LAND COVER CHANGES IN EUROPEAN SHRINKING URBAN REGIONS

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ABSTRACT

Future population decline in Europe will lead to depopulation of many cities, what is already seen in many parts of Europe over the last decades. In rural areas, depopulation frequently leads to land abandonment. For urban regions however, not much is known about the way land cover develops. This research explores land cover developments between the years 2000 and 2018, in 69 shrinking functional urban areas within ten European countries. The types of land cover transitions are explored as well as the correlation between land cover transitions and the rate of depopulation. No relation was found between the rate of depopulation and land cover transitions.

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INTRODUCTION

Many cities in the world face population growth and that results in urban expansion (Angel, Sheppard, & Civco, 2005). In Europe, on the other hand, many cities are facing a decline in population (Eurostat regional yearbook, 2018). This phenomenon, urban shrinkage, can be caused by many factors (Döringer, Uchiyama, Penker, & Kohsaka, 2019). Migration to larger cities is one of the main drivers of this process, leaving particularly rural areas and smaller cities vacant (Li & Li, 2017). Depopulation of rural areas often leads to land abandonment, a subject extensively described in many studies. Li and Li (2017) have stated that the environmental consequences of land abandonment vary considerably because of regional differences like climate. Also many studies have been conducted about the depopulating city itself. Döringer et al., (2019) have concluded in their meta-analysis that the most debated implications of city shrinkage in Europe are housing vacancy, unemployment and economic decline. But while city depopulation logically leads to less liveliness in the city, a depopulating city does not necessarily lead to a decrease in built-up area (Kroll & Haase, 2010).

As said, socio-economic consequences of depopulating cities are quite well-known and the effect of depopulation in rural areas on land use is researched a lot. However, there exists a knowledge gap about the way land covers in depopulating urban regions develop. Some case studies have been conducted, mainly in Germany (Kroll et al., 2010), but general comparative researches are rare. It would be interesting to analyse if the rate of urban shrinkage directly links to the way surrounding land covers change nonetheless. It seems plausible that the higher the rate of depopulation, the more neglect land will face thus the more chance natural processes will have to regain surface. But one can assume that regional factors like climate and political steering also play a very big part in the way land cover can converse. Therefore it remains to be seen if there is a generalizing trend in land cover change to be found.

Results from this study are important to acquire a full understanding of the influence a decline in population has on way land cover develops. With this knowledge, the opportunities these land cover developments may bring about can be fully exploited. Less intensively used land is especially interesting when dealing with sustainability challenges. For instance farmland abandonment, a phenomenon seen in shrinking rural areas, has led to rewilding in many places in Europe. Rewilding is a chance for natural areas to restore and increase biodiversity again, which is good for maintaining ecosystem services (Pereira & Navarro, 2015).

For a few years now, the European population size has stopped growing and is stabilizing at approximately 746 million people. Current demographic projections by the United Nations are suggesting a decrease of around 35 million people between now and the year 2050. After 2050 the population size will go down even further (United Nations, 2019). We should now get familiar with the consequences of urban shrinkage on land cover, because what is happening in some places in Europe now, will most likely happen on much larger scale in the future. That is why the following research question will be addressed:

"How does land cover develop around shrinking urban regions in Europe?

To be able to answer this research question properly it is divided into three sub-questions, namely:

1. Which changes in land cover can be observed in several shrinking urban regions between 2000 and 2018?
2. Are these land cover changes different for areas with different rates of depopulation?
3. What may explain these differences?

Methods and data

Urban shrinkage data

In this research, land cover changes in several depopulating functional urban areas within Europe will be analysed. The so-called "functional urban area" was formerly known as "larger urban zone" (*Spatial Units - Cities (Urban Audit)*, n.d.). The OECD (2012, p. 21) has defined functional urban areas (FUA's) as: "Densely inhabited urban cores and hinterlands whose labour market is highly integrated with the cores." For the definition of these urban zones, population density and travel-to-work flows are used as key information. All cities around which FUA's are stated, have a population of at least 50.000 (OECD, 2012).
Because the OECD has officially stated these FUA's to be an urban area, it is certain that there will be no entanglement with rural areas and the definition of urban will not vary over the different countries analysed. Therefore the FUA as spatial unit is very appropriate for this study.
Furthermore, Eurostat provides precise population data on these FUA's and clear official borders exist. To differentiate the shrinking from the growing FUA's, the dataset "Population on 1 January by age groups and sex – functional urban areas" from Eurostat was exported to Excel. Data from the year 2000 to 2018 is explored, because the CORINE Land Cover data also features those years and because a time lapse of approximately twenty years seems appropriate for detection of land cover changes. There is filtered on a continuous declining population. This means that every next year has to have a smaller population than the previous year, instead of just a negative difference between the initial and final year. The FUA's that were growing first before they experienced some decline are filtered out this way, because land cover change is a slow process that cannot react within a few years to the shrinkage phenomenon.
Some FUA's have missing values. This is ignored by looking at the next available year. Only when the final year was missing, the FUA was excluded from further analysis because the population number of 2018 is necessary for calculating the absolute and relative shrinkage between the first and final year. 69 shrinking functional urban areas remain, which are shown in order of shrinkage rate in the appendix.

Reclassification of the CLC land cover classes

The objective of this research was to explore if there is a link between the amount of land cover change and the rate of depopulation. Also the importance of types of land cover changes were examined. To do this, a method using transition matrices, found by Peña et al. (2007), is applied.

From the shapefile with the borders of all European FUA's, the depopulating ones are selected. The two Corine Land Cover layers (2000 and 2018) are analysed within the selected FUA's. But first the CLC layer had to be reclassified, because the original CLC data consists of 44 land cover classes. In order to be able to discern main trends in land cover change though, it is necessary to limit the amount of land cover classes to a maximum of ten. The reclassification is also based on ideas Peña et al. (2007) proposed in his case study. When reality is simplified into a model, the events that are vitally important processes in the shaping of surroundings can be distinguished in two processes: Autogenic and anthropogenic processes. In this study autogenic processes are land cover change processes leading to rewilding. Anthropogenic processes are enabled by technological changes, leading to agricultural intensification and expansion of urban areas with sealed soil surface.

With this main idea the 44 land cover classes are reclassified into 10. A table with the full reclassification is shown in the Appendix A. Some of the choices made, are clarified below.

One of the objectives of this research is to find if land cover change from urban area into green area is a common phenomenon in shrinking urban regions. So all artificial surfaces are joined into one class, for changes within these classes are not interesting to see. An exception on this is the "sport and leisure facilities" class, which is only joined with "green urban area". This is because both classes are man-made and usually have a recreational purpose (European Topic Centre on Urban, land and soil systems; ETC/ULS, 2019) but both have a more natural character than the other artificial surfaces.
Non-irrigated arable land is kept separately from the other permanent crop classes because usually this is a less intensive form of agriculture, in terms of investments. Therefore this class might be more sensitive to land use changes. "Annual crops associated with permanent crops" is joined together with the other permanent crop types because this is quite a common type of agriculture while the other heterogeneous agricultural areas could be pointing more towards natural succession or some other kind of rewilding.
Lastly inland marshes and peatbogs are put together with the other seminatural areas since these are both natural areas on land, while the last land use class consists of real water bodies.

After reclassification of the land use classes, a table with the values 0 up to and including 99 is generated in GIS. These represent all possible land use conversions: The first numeral in a number stands for the land use class in 2000 and the last number for the land use class it was converted in up until 2018. To each transition belongs a pixel counts, which represent the converted area in hectares. The pixel counts have to be divided by the initial areas in the year 2000 to generate a percentage change. This data will be exported to Excel to produce a matrix, containing general information about land cover transitions in shrinking FUA's.

COLOUR CODING OF THE TRANSITIONS

For optimal understanding and clarification of the spatial developments going on in the different FUA's, there is a two-step colour coding applied. Of all 89 possible land cover conversions, ten different transition classes are first discerned to get a proper idea of the different processes going on in the shrinking FUA's. These classes are elucidated in the first column below. In order to generate a clear change map in GIS, these ten transitions are further simplified into two important opposite processes: Urbanisation versus rewilding and agricultural intensification versus extensification. Transitions that do not fit in either of these processes, are labelled "other".

First classification	Second classification
Urbanisation (anything into urban)	Urbanisation
Urban greening (anything into green urban)	Urbanisation
Rewilding (urban or agriculture into nature)	Rewilding
Natural succession (nature into nature of "higher" class, positive succession; including afforestation)	Rewilding
Natural retrogression (e.g. following human intervention, climate impacts etc	Other
Agricultural expansion (from urban or nature into agriculture)	Intensification
Agricultural extensification (from high intensity into low intensity agriculture)	Extensification
Agricultural intensification (from low intensity into high intensity agriculture)	Intensification
Other agricultural changes (within same intensity class)	Other
Other (anything into or out of water)	Other

Every land use type that converts into artificial surface or green urban area is marked as an urbanisation processes, since green urban area is also planned by and for people and thus counts as being artificial. All non-agricultural land use types that conversed into agricultural land are labelled as "agricultural intensification", since expansion is a form of intensification.Reciprocal conversions from one agricultural class into another agricultural class are a lot harder to label. That is because the classes "permanent crops" and "heterogeneous agricultural areas" both consist of many sub-classes in which conversions cannot always be clearly labelled as intensification or extensification. This research is only executable with a simplification of reality though, therefore, conversions from permanent crops into other agricultural land uses are seen as extensification and conversions into permanent crops are seen as intensification. The class "permanent crops" consists among others of fruit tree kind of crops and permanently irrigated land which is often used for crop rotation, dependently on the region (European Topic Centre on Urban, land and soil systems; ETC/ULS, 2019). The rationale here is that all land use types labelled as "permanent crops" have higher input levels than non-irrigated arable land or heterogeneous types of agriculture and thus a conversion into anything labelled as "permanent crops" can be seen as a form of agricultural intensification (Peña et al., 2007). All conversions into heterogeneous agricultural area are labelled as "agricultural extensification" because there is often a lot of green space involved in this (European Topic Centre on Urban, land and soil systems; ETC/ULS, 2019), which doesn't need as much care from the farmer or might even help the farmer with natural pest control or natural pollination. All conversions from heterogeneous agricultural area into other agricultural land are therefore labelled as "agricultural intensification". Conversions from pastures into non-irrigated farming land and the other way around are labelled as "other agricultural changes" because these types often require more or less the same intensity of labour and capital. Furthermore, there is chosen to gather all rewilding events. Afforestation is always achieved through human action while ecological succession can also occur on natural basis. Whether agricultural land is neglected or left fallow on purpose and natural succession occurs, it will lead to some kind of rewilding. When the opposite of natural succession occurs, this is labelled as "retrogression". Because this class does not really fit into the objective of this research, it's classified as "other". Also all classes turning in or out of water are labelled as "other" because this does not seem very realistic.

CHANGE MAP

The following crucial step was to explore if there is a particular spatial distribution of these processes to find within Europe. First, a change map based on the second colour classification is made. In order to relate the transition processes each FUA underwent with the rate of depopulation, a scatterplot showing the rate of depopulation relative to the amount of conversed land is made. Also the importance of each transition type will be scatter plotted against the rate of shrinkage for each FUA. Some illustrative parts of the map on the found results will be shown.

RESULTS

SHRINKING FUNCTIONAL URBAN AREAS

This research is based on sixty-nine depopulating functional urban areas within ten European countries. A table with all FUA's is shown in Appendix B, ordered on ascending relative population change and with colour coding divided into three classes: -1% to -5%; -5% up to and including -10%; -11% up to and including -30%. All shrinking regions are also shown on the map below. Remarkable is that Italy and Spain have many shrinking urban regions but these are all depopulating at a low rate. Bulgaria, Lithuania, Latvia and the east of Germany are facing the most shrinkage.

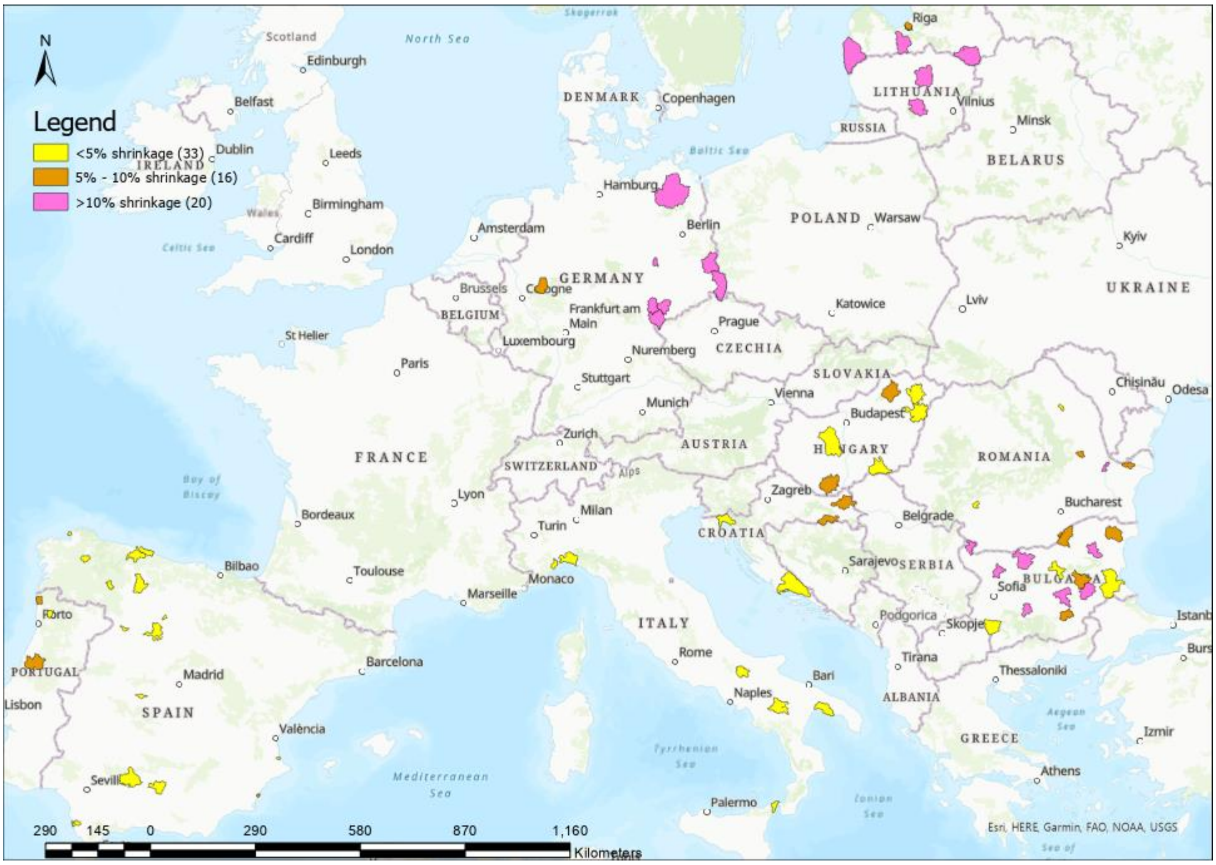


FIGURE 1: SHRINKING FUNCTIONAL URBAN AREAS IN EUROPE

TRANSITION MATRICES

The generated transition matrices are shown below. These contain general information about land cover transitions in all shrinking FUA's. The first matrix shows on the bottom right how much area conversed in total. Dividing this by the number above it, that shows the total area of all FUA's, gives that 20% of all land cover has conversed in between the years 2000 and 2018.

	Artificial surfac	Green urban a	Non-irrigated a	Permanent cro	Pastures	Heterogeneous	Forest	Shrub and he	Open space v	Water bodie	*Area in 2000*	
Artificial surface	416456	4885	14019	1419	14173	9319	8113	7021	617	2169	*478191*	
Green urban area	2201	14153	151	1	383	715	363	50	15	46	*18078*	
Non-irrigated arable land	40117	2277	2499038	78158	123470	64405	41556	25971	999	2020	*2878011*	
Permanent crops	9377	547	31680	242726	3618	39472	3522	5402	485	1530	*338359*	
Pastures	10736	821	82178	1683	287005	41747	18854	25477	4070	1280	*473851*	
Heterogeneous agricultural area	32843	4735	122479	24741	69186	510407	39797	34387	2799	2984	*844358*	
Forest	17282	3592	17188	2606	16980	21195	1726778	170130	5206	2849	*1983806*	
Shrub and herbaceous vegetation	9220	641	10867	5000	15069	30946	98531	440328	12034	3407	*626043*	
Open space with little vegetation	1723	174	1754	50	2373	1353	4545	21129	59108	3881	*96090*	
Water bodies	1289	219	1485	228	1245	829	2470	764	2031	129779	*140339*	
Area in 2018 (ha)	*541244*	*32044*	*2780839*	*356612*	*533502*	*720388*	*1944529*	*730659*	*87364*	*149945*	***7877126***	Total area
Surface gain/loss (ha)	*63053*	*13966*	*-97172*	*18253*	*59651*	*-123970*	*-39277*	*104616*	*-8726*	*9606*	***1551348***	Changed area

	Artificial surfac	Green urban a	Non-irrigated a	Permanent cro	Pastures	Heterogeneous	Forest	Shrub and he	Open space v	Water bodie	*Total*
Artificial surface	87%	1%	3%	0%	3%	2%	2%	1%	0%	0%	*100%*
Green urban area	12%	78%	1%	0%	2%	4%	2%	0%	0%	0%	*100%*
Non-irrigated arable land	1%	0%	87%	3%	4%	2%	1%	1%	0%	0%	*100%*
Permanent crops	3%	0%	9%	72%	1%	12%	1%	2%	0%	0%	*100%*
Pastures	2%	0%	17%	0%	61%	9%	4%	5%	1%	0%	*100%*
Heterogeneous agricultural area	4%	1%	15%	3%	8%	60%	5%	4%	0%	0%	*100%*
Forest	1%	0%	1%	0%	1%	1%	87%	9%	0%	0%	*100%*
Shrub and herbaceous vegetation	1%	0%	2%	1%	2%	5%	16%	70%	2%	1%	*100%*
Open space with little vegetation	2%	0%	2%	0%	2%	1%	5%	22%	62%	4%	*100%*
Water bodies	1%	0%	1%	0%	1%	1%	2%	1%	1%	92%	*100%*

FIGURE 2 & 3: LAND USE TRANSITION MATRICES FOR THE YEARS 2000 TO 2018 IN DEPOPULATING FUNCTIONAL URBAN AREAS IN EUROPE. BOTH MATRICES SHOULD BE READ FROM LEFT TO RIGHT. THE FIRST MATRIX SHOWS THE ABSOLUTE LAND USE CHANGES IN HECTARE. ALL AREA THAT HAS CHANGED SUMS UP TO 1551348 HECTARE. THE COLOUR CODING IN THE FIRST MATRIX DISCERNS THE MOST IMPORTANT SPATIAL DEVELOPMENTS. GREY INDICATES THE AREA THAT REMAINED CONSTANT BETWEEN 2000-2018. THE SECOND MATRIX SHOWS HOW MUCH AREA OF A LAND USE TYPE IN 2000 (ON THE Y-AXIS) CONVERTED INTO ANOTHER LAND USE TYPE BEFORE 2018 (ON THE X-AXIS). CHANGES EQUAL TO OR LARGER THAN 5% ARE SHOWN IN ORANGE, WHILST CHANGES LARGER THAN 10% ARE SHOWN IN RED.

The surface gain of each land cover class is calculated by subtracting the area of that class in 2018 by the area it was in 2000. Remarkable is that urban areas still gained much surface in these depopulating urban regions, while only 87% of the artificial surface in 2000 was still present in 2018. Shrub and herbaceous vegetated land covers gained an impressive amount of land, partially because a large area of forest retrograded to shrubland. Forest occupies less land cover than in the year 2000 although, looking at the second matrix, of all land cover types some surface area transitioned into forest. Permanent crops and pastures gained surface whilst heterogeneous and non-irrigated agriculture lost surface area. Looking at the second matrix, it may at first not look like non-irrigated agriculture lost surface area since large percentages of the other agricultural land use types transitioned into it. But because non-irrigated agricultural land already covered a great area, the surface gain is negligible compared to the loss. The same logic accounts for heterogeneous agriculture land cover types whilst the exact opposite logic accounts for permanent crops. Summing up all conversed areas of the same colour and dividing this number by the total changed area, gives the following percentages. These give insight in the importance of a spatial process, in terms of surface area.

Spatial development process	*Percentage of all conversed area (1551348 ha)*
Urbanisation	8%
Rewilding	22%
Agricultural intensification	30%
Agricultural extensification	12%
Other	27%

TABLE 1: RELATIVE IMPORTANCE OF THE SPATIAL DEVELOPMENT CLASSES

This shows that both opposite processes (urbanisation versus rewilding and agricultural intensification versus agricultural extensification) are more or less equally occurring in shrinking regions.

CHANGE MAP

The change map generated in GIS is used to see if a clear spatial distribution of the land cover change processes appears, either by rate of shrinkage or geographic location.

No obvious spatial distribution of the two opposite processes appeared on this map. In general, there is not more land cover conversion in urban regions with a higher rate of depopulation. Neither can the relative importance of the rewilding process be linked to the rate of urban shrinkage. These analyses can also be confirmed by the following generated scatterplots. A R-squared close to zero means that there is no direct relationship between the data points on the x-axis and y-axis to be found. On the contrary, a R-squared close to one would mean that there is an irrefutable relationship between the data points on the x-axis and y-axis to be found.

Also for the three other important transition processes, scatter plots are made to examine the connection between the importance of these processes in all land cover change and the rate of depopulation. For neither of the transition processes a high R-squared was found. All graphs are shown in Appendix C.

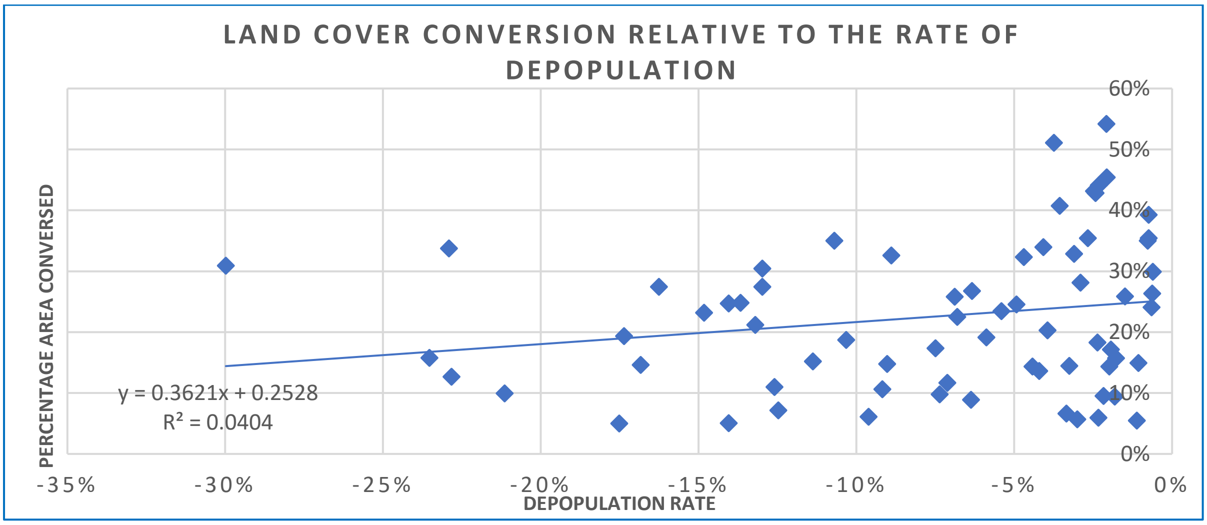


FIGURE 3: LAND COVER CONVERSION RELATIVE TO THE RATE OF DEPOPULATION. ALL POINTS REPRESENT A FUA.

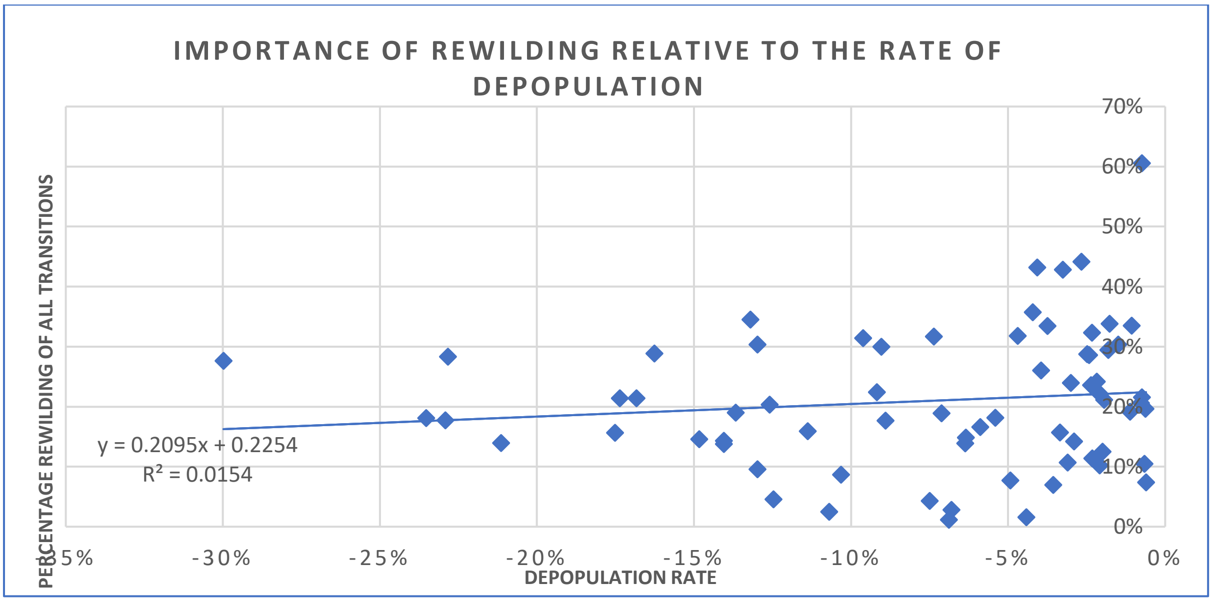


FIGURE 4: IMPORTANCE OF REWILDING RELATIVE TO THE RATE OF DEPOPULATION. ALL POINTS REPRESENT A FUA.

The fact that there is no relation found between land cover transitions and the rate of depopulation, is well illustrated by the following map fragments of different urban regions in Bulgaria.

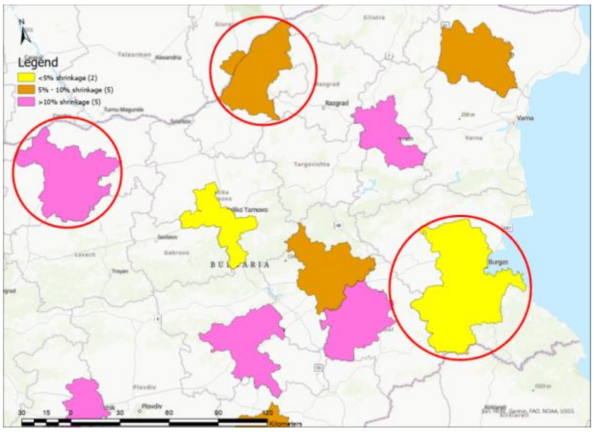
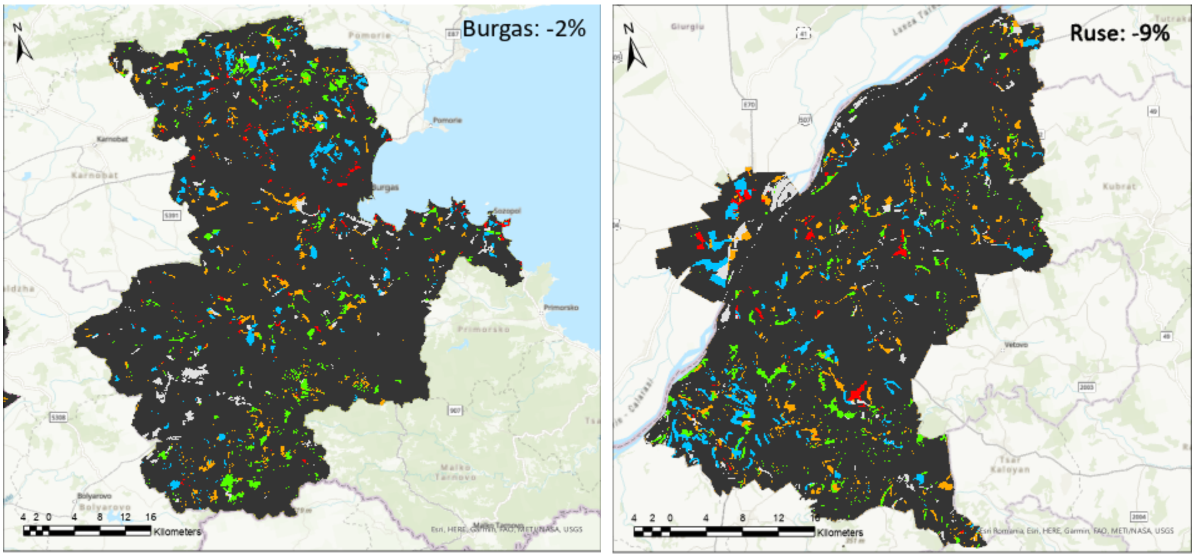
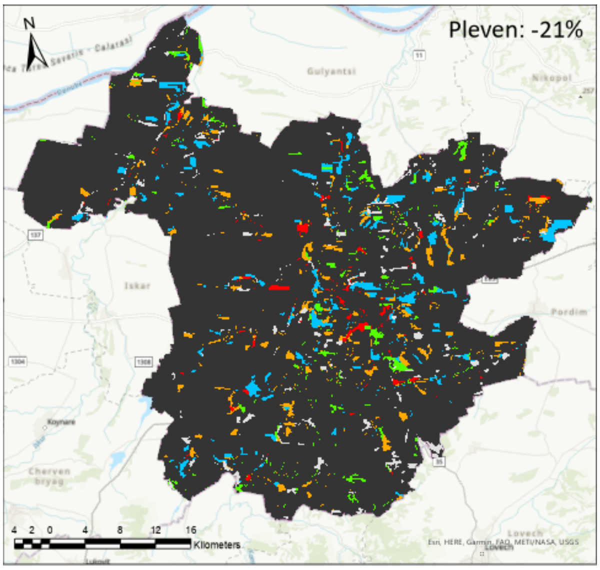
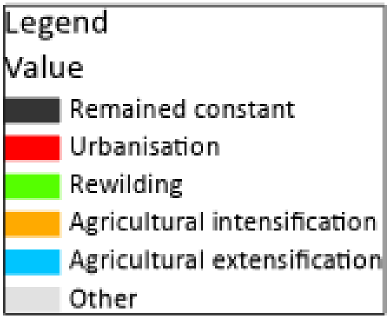


FIGURE 5: INDICATION OF THE GEOGRAPHICAL POSITION OF THE FUA'S SHOWN IN FIGURE 6, 7 & 8.







FIGURES 6, 7 & 8: RESPECTIVELY THE FUA'S BURGAS, RUSE & PLEVEN IN BULGARIA. ALL FUA'S ARE SHOWING SIMILAR LAND COVER CHANGE PATTERNS.

DISCUSSION

The aim of this research was to explore how land cover develops in shrinking urban regions within Europe. There are four important main land cover change processes found, namely: Urbanisation, rewilding, agricultural intensification and agricultural extensification. The tested hypothesis is that the surface area conversed as a consequence of autogenic processes, like rewilding and in some cases agricultural extensification, is related to the rate of depopulation. However, no relationship was found between the relative importance of autogenic land cover changes and the rate of depopulation. Neither was a relationship found between the total area conversed and the rate of depopulation.

To explore how land cover develops in shrinking urban regions within Europe, land cover transition matrices containing general information on the shrinking urban regions were made. From the transition matrix could be concluded that more than 70% of all land cover conversions can be categorized in four important environment-shaping processes: Urbanisation, rewilding, agricultural intensification and agricultural extensification. Looking at percentages, rewilding happened more than twice as much as urbanisation whilst agricultural intensification happened more than twice as much as agricultural extensification. From this finding may be concluded that autogenic land cover change processes are not more dominant than anthropogenic processes in depopulating urban regions. This conclusion falsifies the premise that depopulation of an urban region would come along with less intensive usage of the surrounding land. Although 22% rewilding is considerably more than the 8% urbanisation (table 1), the found extension of artificial surface still seems quite a lot for urban regions that are losing inhabitants. Angel et al. (2005) clarified that urban expansion takes place in different forms. Many cities in more developed countries, nowadays expand in a lower density than before. This shows nicely how human preferences, living standard in this case, play a very big part in determining the way in which the environment is shaped. A “random event” like population decline has thus little impact on land use in comparison with effective policy. The fact that agricultural intensification happens more than twice as much as extensification, can partially be explained by the fact that agricultural developments have to a great extent become disconnected of nearby population growth due to globalization of the food market. This implies that the drivers of agricultural land use changes work on a much larger scale than the policies targeting or preventing these changes (van Vliet et al., 2015). Policy makers should therefore mainly consider global drivers, in combination with some local conditions like soil type and climate.

In addition to the transition matrices, a land cover change map was made to assess the spatial distribution of the four land cover change processes between the sixty-nine shrinking functional urban areas in Europe. There was no relation found between the amount of land cover that conversed and the rate of depopulation. Neither was a relation found between the appearance of rewilding and the rate of depopulation. Fast shrinking regions (e.g. in Bulgaria) do not face more land use change than regions that are shrinking at a slower rate (e.g. Spain). There might thus be concluded that depopulation is not a driver of land cover changes. The lack of a clear pattern on the change maps might not be a very surprising result when thus taking into account that many driving forces, working on different scales, play a role in land cover development. Pereira et al. (2015) already found that rewilding only appears when specific climatic conditions are met. This implies that policies targeting on greening the environment should take deliberate action to achieve this, also in urban regions that are becoming less densely populated.

The two datasets used in the analysis seems to be legit. Eurostat is the official European statistics office and the Corine Land Cover data is co-founded by the European Environment Agency (EEA), whose main objective is to provide policy makers with timely and relevant environmental information (Büttner et al., 2004). However, some limitations need mentioning. More shrinking urban regions in Europe could have been included into the analysis if Eurostat would provide more data on countries like France and the Netherlands. These are now excluded from the entire analysis and that makes the results found less generalizable for the whole of Europe. Well enough there is already a great variety between the countries included, in terms of geographical position as well as socio-economic situation. Moreover, the CLC land cover data uses a minimum mapping unit of 25 hectares. This means that surface areas smaller than 25 ha could be missing in the initial data. But reclassification of the land cover classes might nullify this effect, since there is a chance that this small area of land would eventually be subdivided in some class and the final change map would look exactly the same. The reclassification itself is disputable considering the validity of this study. If land cover types are allocated to a suboptimal category, the land cover conversion it went through can be incorrectly determined. Thus the generated transition matrices would be more accurate and informative if the amount of land cover classes in the analysis is expanded. The method Peña et al. (2007) proposed in his research has proven to be solid for this research, since roughly the same land cover change processes turned out to be important for shaping the environment. But a more informative change map could be generated when other important land cover conversion processes, based on other literature, are added to the analysis.

It has become clear that land use change is a very complicated phenomenon, with the involvement of driving factors that work on different spatial levels. A suggestion for further research would therefore be to investigate this subject on a different scale. A case study on national level could be very informative when more information about political decisions would be included, for example more details about running projects shaping the urban environment. Also more information about the global population growth could help to better predict and steer agricultural land use changes food. Lastly, a different reclassification of the land cover classes and transitions could result in new insights. For example, when working on a smaller scale, green urban could be separated from other artificial surface structures to explore how the ratio between those land cover classes develops in shrinking urban regions.

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APPENDIX

A. RECLASSIFICATION TABLE OF THE CLC LAND USE CLASSES

Number	Category	Distinction	Class	Reclassification
1.1.1	Artificial Surfaces	Urban fabric	Continuous urban fabric	0
1.1.2	Artificial Surfaces	Urban fabric	Discontinuous urban fabric	0
1.2.1	Artificial Surfaces	Industrial, commercial and transport units	Industrial or commercial units	0
1.2.2	Artificial Surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	0
1.2.3	Artificial Surfaces	Industrial, commercial and transport units	Port areas	0
1.2.4	Artificial Surfaces	Industrial, commercial and transport units	Airports	0
1.3.1	Artificial Surfaces	Mine, dump and construction sites	Mineral extraction sites	0
1.3.2	Artificial Surfaces	Mine, dump and construction sites	Dump sites	0
1.3.3	Artificial Surfaces	Mine, dump and construction sites	Construction sites	0
1.4.1	Artificial Surfaces	Artificial, non-agricultural vegetated areas	Green urban areas	1
1.4.2	Artificial Surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	1
2.1.1	Agricultural areas	Arable land	Non-irrigated arable land	2
2.1.2	Agricultural areas	Arable land	Permanently irrigated land	3
2.1.3	Agricultural areas	Arable land	Rice fields	3
2.2.1	Agricultural areas	Permanent crops	Vineyards	3
2.2.2	Agricultural areas	Permanent crops	Fruit trees and berry plantations	3
2.2.3	Agricultural areas	Permanent crops	Olive groves	3
2.3.1	Agricultural areas	Pastures	Pastures	4
2.4.1	Agricultural areas	Heterogeneous agricultural areas	Annual crops associated with permanent crops	3
2.4.2	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	5
2.4.3	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	5
2.4.4	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas	5
3.1.1	Forest and seminatural areas	Forest	Broad-leaved forest	6
3.1.2	Forest and seminatural areas	Forest	Coniferous forest	6
3.1.3	Forest and seminatural areas	Forest	Mixed forest	6

3.2.1	Forest and seminatural areas	Shrub and/or herbaceous vegetation associations	Natural grassland	7
3.2.2	Forest and seminatural areas	Shrub and/or herbaceous vegetation associations	Moors and heathland	7
3.2.3	Forest and seminatural areas	Shrub and/or herbaceous vegetation associations	Sclerophyllous vegetation	7
3.2.4	Forest and seminatural areas	Shrub and/or herbaceous vegetation associations	Transitional woodland/shrub	7
3.3.1	Forest and seminatural areas	Open spaces with little or no vegetation	Beaches, dunes, sands	8
3.3.2	Forest and seminatural areas	Open spaces with little or no vegetation	Bare rock	8
3.3.3	Forest and seminatural areas	Open spaces with little or no vegetation	Sparsely vegetated areas	8
3.3.4	Forest and seminatural areas	Open spaces with little or no vegetation	Burnt areas	8
3.3.5	Forest and seminatural areas	Open spaces with little or no vegetation	Glaciers and perpetual snow	8
4.1.1	Wetlands	Inland wetlands	Inland marshes	8
4.1.2	Wetlands	Inland wetlands	Peatbogs	8
4.2.1	Wetlands	Coastal wetlands	Salt marshes	9
4.2.2	Wetlands	Coastal wetlands	Salines	9
4.2.3	Wetlands	Coastal wetlands	Intertidal flats	9
5.1.1	Water bodies	Inland waters	Water courses	9
5.1.2	Water bodies	Inland waters	Water bodies	9
5.2.1	Water bodies	Marine waters	Coastal lagoons	9
5.2.2	Water bodies	Marine waters	Estuaries	9
5.2.3	Water bodies	Marine waters	Sea and ocean	9

B. Shrinking functional urban areas in Europe

	Functional urban area	Country	Absolute change in population 2000-2018	Relative change in population 2000-2018	Conversed land cover 2000-2018
1	Târgu Jiu	Ro	-662	-1%	30%
2	Palencia	Es	-617	-1%	26%
3	Taranto	It	-2,751	-1%	24%
4	Córdoba	Es	-2,692	-1%	35%
5	Lugo	Es	-905	-1%	39%
6	Valladolid	Es	-3,315	-1%	35%
7	Split	Hr	-3,721	-1%	15%
8	Savona	It	-1,186	-1%	5%
9	Gandia	Es	-1,653	-1%	26%

10	Debrecen	Hu	-5,910	-2%	16%
11	Veliko Tarnovo	Bg	-1,613	-2%	9%
12	Potenza	It	-2,557	-2%	17%
13	Jaén	Es	-3,224	-2%	14%
14	Talavera de la Reina	Es	-2,121	-2%	45%
15	Gijón	Es	-6,321	-2%	54%
16	Burgas	Bg	-6,116	-2%	10%
17	Avilés	Es	-2,902	-2%	44%
18	Genova	It	-16,886	-2%	6%
19	Nyíregyháza	Hu	-5,702	-2%	18%
20	Oviedo	Es	-7,687	-2%	43%
21	Ponferrada	Es	-2,162	-2%	43%
22	Ferrol	Es	-4,053	-3%	35%
23	Zamora	Es	-2,060	-3%	28%
24	Székesfehérvár	Hu	-8,408	-3%	6%
25	Guimarães	Pt	-5,687	-3%	33%
26	Campobasso	It	-3,363	-3%	14%
27	Rijeka	Hr	-7,262	-3%	7%
28	Cádiz	Es	-9,379	-4%	41%
29	León	Es	-8,168	-4%	51%
30	Blagoevgrad	Bg	-3,853	-4%	20%
31	Messina	It	-11,444	-4%	34%
32	Szeged	Hu	-10,654	-4%	14%
33	Roman	Ro	-4,465	-4%	14%
34	Viana do Castelo	Pt	-4,193	-5%	32%
35	Osijek	Hr	-8,951	-5%	25%
36	Coimbra	Pt	-15,194	-5%	23%
37	Tulcea	Ro	-5,898	-6%	19%
38	Torrevieja	Es	-5,925	-6%	27%
39	Sliven	Bg	-8,168	-6%	9%
40	Slavonski Brod	Hr	-7,304	-7%	22%
41	Giurgiu	Ro	-5,142	-7%	26%
42	Miskolc	Hu	-22,028	-7%	12%
43	Pécs	Hu	-19,713	-7%	10%
44	Focsani	Ro	-10,011	-8%	17%
45	Iserlohn	De	-40,398	-9%	33%
46	Haskovo	Bg	-8,719	-9%	15%
47	Ruse	Bg	-18,107	-9%	11%
48	Plovdiv	Bg	-57,736	-10%	6%
49	Riga	Lv	-107,419	-10%	19%
50	Pazardzhik	Bg	-12,990	-11%	35%
51	Braila	Ro	-27,014	-11%	15%
52	Yambol	Bg	-12,925	-12%	7%
53	Shumen	Bg	-13,607	-13%	11%
54	Zwickau	De	-47,745	-13%	27%
55	Cottbus	De	-32,313	-13%	30%

56	Dessau-Roßlau	De	-12,497	-13%	21%
57	Plauen	De	-36,374	-14%	25%
58	Gera	De	-31,731	-14%	25%
59	Vratsa	Bg	-10,657	-14%	5%
60	Jelgava	Lv	-15,385	-15%	23%
61	Görlitz	De	-49,821	-16%	27%
62	Neubrandenburg	De	-52,746	-17%	15%
63	Kaunas	Lt	-80,072	-17%	19%
64	Vidin	Bg	-12,177	-18%	5%
65	Pleven	Bg	-40,215	-21%	10%
66	Stara Zagora	Bg	-47,381	-23%	13%
67	Liepaja	Lv	-27,626	-23%	34%
68	Panevezys	Lt	-38,282	-24%	16%
69	Daugavpils	Lv	-47,477	-30%	31%

C. Graphs showing the relationship between land cover transitions and the rate of depopulation

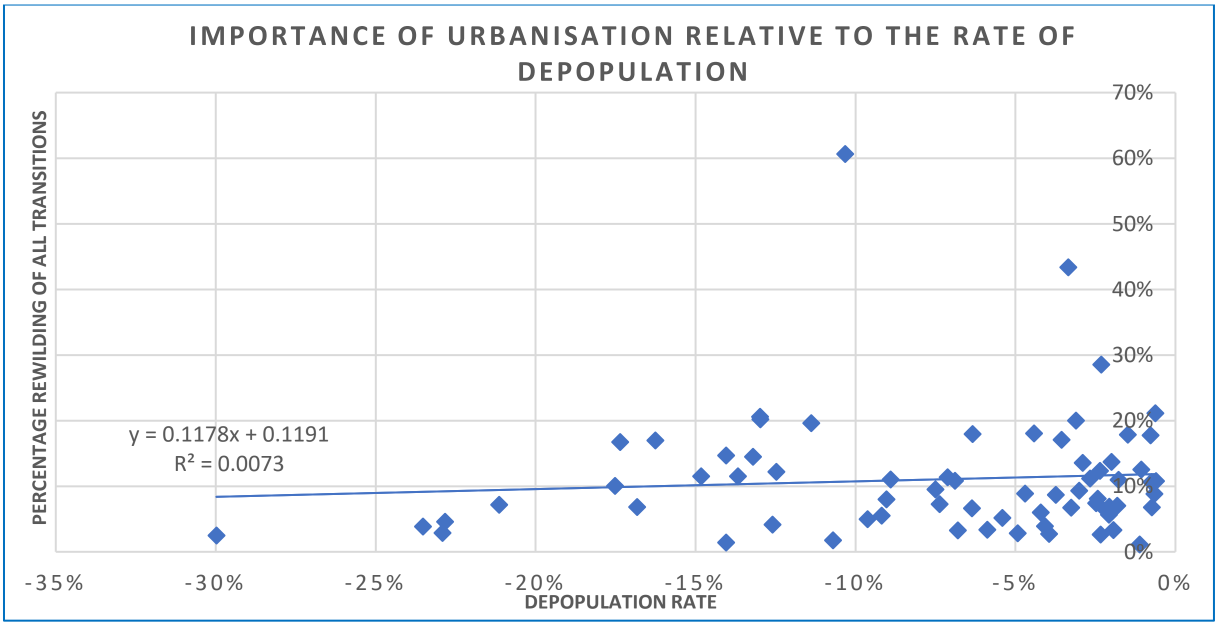

FIGURE 7: IMPORTANCE OF URBANISATION RELATIVE TO THE RATE OF DEPOPULATION. ALL POINTS REPRESENT A FUA.

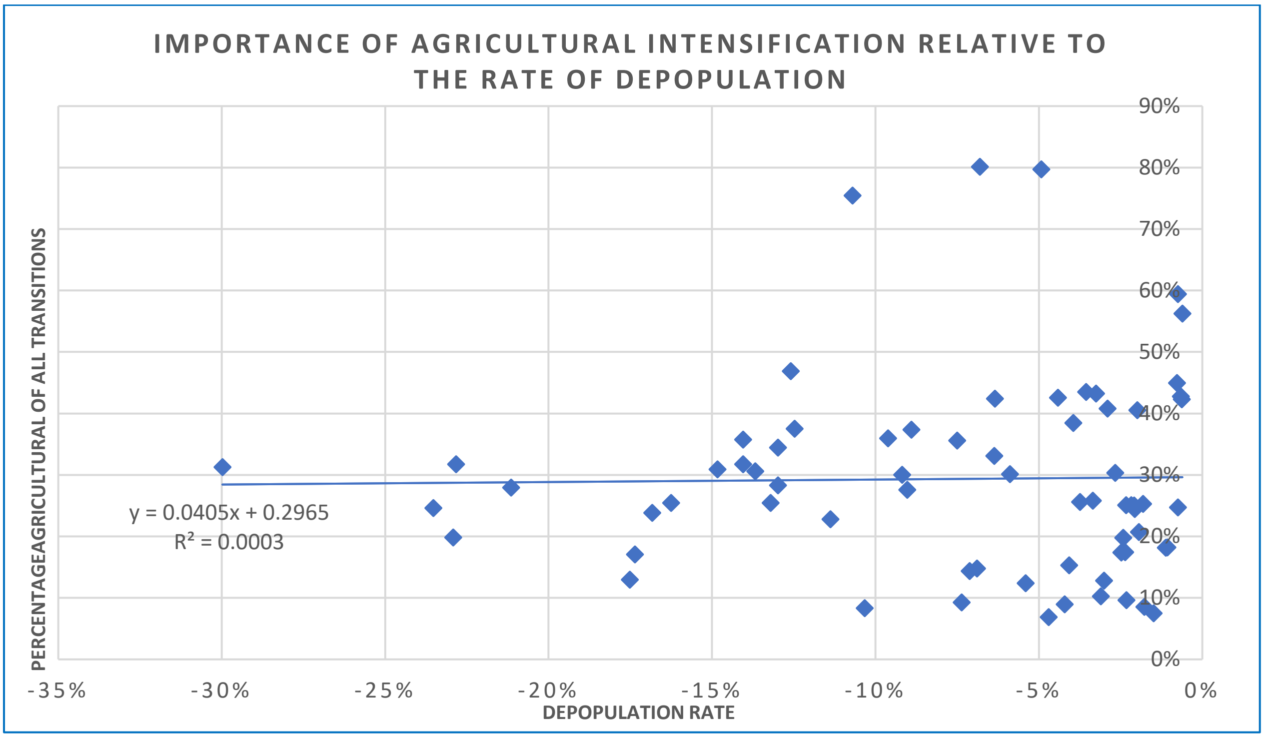

FIGURE 8: IMPORTANCE OF AGRICULTURAL INTENSIFICATION RELATIVE TO THE RATE OF DEPOPULATION. ALL POINTS REPRESENT A FUA.

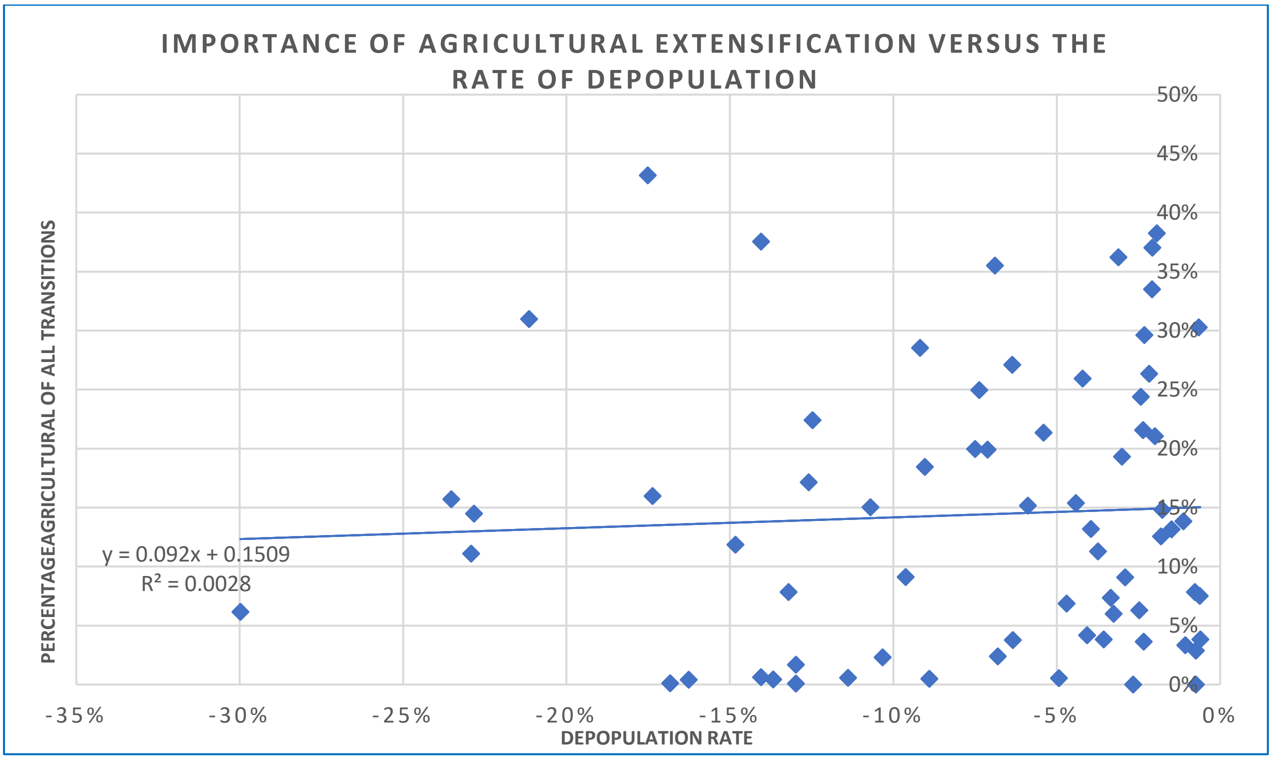

FIGURE 9: IMPORTANCE OF AGRICULTURAL EXTENSIFICATION RELATIVE TO THE RATE OF DEPOPULATION. ALL POINTS REPRESENT A FUA.