Expected negative externalities and public budgets costs depending on 2 zoning plans scenarios

Prague case-study on transportation

Prague planning and development institute

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Extended abstract

In this paper we focused on comparing 2 Prague's possible growth scenarios to the year 2030. The firs scenario is based on current "1999 zoning plan" and the second scenario on proposed "Metropolitan plan" that is currently in the stage of preparation and that should replace the "1999 zoning plan". The main difference of these plans is that the new Metropolitan plan proposes more compact and more intensive development.

The aim of the analysis is to compare expected negative externalities of individual car transport and public transport costs for both concerned scenarios and also to compare land-use characteristics of defined concentric zones.

The whole analysis is done on Prague empirical data and projections. Among sources are real-estates trends data, 2011 Census data, population spatial behavior data by cell-phone service provider, public transport operation costs data, current land-use, proposed zoning plans restrictions, population, economic and real estates prognosis.

The analysis was processed in GIS software. The subresults elaborated in scale of Elementary statistical units were analyzed by statistical tools to propose general model for predicting parameters of considered 2030 scenarios.

One of subresult to mention is difference of population distribution between 2 scenarios. Based on our model we expect 20 000 more resident will live in the central part of the city in scenario based on Metropolitan plan. Conversely these 20 000 residents are allocated in the city edge zone in scenario based on 1999 zoning plan. This spatial difference is mostly responsible for differences in the results.

The results based on our models predict savings both on public transport costs and individual car transport. If the Metropolitan plan is implemented, the savings in 15 years should reach approximately 0,5% of total public transportation costs and at a same time externalities of individual car transport should decrease by 0,88% that equals 1,97 million Euros annually that is caused by expected 128 194 reduction of daily commute driven vehicle kilometers.

Although savings might seem not to be significant, it is important to mention that they are caused only by 15 years of alternative development and more significant savings are expected in long-term horizon that should be analyzed in further research.

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The analysis background

This spatial-development analysis was elaborated as a part of wider document called 'Economic sustainability of the city (of Prague): Economic impact analysis of Strategic plan, 2016 update, preliminary analysis,' that is a result of cooperation of Prague planning and development institute, Czech chamber of commerce and Deloitte.
This analysis is an initial step of urban-development economic evaluation done at Prague planning and development institute.

The aim of the analysis

The goal of the analysis was to compare negative externalities and public budgets costs caused by two different zoning plans. The compared zoning plans are 1999 Prague zoning plan and proposal of new zoning plan, so called Metropolitan plan, that should come into force in 2020 to replace the 1999 zoning plan. In the analysis we especially focused on transport related externalities and public budgets costs.

Our presumption was that development according to Metropolitan plan should induce less transport costs and externalities thanks to its more compact and more intensive land-use proposal. For the same reason we expected costs of publicly managed infrastructure, like public spaces, to decrease as well. Generally the advantages of compact urban development compared to expansive modernist development are widely discussed, starting with Jane Jacobs (1975) or recent Czech authors like Pavel Hnilička (2012) or Roman Koucký (2006). We wanted to confirm these assumptions with analysis of Prague empiric data.

Moreover the aim was to conceptualize complex analysis for estimating future impacts of urban development using wide range of data including economic and demographic prognosis, real-estates trends, census data, transportation and mobility data, zoning plan restrictions and land-use.

Input sources review

To elaborate the analysis it was necessary to obtain elementary data sources about Prague future development. First of all we used internal sources of Prague planning and development institute and public available data about housing construction in Prague provided by Czech statistical office.

[1] Demographic projection

As the first we considered Prague demographic prognosis projected to year 2030. This analysis was compiled at Prague planning and development institute. The demographic prognosis itself is based on previous demographic prognosis Burcin et al. (2014), but it was adjusted with demographic development in 2015 and shortened to year 2030 from original 2050. For the analysis we used the medium variant of demographic projection. The relevant outcome of this demographic analysis is population increase in Prague between 2015 and 2030.

[2] ECONOMIC PROJECTION

Another two basic variables considered in the project were predictions elaborated by consulting company Deloitte.
The first output of Deloitte was Prague economic prognosis between 2015 and 2030. The model itself is based on DGSE economic model that predicted GDP development, price level, average salaries and other economic indicators defined in DGSE model (the model as a whole is internal property of Deloitte co. and authors were provided only with its results). In the model the medium variant of demographic prognosis provided by Planning and development institute was involved as one of variables. The DGSE model was constructed assuming constant tax burden (valid in 2015) and stable economic and price level development. The key output of the model was Prague GDP development in the considered period.

[3] REAL ESTATES PROJECTION

The second output by Deloitte co. was real estates market prediction. The monitored variables were total apartments area and average apartment's area per resident. The results were calculated using statistical multiple regression analysis and as independent variables Prague GDP and Prague population were used. Then for the further usage Prague tax revenues in 2030 were calculated based on estimated GDP and current budgetary taxes allocation.
The key outcomes of these external data sources for further analysis were apartments floor area increases and population increase. These two variables are foundations for spatial-development analysis and scenarios comparison.

Research concept

To estimate the difference in costs and externalities induced by two urban forms we consider 2 development scenarios. The first scenario expects current 1999 zoning plan to continue in force without changes until the year 2030. The second scenario describes potential development until 2030 if the Metropolitan plan came into force in 2016. The model should capture difference in urban development that should occur after 15 years of Metropolitan plan being implemented.

Having expected 2030 development scenarios we assign to them parameters of residents behavior and land-use characteristics. These parameters, such as share of automobile commuters, average commute distance, size of public space per person, then could be recalculated as costs or externalities as it will be more described later.

The parameters mentioned above are results of current land use analysis that was done on Prague administrative area.

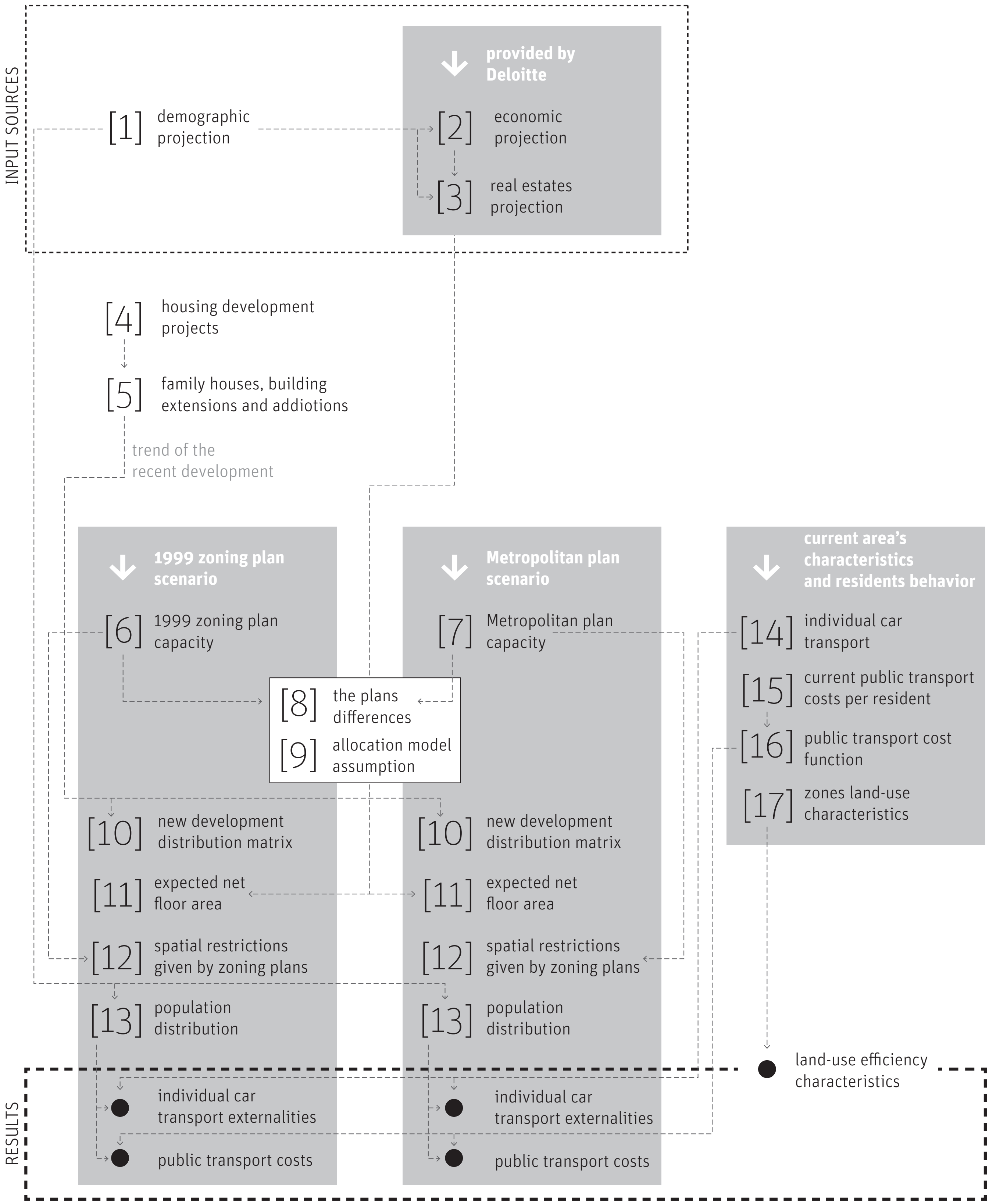
Our assumption is, that current development maximizes utility under conditions of current market relations. One of tools creating these relations is zoning plan that enable developing land and limits maximum building volume.

If the zoning plan is changed, especially when maximum building capacity is in some localities increased or decreased in others, we expect spatial distribution of new development to change.

Our expectation follows Supply-Demand relation: If there are areas where maximum building volume would be increased, price of building there should decline and this should encourage higher construction activity. Vice versa in areas where building volume is decreased by new zoning plan, the consecutive effect should be declined construction activity. This expectation is based on Edward Glaeser's (2012) assumption that more restrictive zoning leads to higher prices and thus decrease new construction activity. Other literature, such as Cheshire P. C. (2014), suggest urban planning restrictions reduce new development and thus encourage prices to rise. They demonstrate it on whole city level and compare cities among themselves, but we expect this should occur as well within zones of one city.

We have focused especially on housing development that we see crucial for urban formation and residents behavior.

Research concept scheme



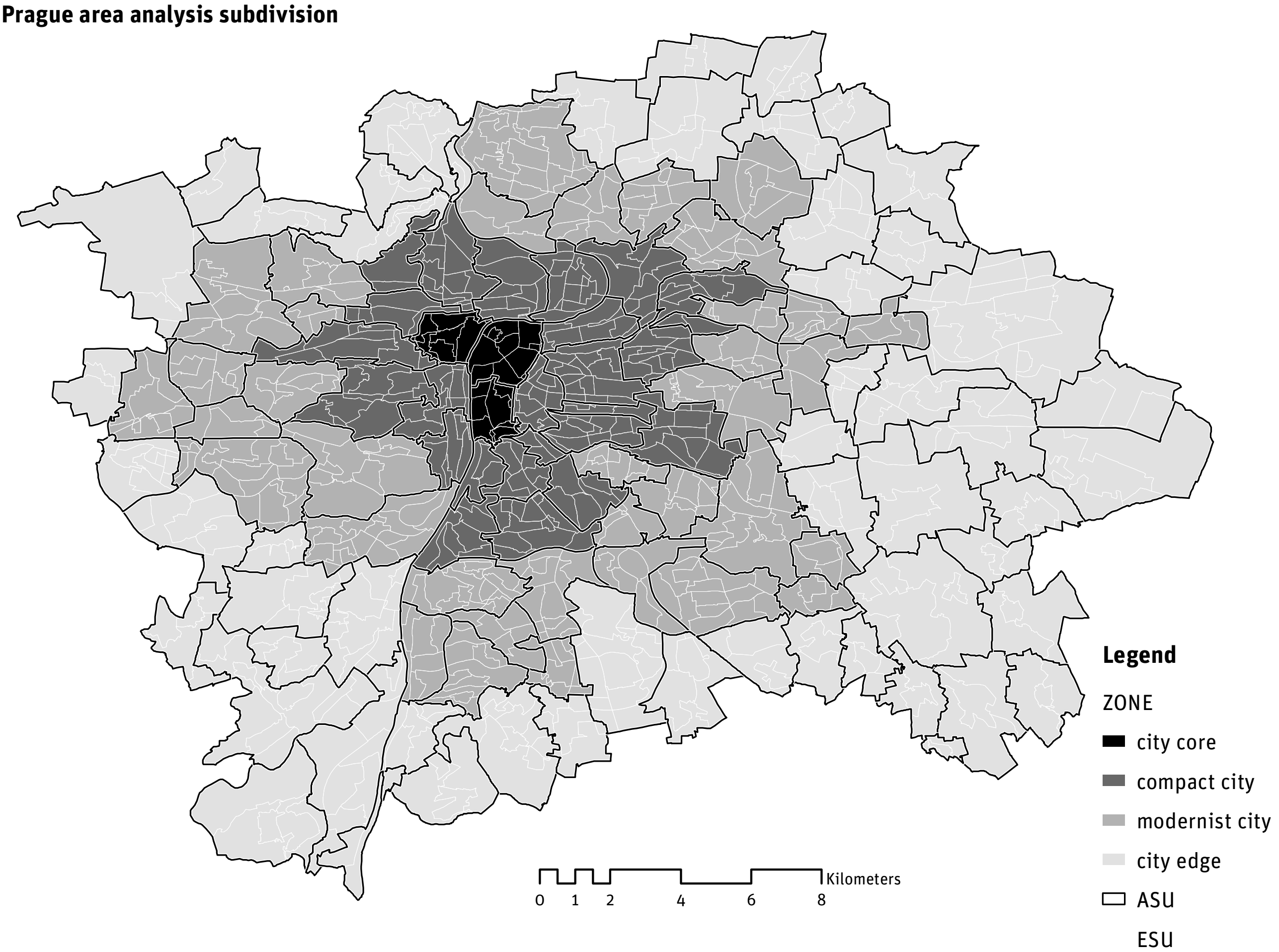
The Prague spatial subdivision

The analysis is based on land division in Elementary statistical units ('ESU', in Czech called ZSJ). These units are used for example by Czech statistical office for decade Census. There is roughly 900 'ESU' in Prague. The 'ESU' are aggregated into Aggregated statistical units ('ASU') that follow functional relations within the city. There is 120 defined 'ASU' in Prague.

For further analysis 'ASU' are assigned to 4 concentric zones that follows urban structure. Zones are 'city core', 'compact city', 'modernist city' and 'city edge'.

The scheme of spatial subdivision is on map bellow.

Prague area analysis subdivision



The trend of recent development

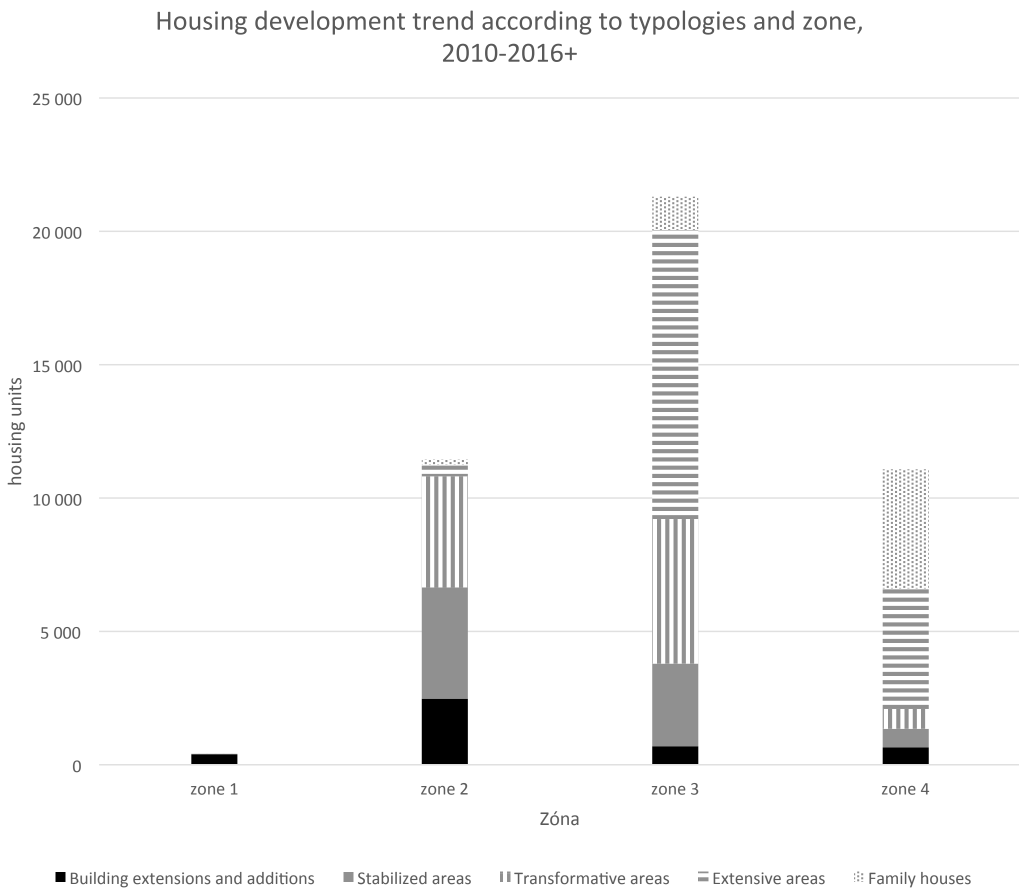
To predict future development we needed to estimate its volume and location. The real-estate volume prediction was data-source we received from Deloitte.
To estimate future development location we analyzed location of recently built housing projects. We expect that scenario “1999 zoning plan” would continue allocation trend.

[4] Housing development projects

We analyzed our database of real-estate housing development (including projects with more than 10 housing units) that covers years 2010 to 2016. This database in total contains 34 176 housing units in 383 development projects. The database contains high share of projects in the year 2016, where are listed beside finished projects also projects under construction that will be finished in following years.
Each project is geographically localized and according to its location has assigned 3 features: floor area ratio, character of area and zone. Floor area ratio (FAR) is assigned according to current 1999 zoning plan in 4 categories: ‘less than 0,6’ that are detached houses, ‘0,6-1,5’ that are heterogeneous urban structures and modernist settlements, ‘1,5-2,5’ that are compact urban structures and ‘more than 2,5’ that are historic urban structures and high-rise.
The characters of area are ‘expansive’ that means green-field developments, ‘transformative’ that are brown-field re-developments and ‘stabilized’ that are additions to existing urban structures.
The zones are concentric areas sets around the city center. We define 4 zones called ‘city core’, ‘compact city’, ‘modernist city’ and ‘city edge’. This makes each project a vector with 3 discrete values. We consider these 3 features as very important, because they describe qualitative aspects of housing development

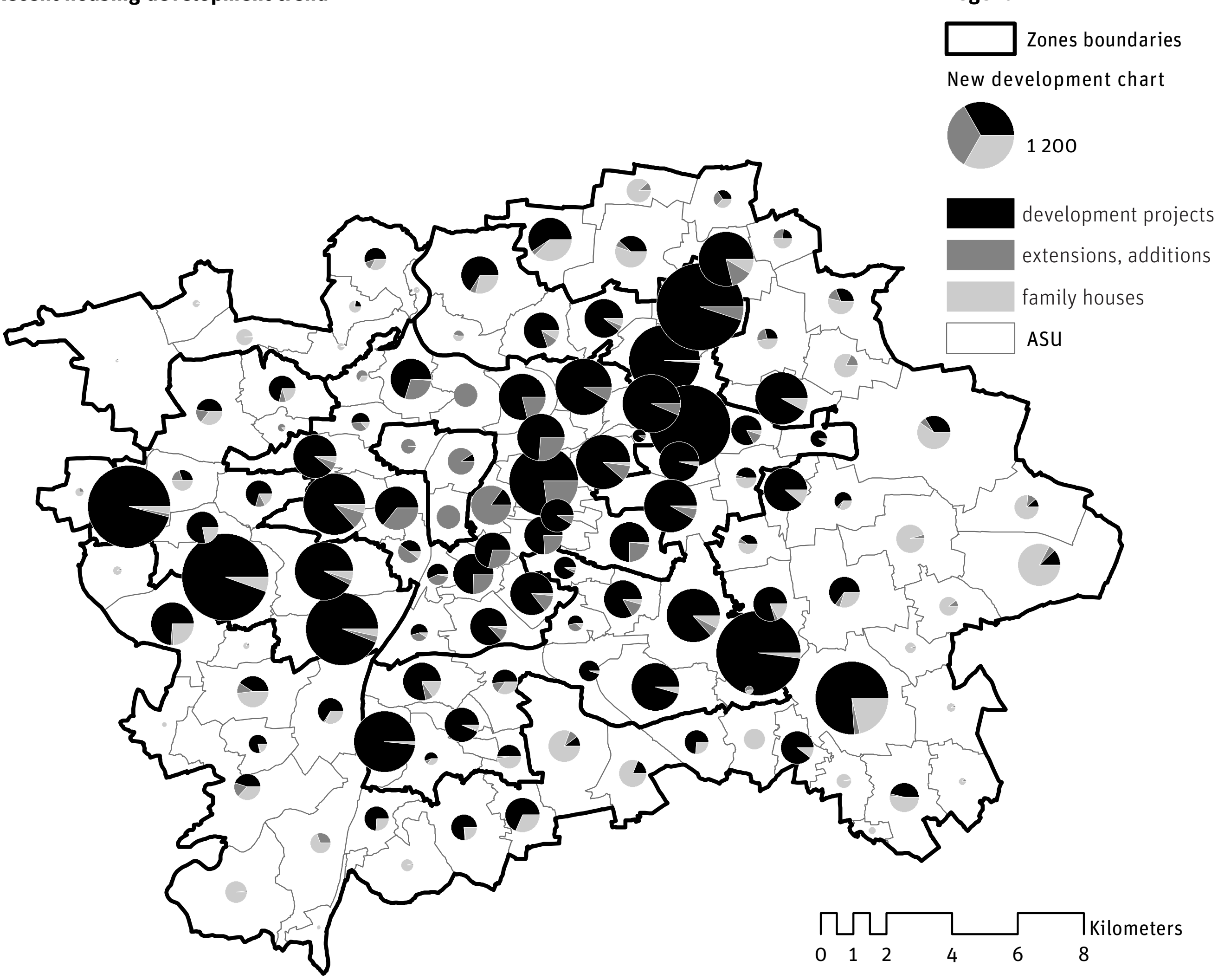
[5] Family houses, building extensions and additions

To complete our housing development trend analysis we had to add 2 other typologies, that are not included in our datasets. These 2 typologies are family (one housing units) houses and building extensions and additions. Although these typologies are in total unimportant (the share of building extensions and additions is 9,5% and the share of family houses is 12,6%), they have higher share especially in city core (building extensions and additions) and in city edge (family houses). To add these typologies into our dataset, we used Czech statistical office data. These data are aggregated for municipalities, so ‘FAR’ and ‘character of area’ features cannot be assigned directly, because for them we need exact location. In case of ‘building extensions and additions’ it doesn’t cause any problem, because this kind of development is not so much dependent on zoning plan, rather than on other regulation. For that reason we consider ‘building extensions and additions’ to be same in both zoning scenarios and therefore it cannot cause difference between both plans. We only need to estimate the total volume of this kind of development, because it would saturate part of future housing space demand.
In case of family houses we assigned them ‘FAR’ less than 0,6 that suits most of development of this typology and ‘character of area’ expansive, that is prevailing for new detached housing projects outside the inner city.
Having combined these two data sources together we captured the trend of recent housing development in Prague.



Apartments built in development projects from our database are divided into categories according to ‘character of area’ of their location. Family houses and building extensions and additions are projected as separate categories.
The spatial distribution of recent residential development is shown on a map on the next page.

Recent housing development trend



New development projection model

The first step was to calculate capacity of potential built-up volume for both scenarios. In both scenarios the potential Gross floor area (GFA) of potential new development was calculated, that means not only the developable land was considered, but also its vertical dimension - the intensity of new development that zoning plan allows.
The total potential GFA was aggregated for Elementary statistical units (there are 916 of them in Prague) and for each Elementary statistical unit its potential GFA was divided into same matrix as in development trend (see above). There are 3 features: floor area ratio (FAR), character of area and zone.
Because there is a significant difference in methodologies of 2 zoning plans these differences will be described on following lines.

[6] 1999 zoning plan capacity

The 1999 zoning plan has more detailed land-use categories and there are 4 of them that are being commonly developed as housing, although 2 of them are mostly mix-used combining housing with other function. Therefore we involve into our calculation 100% GFA of categories 'housing' and 'general housing', 50% of categories 'mix-use' and 25% of categories 'mix-use core areas'. The reduction of last two groups is based on experience that these groups are commonly developed as retail, accommodation or office space.

[7] Metropolitan plan capacity

The Metropolitan plan unlike the 1999 zoning plan has significantly less land-use categories. In our analysis we focused on category 'residential' that should host most of potential residential development, but beside that also all other functions common for mix-used city including retail, accommodation, amenities and offices. For that reason we cut the GFA to two thirds of total GFA to exclude share of function others than housing. This share is based on proportion between housing and other functions in current 1999 zoning plan. Although there are mentioned problems in different methodologies we estimated potential GFA of new development for both scenarios.

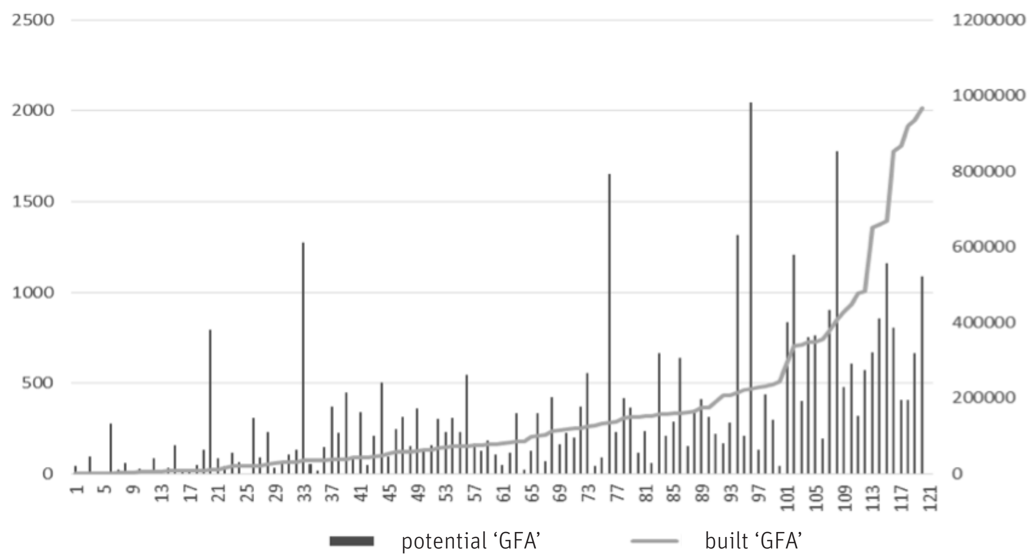
[8] The plans differences

The main difference in potential GFA's of two scenarios is in capacity distribution of 2nd zone 'compact city' and 4th zone 'city edge'. Whereas in scenario based on 1999 zoning plan the 'compact city' zone has 22% of GFA and 'city edge' zone 40% of GFA of the total capacity, the scenario based on Metropolitan plan proposes in 'compact city' zone 39% of GFA and in 'city edge' 22% of GFA of total plan's capacity. This general distribution shows us that Metropolitan plan has significantly more intensive concentric development than extensive 1999 zoning plan. Detailed potential GFA's are listed in the table bellow.

zone	Current GFA	potential GFA, Metropolitan plan	potential GFA, 1999 zoning plan	Metropolitan plan and 1999 zoning plan ratio
1	13 882 864	200 211	109 631	183 %
2	50 211 320	16 887 267	6 513 049	259 %
3	49 684 098	17 906 885	11 159 230	160 %
4	20 064 854	8 308 926	12 038 568	69 %
total	133 843 136	43 303 288	29 820 478	145 %

[9] New development allocation assumption

The elementary assumption of new housing development projection to 2030 is that the development itself is relatively spatial consistent. Spatial consistency is determined by possibility of new development construction in given areas, and that new apartments construction is relatively consistent in time in given area. It's possible to argue that construction in some areas is higher, but these extreme observations shouldn't affect the progress of housing development as whole, because there are not so many biases in the total set of observed items.
The observed variables for basic housing development trend are potential 'GFA' (apartment's floor area that might be built according to 1999 zoning plan) and number of built apartments and family houses. The primary exploration of relation between potential 'GFA' and number of built apartments and family houses was done based on graphical analyze of these two variables. The results are shown on the chart bellow.



Although it is not apparent the relation between potential 'GFA' and built apartments and family houses is relatively constant. Another test of relation of above mentioned variables vas correlation analysis. The result of this analysis was Pearson's r reaching 0,4933, when considering amount of observations is proven correlation between variables on 1% level of importance.

[10] Newdevelopment distribution matrix

For the following analysis the administrative area of Prague was divided into 4 concentric zones according to prevailing urban structure: 1-'city core', 2-'compact city', 3-'modernist city', 4-'city edge'.
Then areas for potential development were divided according to already described characters of area ('expansive', 'transformative' and 'stabilized'). The last criterion for areas was also already mentioned floor area ratio 'FAR' summed into 4 intervals.
The total potential 'GFA' for both zoning plans with 3 considered criteria was calculated by analytics at our Spatial information section at Planning and development institute.
To compare future development based on either 1999 zoning plan or on Metropolitan plan it was necessary to predict trends in spatial distribution of new housing development. Due to fact that 1999 zoning plan and Metropolitan plan differ in total potential 'GFA' and its distribution among zones we had to norm spatial distribution matrix for both scenarios separately. The spatial distribution matrix for scenario based on 1999 zoning plan is reflects current trend in residential real estates development, because we expect there won't be any change in distribution scheme when the zoning plan remains the same.
For the Metropolitan plan scenario the distribution matrix differs, because the proportion of potential 'GFA' is in Metropolitan plan different from 1999 zoning plan as it is shown on previous table. Therefore we re-weighted expected distribution among zones with ration of potential 'GFA' between 1999 zoning plan and Metropolitan plan. We assume that along with higher supply of potential 'GFA' proportionally higher share of new development should occur.

The table bellow shows normed distribution matrix for 1999 zoning plan.

zone	E_FAR_1	E_FAR_2	E_FAR_3	E_FAR_4	E_Total	T_FAR_1	T_FAR_2	T_FAR_3	T_FAR_4	T_Total	Total
1	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,01%	0,03%	0,04%	0,05%
2	0,69%	0,61%	0,26%	0,00%	1,57%	1,13%	3,92%	9,00%	6,78%	20,83%	22,40%
3	4,88%	18,16%	5,93%	1,22%	30,20%	1,76%	8,75%	7,43%	3,35%	21,29%	51,49%
4	14,55%	7,91%	0,00%	0,00%	22,46%	1,11%	2,44%	0,05%	0,01%	3,61%	26,06%
total	20,13%	26,68%	6,19%	1,22%	54,23%	4,00%	15,11%	16,49%	10,18%	45,77%	100,00%

The table bellow shows normed distribution matrix for Metropolitan plan.

zone	E_FAR_1	E_FAR_2	E_FAR_3	E_FAR_4	E_Total	T_FAR_1	T_FAR_2	T_FAR_3	T_FAR_4	T_Total	Total
1	0,01%	0,00%	0,00%	0,00%	0,01%	0,00%	0,01%	0,01%	0,04%	0,05%	0,06%
2	1,13%	1,00%	0,42%	0,00%	2,56%	1,84%	6,40%	14,70%	11,08%	34,02%	36,58%
3	4,93%	18,36%	5,99%	1,24%	30,52%	1,78%	8,84%	7,51%	3,39%	21,52%	52,04%
4	6,32%	3,44%	0,00%	0,00%	9,76%	0,48%	1,06%	0,02%	0,01%	1,57%	11,33%
total	12,40%	22,79%	6,42%	1,24%	42,85%	4,11%	16,30%	22,24%	14,51%	57,15%	100,00%

[11] Expected Net floor area

To model residential housing stock in 2030 it was necessary to set ration between apartments in new development, building extension and additions and family houses. In case of building additions and extensions it's annual increase was considered to be same in both zoning plans scenarios, because it's more dependent on existing built–up urban form rather than on zoning plan. For that reason building extensions and addition were in development distribution model omitted. The spatial capacity of building additions and extensions were included in estimating future population that will be described later. Therefore we deducted 9,5% from the expected housing area (Net floor area, 'NFA') increase that is current share of building additions and extensions on new residential construction. The remaining housing area is composed of 86,7% apartments and 13,3% of family houses according to analyzed trends. The last adjustment was recalculating Net floor area (provided by Deloitte model) to Gross floor area (that we are using in urban planning). This was done by multiplying apartment area with coefficient 1,3 (10% of loadbearing and other structures and 20% of common spaces) and family houses with coefficient 1,1 (10% of loadbearing and other structures). After all adjustments the expected 'GFA' for 2030 was known as well as the allocation matrix of new development and potential 'GFA' given by two zoning plan scenarios. Multiplying the relative allocation matrix by expected 'GFA' we got distribution of new housing development until 2030 according to our land division and considered zoning plan.

[12] Spatial restrictions given by zoning plans

Unfortunately the model based only on allocation matrix cannot consider spatial limits of given areas (given by zoning plan - the potential 'GFA'). Therefore the result of projection, if in given area and given parameters of 'FAR' and 'character of area' exceeded spatial capacity given by potential 'GFA', was adjusted with expert estimate. Exceeding spatial volumes were moved to categories with lasting potential 'GFA' while the main priority was to keep same city zone. If the city zone's potential 'GFA' exhausted, the expected 'GFA' was moved to neighboring zones while priority was to keep the same 'FAR' of development.

[13] Population distribution

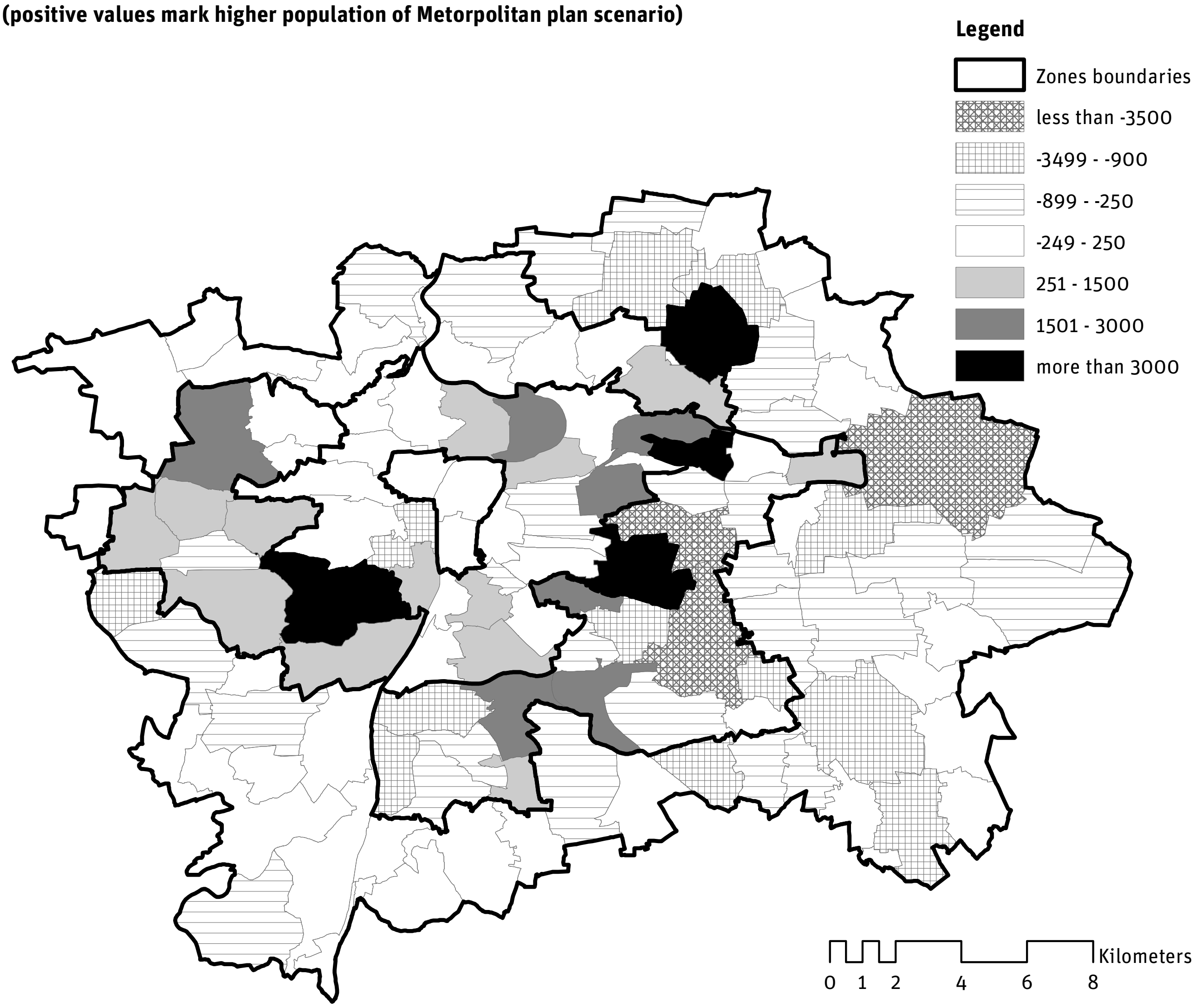
The last step of Prague 2030 projection was population distribution in new housing stock. First of all we had to allocate population increase. Regarding the fact we already knew total 'GFA' in each 'Elementary statistical unit' from previous calculations, we only had to modify this value to 'NFA' (dividing by mentioned coefficients) and calculate average floor area per resident, that is expected to be 30,75 m2 in 2030. This process led to allocation of new population in 'Elementary statistical units'.

Then we had to consider increase of average floor area per residents already living in Prague. This increase was calculated as average floor area increase per resident from 2015 to 2030 (based on Deloitte real estate prediction) and then this additional spatial demand was multiplied by number of inhabitants for each 'Elementary statistical unit'. In this model the population change is always dependent on construction of housing space.

The last step to estimate population distribution was adding housing floor area in building additions and extensions. The volume of this housing typology is 9,5% of estimated new construction floor area increase. The distribution of this typology floor area among 'Elementary statistical units' was done according to recent trend of their construction (as it was describe in part "The trend of recent development"). This area projected into 'ESU' was again converted from 'GFA' to 'NFA' and then 'NFA' was divided by floor area

per resident and the result is amount of population living in building extensions and additions in 2030.
After summing the results the prediction of population using floor area reached total population of 1,345 millions inhabitants while the demographic projection was 1,355 millions inhabitants. Based on these results we can say that population distribution based on floor area increase method is very accurate.
Differences in population between 2 considered scenarios are projected on the map bellow aggregated for 'AGU'. The model confirms our expectation that population located according to Metropolitan plan is distributed more to the city center (positive values show represent more residents in Metropolitan plan). In the 4th zone called 'city edge' has 1999 zoning plan in all 'ASU' same or higher population than Metropolitan plan (negative values represent more residents in 1999 zoning plan).

The difference in population between 2 scenarios in 2030
(positive values mark higher population of Metorpolitan plan scenario)



Current area's characteristics and residents behavior

According to 2011 Census data we can prove that commuting behavior depends on resident's location within the city. The difference is obvious if we compare 4 analyzed zones. The modal split in each zone is in the table bellow.

zone	PT	ICT	Pedestrians and cyclists
1	60,6 %	20,9 %	17,6 %
2	65,2 %	22,8 %	10,9 %
3	64,2 %	27,4 %	6,9 %
4	55,3 %	37,6 %	6,2 %
total	62,3 %	28,2 %	9,6 %

In general we can conclude, that share of walkers decreases to one third from the city core to the city edge whereas the share of automobile commuters almost doubles from the city core to city edge. Compared to these transport modes the share of public transit riders doesn't vary so much.

[14] Individual car transport ('ICT')

To predict individual car transport 'ICT' depending on one of zoning plan scenario in 2030 we used method of multiple regression analysis. The explained variables were average commute distance in 2015 and share of 'ICT' commuters in 2015. The explanatory variables were distance to the city center (statue of St. Wenceslas on Wenceslas square) and people density (residents and jobs per hectare) in 2015. Then values of 2030 were set into the projection. Before regression analysis it was necessary to adjust explanatory variables, because we have to estimate future number of jobs in 'ESU'. Regarding the fact that another regression analysis didn't provide us statistically accurate estimates, we estimated number of jobs in 2030 as a proportional part of residents increase in 'ESU'.

$$jobs_{2030} = \frac{jobs_{2015}}{residents_{2015}} * (residents_{2030} - residents_{2015}) \quad (1)$$

This estimate is based on assumption of relatively constant distribution of jobs in observed time period when demographic changes in 'ESU' were omitted. Numbers of residents and jobs in 2030 were used to calculate people in 2030 (area of 'ESU' and its distance is constant in time). After setting explanatory variables it wasn't problem calculate static multiple regressions. For estimated commute distance by car was derived regress function bellow:

$$cummuting_{km} = 4{,}941 + 0{,}003366 * people\ density + 0{,}3862 * avg\ distance\ from\ center \quad (2)$$

Model diagnostic control check:

CORRELATION COEFICIENT BETWEEN INDENPENDANT VARIABLES	-0,572			
F-TEST VALUE	101,091			
F-PROBABILITY	0,000			
ADJ. I2	0,307			
N. OF OBSERVATION	492			
VARIABLES	COEFFICIENT	STD. ERROR	T-VALUE	T-PROBABILITY
CONSTANT	4,941	0,259	19,093	0,000
PERSONS DENSITY (HA)	0,003	0,001	4,655	0,000
AVG DISTANCE FROM CITY CENTER (KM)	0,386	0,027	14,219	0,000

And the equation of estimated share of people using 'ICT' for commuting:

(3)
$$share\ of\ ICT = 0{,}2631 + 0{,}0107 * avg\ distance\ from\ center - 0{,}0003 * people\ density$$

With diagnostics:

CORRELATION COEFICIENT BETWEEN INDENPENDANT VARIABLES	-0,572			
F-TEST VALUE	94,579			
F-PROBABILITY	0,000			
ADJ. I2	0,276			
N. OF OBSERVATION	492			
VARIABLES	COEFFICIENT	STD. ERROR	T-VALUE	T-PROBABILITY
CONSTANT	0,263	0,017	15,901	0,000
PERSONS DENSITY (HA)	-0,000	0,000	-6,534	0,000
AVG DISTANCE FROM CITY CENTER (KM)	0,011	0,002	6,182	0,000

With these equations it was possible to calculate amount of kilometers caused by daily car commute for each 'ESU' with the formula:

(4)
$$car\ traffic_{km\ 2030} = residents_{2030} * share\ of\ ICT_{2030} * commuting_{km2030} * 2$$

In this equation we considered that 'ICT' commuters are travelling to the job and then back, so the equation is multiplied by 2.

[15] Current public transport costs per resident

Unlike the automobile transport, where we suppose costs and externalities per vehicle kilometer to be constant over the city, in case of public transport we assume costs to be variable upon location in the city. We base this assumption on references such as Hnilička (2012), who argues that public transport is more effective in denser urban areas and mentions 50 residents per hectare as a minimal density for effective public transport. We wanted to confirm this assumption on Prague empiric data. Prague is also specific with having on its administrative area only one transport zone with same pricing (for residents are most common years passes) for all Prague residents regardless what are real costs of their public transit usage. For that reason we did analysis of expected costs of commute per one commuter depending on their place of residency.

For this analysis we combined 2011 Census data with 2015 cell-phone providers data to estimate appropriate number of public transport riders. We used cell-phone data to calculate amount of commuters, who are people with regular daily trips. Then we estimated number of commuters by public transport using modal split from 2011 Census, because from the cell-phone data isn't possible to determine transport mode. Having amount of commuters in each 'Elementary statistical unit' (source of commute) we focused on their destination 'Elementary statistical units' (known also from 2011 Census). For each trip from one 'Elementary statistical unit' to another 'Elementary statistical unit' was calculated optimal route via public transport. Knowing amount of commuters from each 'Elementary statistical unit' to other 'Elementary statistical unit' we could assign total commuter kilometers travelled by public transport to each source 'Elementary statistical unit'.

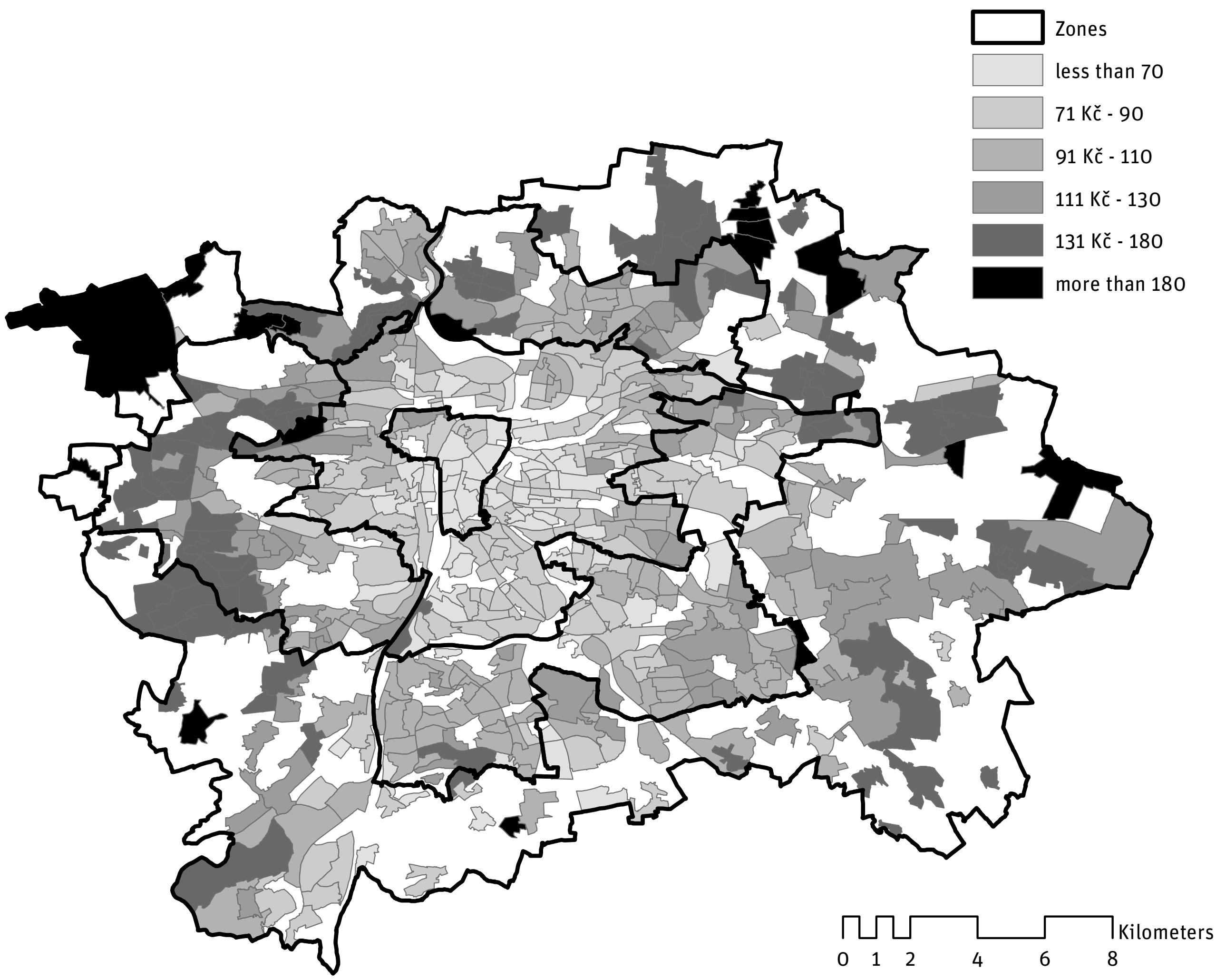
Then we calculated costs of operating public transport lines. This was done on data provided by Prague public transport company (2016). This data set contained daily cost of each transport line operation. In the previous part of the analysis we calculated passenger kilometers travelled on each line so knowing the daily operation cost we were able to compute costs on each line per one passenger kilometer. After that we projected these costs on commuters from each 'Elementary statistical units' based on their daily routes. The final result of this sub-analysis is average cost of commute by public transport per resident based on residency location that is shown on the map on the next page. Although there are some biases due to methodology (for instance 'ESU' with an airport [north-west edge of the city] seems to be very expensive, because we don't others than regular commuters), the general result corresponds to our expectations.

If we calculate zone averages of transport cost per resident, then 'zone 1' has 67%, 'zone 2' 80%, 'zone 3' 111% and 'zone 4' 122% of Prague average.

Yet there are still some limits in our model. Due to the data availability we calculated all the costs to regular commuters (to work or school) who are living in Prague administrative area excluding all commuters from Mid-Bohemian region. This simplification leads to higher expected costs per one commuter then probably is, but we expect that the ratio of commute costs between different locations should be unaffected.

We also assume in this model the operation costs of public transport vehicles are same along the whole route without considering efficiency of their capacity usage, because vehicles occupancy is most probably higher in the middle parts of lines compared to the lines ends. These aspects should be considered in further research.

Expected dayly costs of public transport per commuter



[16] PUBLIC TRANSPORTATION COSTS FUNCTION

The public transportation ('PT') costs in 2030 calculation was elaborated as multiple regression analysis as well. The explained variable is costs of public transport per resident of 'ESU' in 2015 and explanatory variable were distance to the city center and amount of residents in 'ESU' in 2015. Due to the fact that classic linear form didn't provided optimal results because of heteroskedasticity of residuals, the log-values of explanatory variables were used and model estimate with robust HC1 standard deviations. The estimated function is bellow:

(5)

$$\ln costs\ per\ person = 3{,}7571 + 0{,}3110 * \ln avg\ distance\ from\ center + 0{,}0408 * \ln residents$$

Diagnostic check of regression analysis:

Diagnostics	HC1 Std. Error			
correlation coeficient between indenpendant variables	-0,206			
F-test value	167,160			
F-probability	0,000			
adj. I2	0,313			
n. of observation	578			
Variables	Coefficient	Std. Error	t-value	t-probability
constant	3,757	0,103	36,340	0,000
ln_avg distance from city center (km)	0,311	0,017	18,210	0,000
ln_residents	0,041	0,012	3,331	0,001

Putting 2030 values we estimated 'PT' costs per person in 2030. The total costs of 'PT' for each 'ESU' were calculated according to this equation:

$$total\ cost\ PT_{ESU2030} = costs\ per\ person_{2030} * residents_{ESU2030} \quad (6)$$

Then summing all 'ESU' made expected total costs of 'PT' for two considered scenarios.

[17] Zones land-use characteristics

The last part of current area's characteristic focused on build-up environment parameters related to area's activity. Analyzed features are calculated for 'Elementary statistical units' and then summed to be presented as averages for whole 4 zones, as it is shown in table bellow.

zone	residents+-jobs	greenery per resident+job [m^2]	public spaces per resident+-job [m^2]	public lightning per 100 residents+-jobs	sewerages per resident+job [m]
1	360	1,7	7,2	2,5	0,3
2	180	8,6	13,3	3,9	0,4
3	110	22,7	18,9	6,7	1,4
4	40	30,8	34,9	12,1	5,4

Values are related to 'area's activity' that is sum of residents and jobs in the area. We do not use only residents, because particularly in the 'city core' and 'compact city' the share of jobs exceeds or is similar to share of residents.

Transport costs differences of 2 scenarios

If we project our automobile commuting model on two predicted development scenarios, the scenario based on Metropolitan results with 14,41 vehicle kilometers driven a day for commuting. The scenario of 1999 zoning plan performs 14,54 vehicle kilometers driven a day for commuting. Therefore the final result for 'ICT' is that Metropolitan plan performs 128 194 less daily driven vehicle kilometers (if average car occupancy is 1,2 persons per vehicle). It is 0,88% vehicle kilometers saved compared to 1999 zoning plan scenario. If we calculate expected savings on externalities that were estimated to be 1,66 CZK per vehicle kilometer, then the daily saving reaches 212 000 CZK, that is annually 53 200 000 CZK (while counting 250 working days a year) that is equal to € 1 970 000. It is important to mention that our model involves only commute trips due to data sources. We assume that there would additional vehicle-kilometers reduction caused by shorter trips for shopping or leisure activities, but unfortunately we currently don't have data to confirm this assumption. This issue should be considered in further research.

To estimate costs and externalities of car transport we used analysis by Danish ministry of transport (2004). This document compares several previous analyzes on transport externalities internalization and gives ranges of possible costs of externalities. From the compared values we took the medium ones. The analysis is more than a decade old, but we didn't have access to more recent one and at least it gave us general view on probable costs and externalities and their shares on vehicle kilometer. According to mentioned study the total costs and externalities for public budgets are expected to be 1,66 CZK per vehicle kilometer. If we divide it into specific fields, it is: petrol engines 0,22 CZK, diesel engines 0,44 CZK, contribution to climate change 0,08 CZK, noise in urban areas 0,25 CZK and costs related with accidents 1 CZK.

In case of public transport if our model is projected on two scenarios the scenario based on Metropolitan plan has 0,5% lower public transport operation costs than scenario based on 1999 zoning plan. This is again caused by more intensive land-use proposal in the 'compact city' zone. The 0,5% saving is caused by different distribution of approximately 20 000 inhabitants (1,5% of Prague population), who are in 1999 zoning plan located in 'city edge' zone, but in the Metropolitan plan are located in 'compact city' zone. Despite the higher share of public transport users in Metropolitan plan scenario public transport is still cheaper, because average daily trip of commuters in 'compact city' zone is significantly shorter than in 'city edge' zone (average 5 kilometers in 'compact city' and 9,4 kilometers in 'city edge' zone).

Results and recommendation for further research

The analysis has shown that future development scenario based on Metropolitan plan (proposing more intensive development in central city area) should save 0,5% of direct costs of public transport and 0,88% of externalities of automobile traffic that might be estimated to be around 1,97 million Euros annually (excluding cost of time, that wasn't considered in the analysis) compared to 1999 zoning plan scenario. Both calculations for automobile and public transport trips were done only for regular daily commute due to data availability, so we expect even higher potential savings caused by non-commute trips. At this point is important to mention, that these savings should occur after 15 years since implementation Metropolitan plan. During these 15 years only limited amount of total plan's capacity is expected to be developed, therefore more significant savings are expected in long-term horizon that should be taken in consideration in further research. Then according to our analysis future development based on Metropolitan plan scenario should be more efficient in terms of public budgets compared to 1999 zoning plan scenario, because it proposes new development in areas and with intensities that requires less public amenities per person than others. In these amenities we include public parks, public space and public services such as public lightning and sewerage.

Development allocation factors:
On the following line we list topics we believe are important for further research and we haven't elaborate them in detail yet.
The first is analysis of new development allocation. We believe better understanding of factors affecting development allocation and then their description in economic terms would be key parameter for better prediction of future urban growth and system of urban planning as well. Among these factors are zoning plan restrictions, building permits processes and its length, involved stakeholders, property and land prices, consumer preferences and others.

Public amenities and services costs:
Then in following research we would like in detail analyze capital and current costs of public spaces as well as its benefits. Knowing these costs we could estimate public expenditures per capita depending on built-up urban typology and land-use intensity. This would bring new tools for evaluating impacts of future urban development and also could be foundation for policy recommendation to support public budgets thrifty urban forms and vice versa to restrict inefficient ones.

Abbreviations list

IPR – Prague planning and development institute
DGSE – Dynamic simultaneous equations system
GDP – Gross domestic product
GFA – Gross floor area
NFA – Net floor area
ČSÚ/CSO – Český statistický úřad/Czech statistical office
PT – Public Transport
ESU – Elementary statistical unit (in Czech also ZSJ)
ASU – Aggregated statistical unit
ICT – Individual car transport

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