP and alternative indices to monitor human wellbeing and to manage eco-system functionality. Journal of Cleaner Production, 87, 11–25. doi: 10.1016/j.jclepro.2014.10.051.
Glatzer W (2012): Cross-national comparisons of quality of life in developed nations, including the impact of globalization. In: Land KC, Michalos AC, Sirgy MJ (eds): Handbook of social indicators and quality of life research, Springer Netherlands, 381–398.
Gul MS, Patidar S (2015): Understanding the energy consumption and occupancy of a multi-purpose academic building. Energy and Buildings, 87, 155–165. doi: 10.1016/j.enbuild.2014.11.027.
Gustavsson L, Joelsson A (2010): Life cycle primary energy analysis of residential buildings. Energy and Buildings, 42, 210–220. doi: 10.1016/j.enbuild.2009.08.017.
Hitchin R, Pout C, Butler D (2015): Realisable 10-year reductions in European energy consumption for air conditioning. Energy and Buildings, 86, 478–491. doi: 10.1016/j.enbuild.2014.10.047.
Jenkins V (2002): Communication from the Commission: A sustainable Europe for a better world: A European Union strategy for 'sustainable development'. Journal of Environmental Law, 14, 261–264. doi: 10.1093/jel/14.2.261.
Junnila S, Horvath A (2003): Life-cycle environmental effects of an office building. Journal of Infrastructure Systems, 9, 157–166. doi: 10.1061/(ASCE)1076-0342(2003)9:4(157).
Kalnay E, Cai M (2003): Impact of urbanization and land-use change on climate. Nature, 423, 528–531. doi: 10.1038/nature01675.
Koellner T, Scholz RW (2008): Assessment of land use impacts on the natural environment. The International Journal of Life Cycle Assessment, 13, 32–48. doi: 10.1007/s11367-006-0292-2.
Kovanda J (2014): Incorporation of recycling flows into economy-wide material flow accounting and analysis: A case study for the Czech Republic. Resources, Conservation and Recycling, 92, 78–84. doi: 10.1016/j.resconrec.2014.08.006.
Kovanda J, Hák T (2007): What are the possibilities for graphical presentation of decoupling? An example of economy-wide material flow indicators in the Czech Republic. Ecological Indicators, 7, 123–132. doi: 10.1016/j.ecolind.2005.11.002.
Kovařík D (2009): Demolition work in the Czech borderland in 1945–1960. Dissertation, Masaryk Univerity (in Czech).
Meadows DH, Meadows DL, Randers J, Behrens WW (1972): The limits to growth. Universe Books, New York.
Milà i Canals L, Bauer C, Depestele J, Dubreuil A, Knuchel RF, Gaillard G, Michelsen O, Müller-Wenk R, Rydgren B (2007): Key elements in a framework for land use impact assessment within LCA. The International Journal of Life Cycle Assessment, 12, 5–15. doi: 10.1065/lca2006.05.250.
Miller JD, Kim H, Kjeldsen TR, Packman J, Grebby S, Dearden R (2014): Assessing the impact of urbanization on storm runoff in a peri-urban catchment using historical change in impervious cover. Journal of Hydrology, 515, 59–70. doi: 10.1016/j.jhydrol.2014.04.011.
Ministry of the Environment – Government of Japan, Tokyo (2013): Waste / Recycle. Ministry of the Environment – Government of Japan Web. http://www.env.go.jp/en/focus/docs/05_wr.html. Accessed 10 December, 2014.
Nelson AC (1990): Economic critique of US prime farmland preservation policies: Towards state policies that influence productive, consumptive, and speculative value components of the farmland market to prevent urban sprawl and foster agricultural production in the United States. Journal of Rural Studies, 6, 119–142.
OECD (2002): Indicators to measure decoupling of environmental pressure from economic growth. OECD Web. http://www.oecd.org/dataoecd/0/52/1933638.pdf. Accesed 15 December, 2014.
Radhi H, Sharples S (2013): Global warming implications of facade parameters: A life cycle assessment of residential buildings in Bahrain. Environmental Impact Assessment Review, 38, 99–108. doi: 10.1016/j.eiar.2012.06.009.
Rolková J. (2009): Development of vegetation and land cover in an abandoned border region Český les. Ph.D. Thesis, University of South Bohemia in České Budějovice. (in Czech)
Rougé C, Cai X (2014): Crossing-scale hydrological impacts of urbanization and climate variability in the Greater Chicago Area. Journal of Hydrology, 517, 13–27. doi: 10.1016/j.jhydrol.2014.05.005.
Ščasný M, Kovanda J, Hák T (2003): Material flow accounts, balances and derived indicators for the Czech Republic during the 1990s: results and recommendations for methodological improvements. Ecological Economics, 45, 41–57. doi: 10.1016/S0921-8009(02)00260-4.
Schoer K, Deggau M, Seibel S (2003): Development of built-up and traffic area in Germany 1993 to 2001 – Approaches to an environmental economic analysis. 8th Meeting of the London Group on Environmental Accounting 5 – 7 November 2003, Rome. London Group on Environmental Accounting Web. https://unstats.un.org/unsd/envaccounting/londongroup/meeting8.asp. Accessed 15 April, 2014.
Sklenička P, Šímová P, Hrdinová K, Šálek M (2014): Changing rural landscapes along the border of Austria and the Czech Republic between 1952 and 2009: Roles of political, socio-economic and environmental factors. Applied Geography, 47, 89–98. doi: 10.1016/j.apgeog.2013.12.006.
Song W (2014): Decoupling cultivated land loss by construction occupation from economic growth in Beijing. Habitat International, 43, 198–205. doi: 10.1016/j.habitatint.2014.03.002.

State Administration of Land Surveying and Cadastre (2014): Aggregate reports of land resources cadastre data. State Administration of Land Surveying and Cadastre Web. http://www.cuzk.cz/Periodika-a-publikace/Statisticke-udaje/Souhrne-prehledy-pudniho-fondu.aspx. Accessed 6 September, 2014.

Stoate C, Báldi A, Beja P, Boatman ND, Herzon I, Van Doorn A, Ramwell C (2009): Ecological impacts of early 21st century agricultural change in Europe – a review. Journal of Environmental Management, 91, 22–46. doi: 10.1016/j.jenvman.2009.07.005.

Thompson AW, Prokopy LS (2009): Tracking urban sprawl: using spatial data to inform farmland preservation policy. Land Use Policy, 26, 194–202. doi: 10.1016/j.landusepol.2008.02.005.

UNEP (2011): Decoupling natural resource use and environmental impacts from economic growth. United Nations Environment Programme.

van der Voet E, van Oers L, Moll S, Schütz H, Bringezu S, de Bruyn S, Warringa G (2005): Policy review on decoupling: development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries. EU Commission, DG Environment, Brussels.

von Weizsäcker EU, de Larderel JA, Hargroves K, Hudson C, Smith MH, Rodrigues MAE, Sparks D (2014): Decoupling 2: technologies, opportunities and policy options. United Nations Environment Programme.

Wenger SJ, Roy AH, Jackson CR, Bernhardt ES, Carter TL, Filoso S, Walsh CJ (2009): Twenty-six key research questions in urban stream ecology: an assessment of the state of the science. Journal of the North American Benthological Society, 28, 1080–1098. doi: 10.1899/08-186.

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Appendix 1. Data for the development in the Czech Republic

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Build-up area (square kilometers) | 1305.2 | 1306.7 | 1305.9 | 1306.1 | 1303.1 | 1300.8 | 1301.9 | 1305.7 | 1309.3 | 1311.3 | 1313.7 | 1316.9 | 1318.0 |
| Population (thousands) | 10192.6 | 10192.6 | 10192.6 | 10192.6 | 10195.3 | 10198.9 | 10223.6 | 10254.2 | 10343.4 | 10425.8 | 10462.1 | 10486.7 | 10505.4 |
| GDP (millions CZK in constant prices in 2010) | 2550148 | 2629135 | 2685643 | 2786789 | 2918955 | 3116056 | 3334815 | 3526071 | 3635344 | 3471494 | 3557216 | 3621908 | 3577164 |
| Build-up area per capita ($m^2$ / capita) | 128.1 | 128.2 | 128.1 | 128.1 | 127.8 | 127.5 | 127.3 | 127.3 | 126.6 | 125.8 | 125.6 | 125.6 | 125.5 |
| Build-up area / GDP (m2 / 1000 CZK) | 0.5118 | 0.4970 | 0.4862 | 0.4687 | 0.4464 | 0.4174 | 0.3904 | 0.3703 | 0.3602 | 0.3777 | 0.3693 | 0.3636 | 0.3684 |

Appendix 2. Statistics for EU-27 countries in year 2012.

| 2012 | Millions of PPS (Purchasing Power Standard) | Build-up area ($km^2$) | Share of the total area (%) | Build-up area / GDP ($m^2$ / 1000 PPS) | Population | Build-up area per capita ($m^2$ / capita) |
|---|---|---|---|---|---|---|
| EU (27 countries) | 12893051.2 | 65055 | 1.5 | 5.046 | 500306522 | 130.030 |
| Belgium | 338929.1 | 2173 | 7.1 | 6.411 | 11094850 | 195.857 |
| Bulgaria | 88570.1 | 1037 | 0.9 | 11.708 | 7327224 | 141.527 |
| Czech Republic | 217215.2 | 1229 | 1.6 | 5.658 | 10505445 | 116.987 |
| Denmark | 179591.4 | 1009 | 2.4 | 5.618 | 5580516 | 180.808 |
| Germany | 2578598.7 | 9184 | 2.6 | 3.562 | 80327900 | 114.331 |
| Estonia | 24466.7 | 195 | 0.4 | 7.970 | 1325217 | 147.146 |
| Ireland | 150968.9 | 842 | 1.2 | 5.577 | 4582707 | 183.734 |
| Greece | 216446.6 | 1394 | 1.1 | 6.440 | 11123034 | 125.326 |
| Spain | 1125305.7 | 6268 | 1.3 | 5.570 | 46818219 | 133.880 |
| France | 1814550.7 | 9028 | 1.7 | 4.975 | 65287861 | 138.280 |
| Italy | 1561306.5 | 8188 | 2.7 | 5.244 | 59394207 | 137.859 |
| Cyprus | 20175.3 | 231 | 2.5 | 11.450 | 862011 | 267.978 |
| Latvia | 33314.1 | 189 | 0.3 | 5.673 | 2044813 | 92.429 |
| Lithuania | 54639.2 | 378 | 0.6 | 6.918 | 3003641 | 125.847 |
| Luxembourg | 35684.8 | 69 | 2.7 | 1.934 | 524853 | 131.465 |
| Hungary | 168604.7 | 1565 | 1.7 | 9.282 | 9931925 | 157.573 |
| Malta | 9266.9 | 60 | 19.0 | 6.475 | 417546 | 143.697 |
| Netherlands | 545229.4 | 1746 | 4.2 | 3.202 | 16730348 | 104.361 |
| Austria | 279282.2 | 1783 | 2.1 | 6.384 | 8408121 | 212.057 |
| Poland | 659676.7 | 4597 | 1.5 | 6.969 | 38538447 | 119.283 |
| Portugal | 204946.5 | 2120 | 2.4 | 10.344 | 10542398 | 201.093 |
| Romania | 271953.2 | 2454 | 1.0 | 9.024 | 20095996 | 122.114 |
| Slovenia | 43985.5 | 158 | 0.8 | 3.592 | 2055496 | 76.867 |
| Slovakia | 104926.1 | 732 | 1.5 | 6.976 | 5404322 | 135.447 |
| Finland | 159190.6 | 951 | 0.3 | 5.974 | 5401267 | 176.070 |
| Sweden | 306392.4 | 1637 | 0.4 | 5.343 | 9482855 | 172.627 |
| United Kingdom | 1696717.9 | 5838 | 2.3 | 3.441 | 63495303 | 91.944 |