ARTIFICIALISED LAND AND ARTIFICIALISATION PROCESSES: DETERMINANTS, IMPACTS AND POTENTIAL RESPONSES

SUMMARY OF THE COLLECTIVE SCIENTIFIC REPORT - DECEMBER 2017

INRA SCIENCE & IMPACT

IFSTTAR

The artificialisation of land is a recent concept, initially corresponding to a need to quantify the loss of available surfaces for agricultural use from land use change. It now refers to the overall decrease in the share of land allocated to agricultural and forestry activities or natural areas, thus taking non-agricultural dimensions into account. As a result, the artificialisation of land and so-called 'artificialised' land have become, especially in France, a major public and political issue. The artificialisation of land, which generates a loss of land resources for agricultural use and for natural areas, is thus considered to be one of the main causes of biodiversity loss. Therefore, the rate of artificialisation of land has since 2015 been one of the 10 'wealth indicators' developed by the French Government to monitor its public policies.

In this context, the ministère de la Transition Ecologique et Solidaire, ADEME and the ministère de l'Agriculture et de l'Alimentation have entrusted IFSTTAR and INRA with carrying out a collective review of the current state of scientific knowledge in order to better understand the economic and social determinants of land artificialisation, its impacts on the environment and on agriculture, and potential policy responses to limit its development and consequent negative effects. Whatever the ambiguities of this notion from a scientific point of view, and the difficulties involved in its measurement, artificial land is essentially the result of human activities: it includes the areas covered by cities, housing, economic activities, and transport networks between these places. It is therefore an essential societal space that responds to the economic and social needs of households, businesses and public authorities, and thus has a social utility. However, since soil is a limited and non-renewable resource on a human scale, any extension of artificial land results in a loss of both natural resources and areas devoted to other uses. In addition, the specific characteristics of each location in terms of suitability for a given use limits land use change as a means to adapt to land artificialisation. On the one hand, any land development has significant environmental impacts on biophysical characteristics, biodiversity or hydrological functioning of the soil. On the other hand, the trend towards the expansion of artificial surfaces exacerbates competition with other uses, especially agricultural uses, particularly in areas of urban extension (edges of cities and peri-urban areas) or transport infrastructure.

For comparability, the definition of the artificialisation of land in this summary is that of the Observatory of Natural, Agricultural and Forest Areas (OENAF), which is adapted from CORINE Land Cover, a statistical source for analyzing changes in the allocation of European land. Artificialisation is an "***actual change of state of an agricultural, forest or natural surface*** *towards artificial surfaces, which in effect includes urban areas, industrial and commercial zones, areas of transport infrastructure such as roads and related infrastructure, open pit mines and quarries, landfills and construction sites, urban green spaces (green spaces included in the urban fabric), and sports and leisure facilities including golf courses.* ***Spaces undergoing artificialisation*** *are* ***no longer available for uses such as agriculture, forestry or as natural habitats***". Artificialised land thus supports most human activities other than agriculture or forestry, and relates to all habitat, all economic activities and all transport infrastructure and roads. This concept is by nature polysemous, and thus can be confusing. Consequently, difficulties arise in its measurement, the analysis of its determinants and the assessment of its impacts on both the environment and agricultural land.

Artificialisation, urbanization, loss of surface permeability: the importance of distinction

The use of the terms "artificialisation of the land" or "artificialised land", may easily be confused with the phenomena of **loss of soil permeability (or soil sealing)**, on the one hand, and **of urbanization (or urban sprawl)**, on the other. This potential confusion can lead to difficulties around scientific debate.

Indeed, if all artificialised land has undergone strong disturbances, they nevertheless differ in their cover and in particular by their degree of water permeability. Artificialised land includes impervious surfaces ('sealed' or 'mineralized' to use Anglo-Saxon terminology) but also soils of gardens and green spaces in and around buildings and along roads, often containing plant canopy cover and, in most cases, retaining permeability.

Human activities are not distributed evenly or randomly over the territory. Driven by powerful agglomeration forces, they are mainly concentrated in cities, which themselves also require agricultural products, renewable resources, and waste recycling. Cities have a spatial extent that tends to increase over time. In the recent past, their spread has largely exceeded the boundaries of the city and a part of the population and urban activities has dispersed in the surrounding countryside, forming a peri-urban space that, while spatially separate from the city, possesses strong functional links with it. Focal locations in peri-urban areas are connected by transport infrastructure to larger urban centres. Thus, the artificialisation of land reaches far beyond the city's borders, and involves peri-urban and rural areas in a more diffuse but not less significant way (Figure 1).

Overall, the causes and consequences of the artificialisation of land must be understood by taking into account **three dimensions**: 1) the degree **of sealing and disturbance** of the surface; 2) their **position in the urban fabric and framework** or in rural landscapes; 3) the **type of activities** that take place in these areas.

Difficulties in measurement

In attempting to measure the artificialisation of land in France, the subject of the measurement, as well as methods, are problematic. Firstly, the tools conventionally used to measure the rate of artificialisation of land at the national scale were created to understand occupancy and land-use changes rather to specifically measure their artificialisation.

Depending on the method, the measurement of the artificial surface of the French metropolitan area **varies** from 5.6% according to The *CORINE* land cover mapping scheme (a European remote sensing program) in 2012, and 9.3% according to Teruti-Lucas 2014, a French measurement tool based on statistical surveys. This difference shows that the accuracy of the measurement (both on the nature and on the size and location of the measured object) is an issue for public policies, especially as the indicator of the artificialisation of land is linked to the objectives of protection of biodiversity by the public authorities. In addition, there is a strong inter-regional variability in these measurements as well as discrepancies between CORINE Land Cover (CLC) and Teruti-Lucas (TL) estimates. The measurement differences between the two sources vary from 2% for the Île-de-France, whose artificialised surfaces are agglomerated, to more than 50% for the

regions showing a more limited and more dispersed artificialisation of land.

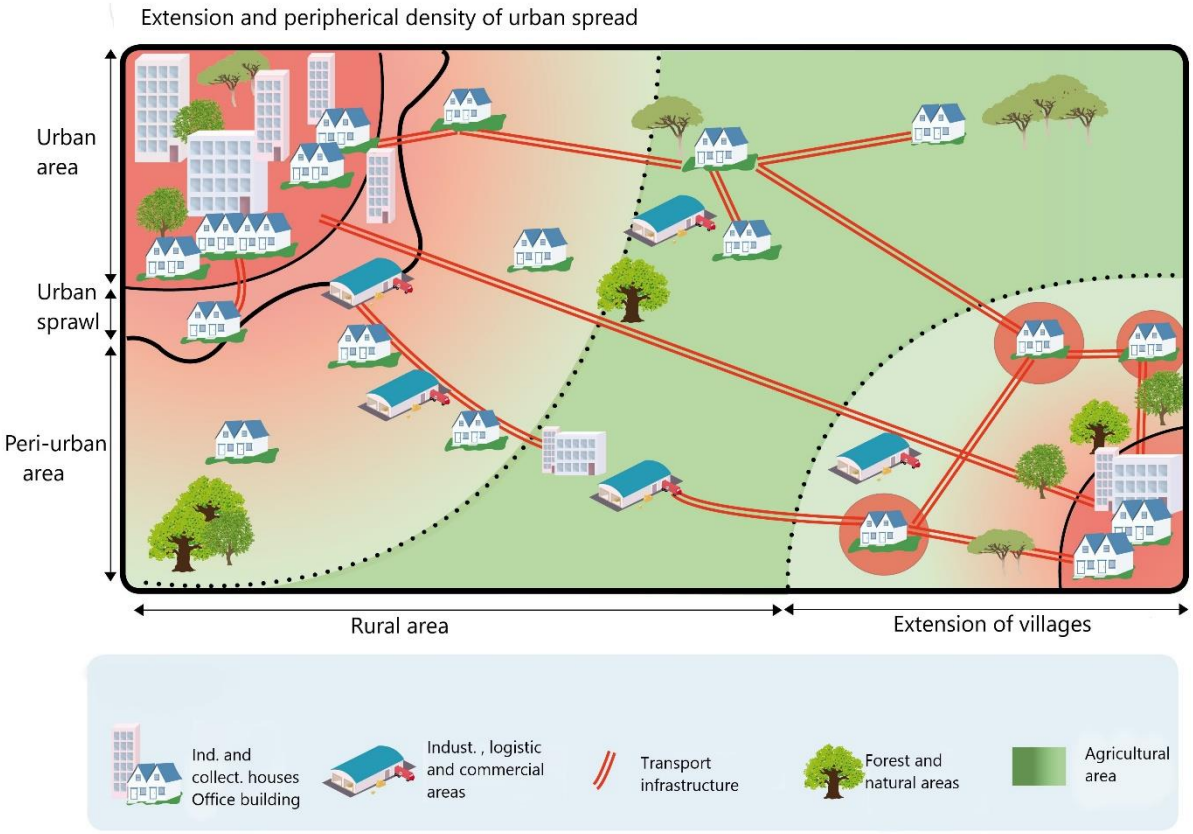
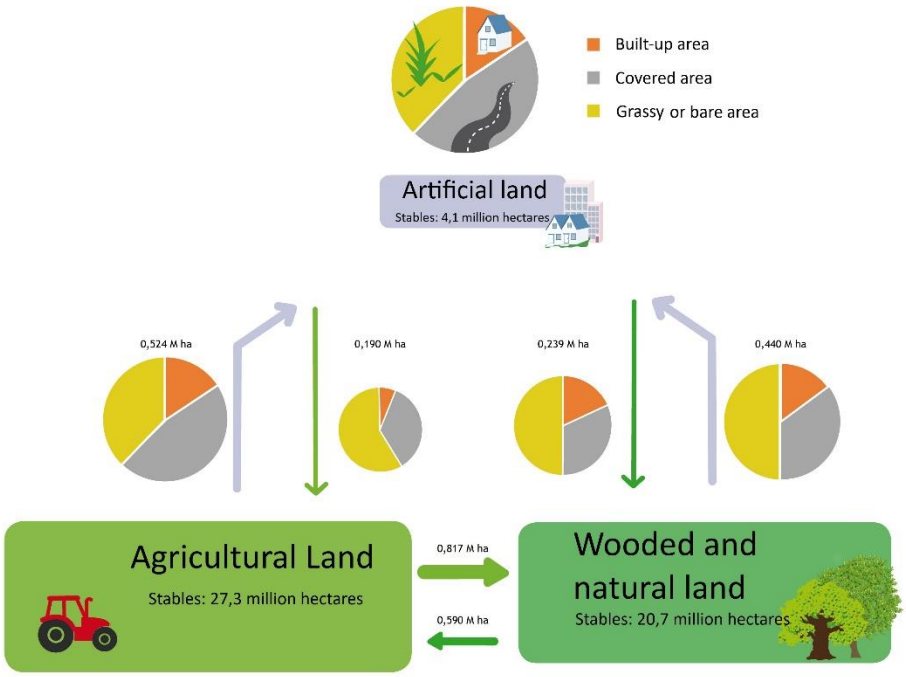


Figure 1 - Spatial organization of human activities, and interaction between artificialisation, urbanization and surface permeability (Graphics: Elodie Carl)



N.B.: "Stables" refers to areas that did not change category during the period 2006-2014.

Figure 2 - Artificial land, agricultural land and wooded and natural land in France: change between categories from 2006 to 2014 (Source: Teruti-Lucas, online file 2017 - Graphics: Elodie Carl)

Two elements in particular underline the limitations of the current tools: the first is related to the resolution thresholds of remote sensing tools (for example, land use areas of less than 25 hectares are not taken into account by CLC), the second is related to interpretation bias in the field or sampling (for statistical tools). Comparative studies at international and European level show that artificialisation in Europe is less sustained than in other parts of the world and that France lies around the European average, both in quantity and in progression.

Currently, the available data on land artificialisation in France allows us to recognize the main trends in the phenomenon, but there is no quantitative measurement that sits as a definitive reference for all of the relevant actors. They must also be

interpreted with caution, taking into account, beyond the global balance sheets, the gross changes in land use, category by category (Figure 2), and their spatial distribution, in order to accurately capture the processes in question. Therefore, in common with the proposals of the Foundation for Research on Biodiversity[1], this report emphasizes the need for a renewal of both the methodology and land cover categories in order to precisely distinguish the types of artificialisation and the state of the land prior to artificialisation. The evolutions of finer resolution remote sensing and geographic information systems (data integration, including cadastral data and linear structures) now make it possible to obtain more precise results. Increasing numbers of local authorities are using these approaches, which make it easier to consider the problems related to artificialisation in urban planning documents. The expansion of these approaches to the whole country would allow a more precise monitoring of the overall dynamics of land artificialisation.

The impacts of artificialisation on the physicochemical and biological characteristics of land

The different types of artificial surfaces are classically distinguished by their degree of **impermeability.** In the context of evaluation of the biophysicochemical properties of soils, it is the intensity of the **disturbance** of the superficial and deeper layers of the 'soil' which must be considered. Regardless of the nature of the environmental impacts to be considered, research suggests that the distinction between pervious and impervious surfaces is the first factor to consider. Whether the focus is on biodiversity, water behavior or impacts on atmospheric temperatures, **the consequences are exacerbated when the level of soil disturbance and impermeability is high.** With the aim of categorizing artificial soils, soil scientists have recently proposed a classification of artificial soils (the 'Anthroposols') based on the nature of the modifications of their morphological characteristics. Then, the modifications would be link to the uses of the soil, classified in SUITMA, an acronym for urban soils, industrial land, transport infrastructure, mining areas and quarries, and military zones (Box 1 and Figure 3).

Studies consistently show that sealed ground, corresponding to built-up areas, roads, sidewalks, squares, car parks, industrial, logistic and military infrastructure, airports, and port facilities) are the poorest both in terms of biological activity and overall biodiversity. These are the most likely to cause runoff and contribute most to the urban heat island phenomenon (as are building walls, roofs and energy sources). Unsealed areas are more 'multifunctional' and prone to changes in use. However, mapping these areas and defining their functional properties is difficult, because they may vary at the scale of a few meters. An analysis of the RMQS[2] points located in artificialised zones could make it possible to develop specific reference points.

The preservation of vegetated soils in artificial environments is a challenge in terms of hydrological regulation, biodiversity and soil carbon storage. In urban areas, the soils of some vegetable gardens are distinguished by their high levels of organic carbon and nutrients, which are often derived from exogenous inputs. However, these soils, as well as those in public gardens, may contain high levels of pollutants (due in particular to industrial activities, backfill materials and atmospheric deposition). For this reason, the development of soil quality indices and functional indicators is a prerequisite for the implementation of actions to preserve soil functions in development projects. Some planning documents take into account soil quality when detailed mapping exists. However, defining the quality of a soil remains a local or regional responsibility. Work is in progress to replace the concept of soil quality with those of soil functions and services through the analysis of their properties. The aim is to combine soil conservation with a more logical focus on their uses.

Box 1 - Characteristics of artificial soils, "Anthroposols" or SUITMA.

Artificial soils are generally characterized by:
- extreme spatial variability;
- the nature of the technogenic materials they contain, their abundance, and size;
- strong stoniness and high compaction rates;;
- low infiltration and water retention capacities (except vegetated soils);
- high pH levels for urban soils and those of transport infrastructure, or acids in the case of mining and industrial soils;
- highly variable organic matter content, depending on the land use and the origin of the soil;
- high concentrations of heavy metals (Pb, Zn, Cu, Cd, Cr, Ni) and polycyclic aromatic hydrocarbons (PAHs);;
- frequently high concentrations of pesticides and emerging pollutants (platinoids, flame retardants or drug residues).).

Figure 3 - Some examples of urban and peri-urban soils classified according to a growing degree of urbanization (photo credits: L. Beaudet).).

The biodiversity of artificialised environments

Terrestrial (aboveground) biodiversity, like **soil (belowground) biodiversity**, is negatively affected by artificialisation. It **is impacted through habitat loss, uniformisation and environmental contamination and habitat fragmentation.**

As the species richness of intermediate-level urban environments can sometimes be higher than in some agricultural areas, more accurate measures or indicators of functional biodiversity, which

[1] Etlicher, B., Kaufmann, B., Rousseaux, F. & Aubertie, S. 2016. Evaluation scientifique de l'indicateur « Artificialisation du territoire métropolitain ». In Fondation pour la recherche sur la Biodiversité (2016), Evaluation scientifique de 55 indicateurs de la Stratégie Nationale pour la Biodiversité, Ed. B. Livoreil et S. Aubertie, 296 p.

[2] *Réseau de Mesure de la Qualité des Sols*, piloté par le GIS Sol.

are not necessarily correlated with specific biodiversity, would be required. In addition, flora is less affected than wildlife by the artificialisation of environments. The biodiversity observed in urban areas, as well as around transport infrastructure, is characterized by an increased presence of generalist species, some of which are invasive and, increasingly, exogenous, to the detriment of the characteristic species of the area. This is due to the horticultural practices and the adaptability of some of these species to highly modified environments.

The **density of road infrastructure** is particularly important in France. **The impacts of fragmentation are severe** for species with low dispersal, forest species or for specialist species. This effect of fragmentation favors generalist species, and reduces biodiversity. Conversely, the presence of trees may also favor the presence or movement of certain species in the vicinity of roads or railways, and the negative effect of transport infrastructure may be slightly mitigated through through the installation of wildlife passages allowing animals to cross them.

Moreover, the effect of transport infrastructures is not only structural (fragmentation), the latter also induce physical and chemical modifications of their immediate environment, and studies mention the difficulty of separating influence variables, especially those associated with. roads (land use, noise, traffic, soil pollution, air pollution, etc.)

The artificialisation of land, an issue in terms of impacts on human amenity'

The artificialisation of land is also a source of **various nuisances to the population**. At the scale of the neighborhood or the urban area, the spatial organization of areas of different levels of artificialisation and permeability will influence the level of impacts. A gradient of these nuisances emerges, from the urban fringes towards the center. Locations closer to the center of an urban area with a significant rate of artificialisation, and therefore more impervious surfaces, will experience greater numbers and concentrations of nuisances.

Decreased surface porosity modifies **hydrological processes** by reducing the infiltration capacity of soils and the evaporation of water. In order to control the hydrological impacts of land artificialisation, alternative systems for managing rainwater at the source have been developed, such as the planting of new vegetation. Their implementation in situ shows satisfactory results, especially when designed in combination with the restoration of ecological corridors.

In addition to direct benefits in terms of water retention, evapotranspiration and the limitation of flood risks, many studies have revealed the effectiveness of vegetated structures for the reduction of particulate contaminants and the reduction of the bioavailability of metals, thus helping to reduce the flow of pollutants (which accumulate in the city), to rivers and natural environments.

In order to mitigate the negative effects of excess artificialisation on the urban environment, policy levers in terms of planning are available. Two important issues that have been identified are 1) **mitigation of heat islands**, and 2) **reduction of noise pollution**. Although green spaces containing trees create more pleasant thermal conditions in summer, their effect extends only to the near vicinity (Figure 4). They also have limited impacts on noise pollution. The use of new and novel materials (clear and reflective pavement or building coverings, green roofs or facades ...) can improve the thermal comfort of buildings,

but has effects that are probably very limited (but not well evaluated) at street / neighborhood / city scales, and may even have negatively affect pedestrians if the buildings have reflective facades..

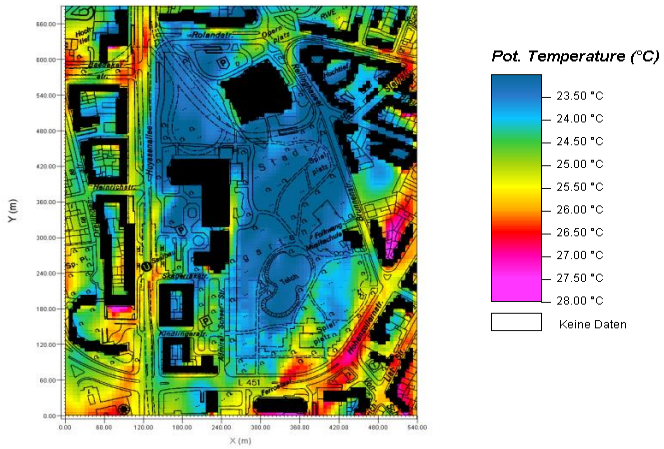


Figure 4 - Air temperature (° C) in and around an urban park in Essen (Germany); (Lahme and Bruse, 2003)

The impacts of land artificialisation on agriculture

According to Teruti-Lucas (TL), 2/3 of the artificialisation of land between 2006 and 2014 came at the expense of agricultural land and 1/3 replaced wooded and natural areas. However**, there are often significant areas that have changed between the three major land-use categories**. Of the former agricultural areas that changed category, 60% became woodland and 'natural land' (Figure 2). Thus, a large part of agricultural land loss is due to abandonment and recolonization by natural vegetation rather than to artificialisation. However, 2/3 is compensated by a reverse flow, illustrating the porosity between agricultural zones and wooded or natural areas. Often, land clearing precedes urbanization on private land by some period of time.

The location and the agricultural potential of these two types of land use changes are nevertheless very different. The areas of abandonment and re-cultivation concerns mostly areas that are less suitable for agriculture (mountain, etc.) and which are by default little affected by urbanization. On the other hand, a significant proportion of peri-urban, artificialised or potentially developed areas have high agricultural suitability.

Estimating the impact of land artificialisation on productive agricultural capacity requires knowledge of the quality of agricultural soils prior to their artificialisation. The agronomic quality or 'fertility' of agricultural soils is complex, depending on the combination of chemical, biological and physical fertility, involving a wide variety of soil properties.

One of the few studies **evaluating potential losses of production capacity** related to artificialisation reveals that in France, 70% of urbanization is to the detriment of very good quality agricultural land, which itself comprises 68% of French land. Given the imprecision of the estimates, however, the bias toward conversion of these good quality agricultural lands is not necessarily significant, and the artificialisation might equally affect lands of different agricultural potential. The loss of productive capacity that the same addresses would be equivalent, for France from 2000-2006, to 0.26% of total agricultural production. This would equate to the European average, with a per capita equivalent also concurring with the European average.

When viewed at a local scale, the **effects** of land artificialisation on agriculture are **perceived in a far more precise and specific manner**, and is very unevenly distributed across France. In particular, it affects certain quality agricultural areas that are likely to be missed in the context of local agriculture. Located near urban cores and easily convertible to other uses, these lands are all the more vulnerable as they are, in general, less protected than natural areas, except for lands benefiting from specific protection mechanisms protected agricultural zone (ZAP) type. Agricultural surfaces facing a possible artificialisation are significant in the crowns of the urban poles. Thus, the effects of the artificialisation of land on agricultural lands and the fragmentation of this productive territory are felt more strongly at the local scale than at the national level: the loss of local agricultural income, but also the difficulties resulting from it (access to parcels, neighborhood conflicts, etc.) are significant and may hinder the very exercise of the activity.

Proximity to urbanized areas can also become an **opportunity** for the agricultural sphere: financial opportunity in case of conversion of use whose effects on agricultural production can be raised; economic opportunities through the deployment of quality productions and / or direct selling channels that improve prices or added value from local productions.

Demand for housing and artificialisation of land

The basic models of the urban economy interpret the residential localization process of households as a tension between the cost of housing, on the one hand, and transport costs of households seeking to settle around a job center on the other. Housing costs tend to increase with competition for land, becoming higher near the center of towns as densities increase. Transport costs decrease in these central areas (for those who can afford it). This house cost/transport cost tension accounts for **the spreading movement of cities from their center**. This is exacerbated by the fact that the proportion of household expenditure on housing is increasing at a faster rate than the expenditure on transport.

This movement is accentuated by **the growth in housing demand** linked to the conjunction of three complementary phenomena: population growth; the decrease in household size; and the preference expressed by households for individual housing, the latter element increasing the demand for artificial land for both buildings and adjacent gardens. To these three components are added the ambivalent role of the attributes of places, natural versus urban amenities, and that associated with the benefits that households can derive from social interactions.

Peri-urban issues: combating diffuse and discontinuous urban sprawl

Peri-urbanization is a basic trend that concerns today both urban areas with a high population, and unattractive urban areas. This phenomenon, reflecting the dual processes of expansion and densification of cities, is not unique to France; in Europe, the highest growth rates of built-up areas are observed at the limits of urban agglomerations. Urban sprawl is first carried out on the periphery of already built and continuous areas. It is reflected in France by a diffuse and discontinuous urban sprawl away from existing urban areas, and results from a range of factors such as exclusion zoning policies and the scarcity of land in areas under pressure.

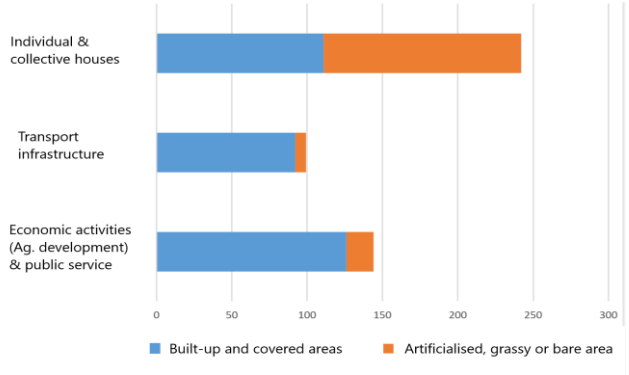


Figure 5 - Balance of 2006-2014 flows of artificial land according to land use (in thousands of hectares). Source : Agreste, 2015

Peri-urbanisation is not necessarily unwanted. It reflects the demand for individual housing but, as a result, is a major source of land artificialisation. Limiting the spread of this source of artificialisation can be through limiting the extension of city borders and/or limiting the spread of peri-urban areas.

In response to these issues, **policy levers being developed in the planning sphere** are working toward a greater mixing of socioeconomic groups, as well as greater consideration of the multifunctionality of cities. A primary lever to limit this diffuse urbanization is the **densification of French cities**, which currently have considerable room for increase in comparison with the already densely-populated cities in Southern and Eastern Europe. However, many town planning studies strongly question the social and environmental limits of compact city models. Debate over densification objectives is therefore ongoing.

Nevertheless, the rehabilitation of vacant spaces, industrial wastelands within already urbanized spaces ('infill') could be an effective lever for responding to the demand for housing and a driver of increased amenity for surrounding neighborhoods. The estimation of real housing needs and measures to identify vacant built-up areas should be the starting point for these policies.

The need to distinguish between individual and collective housing

According to Teruti-Lucas, residential areas in 2014 accounted for only 42% of current built up areas. However nearly half of the new artificial surfaces created between 2006 and 2014 were for housing (Figure 5). Although this trend is much greater than that for economic activities or transport infrastructure, it generally leads to less surface sealing, since only 45% of these individual housing areas are sealed. Conversely, 90% of the surfaces intended for infrastructures or economic activities are impervious.

Location of companies and transport infrastructure, have significant impacts on the artificialisation of land

Other activities that contribute to the artificialisation of land include the development of transport networks and other economic activities and, in particular, areas of commercial activity and logistics zones.

Today, **non-agricultural economic** land (company locations, commercial areas, warehouses) covers 30% of artificial surfaces, according to estimates from Teruti-Lucas. Their increase in terms of the creation of impervious surfaces was, between 2006 and 2014, faster than that of residential uses (Figure 5). As of 2014, transport infrastructure accounted for 28% of all artificial surfaces with an equal contribution to the artificialisation of land and reduction of surface permeability.

In Europe, as in all other regions of the world, economic activities are **highly concentrated in and around major centers**. It is the result of a process of circular and cumulative causation underlying the mechanisms of contemporary urbanization. Economies of scale (within firms) and economies of agglomeration (market and non-market), where companies can benefit by getting closer to one another (industrial or tertiary) encourage geographic concentration in already existing cities. On the one hand, relations between customers and suppliers favor the search for proximity between economic activities and with consumers. On the other hand, proximity between firms in the same sector or in different sectors may reduce certain costs, such as those relating to access to information, the use of common equipment or access to similar labor markets.

Today, there is a **tendency to locate businesses on the outskirts** of cities or peri-urban areas, creating secondary employment centers. Two mechanisms can influence this movement. On the one hand, the dynamics of land markets within the city can lead companies to choose to settle in the periphery to benefit from cheaper land without limiting their access to employees and consumers. On the other hand, the addition of infrastructure away from the center (ring-type) can encourage companies to locate near it rather than in the center.

However, given the low weighting of land costs in the location decisions of most economic activities, there is a surprising lack of research on the **consequences of these choices on the footprint of economic activities**, and therefore on their contribution to the artificialisation of land, in comparison to the focus on the proportion of total of artificialised surfaces that companies represent.

The impact on artificialisation by economic 'large objects' such as shopping malls or logistics terminals that consume large amounts of space is also poorly understood. However, it is apparent that if logistic warehouses were traditionally located at the fringes of the dense agglomeration, or even at their heart when they were linked to rail networks, they moved into suburban and peri-urban areas, thus moving closer to networks, motorway nodes and major intermodal hubs, including airports. These locations offer real estate or low-cost real estate rental, but consume significant farmland.

Economic activities conducted by companies, and transport infrastructure are a significant component of the urban footprint, and their location has a direct impact on land consumption and greenhouse gas emissions.

Actions to avoid, reduce or compensate for the impacts of land artificialisation

Experience has shown that land artificialisation, especially on agricultural land, has been largely immune from the **fiscal and planning tools** developed by public authorities since the 1980s. Despite many laws and regulations, economical land use remains an elusive goal at the national level. Although the available legal tools may potentially limit land artificialisation, their implementation varies from one region to another and is globaly limited.

The intercommunal level is now the appropriate level of governance to better manage land use, but experts recognize the ambiguity of the law in relation to this management. On the one hand, artificialisation appears to be encouraged in order to meet economic and social needs as well as the goal of local development, while on the other hand, the mechanisms to control land-use change in most cases lack binding force. This fundamental contradiction must be solved in order that the policy of limitation of the artificialisation of land, as has been committed to, is effective.

To this end, both the tax system and the law emphasize that the concept of artificialisation must be better defined in order to be better understood. Were this is the case, different public policies could converge and operate in a complementary manner integrating issues relating to transport, housing, industry, and agriculture, etc. This would lead to more effective consideration of both direct and cumulative impacts. One of the levers lies in the development of an integrated land protection framework at national or even European level.

Taxation does not have an insignificant effect on landuse. Most of the players recognise this as a primary policy lever in the fight against the lack of housing in France. Clearly, however, any tax reform will only be fully effective if

Box 2 - The specificities of the artificialisation of land in coastal environments

Although coastal areas are subjected to the same artificialisation processes as are other areas, they may also include **particular** stressors including tourism, uncontrolled urban sprawl, and the influence of the maritime activities (fishing, military, trade, pleasure craft) in the development of infrastructure such as ports etc. The shoreline also has a **specific form of artificialisation**: land use improvements to protect land from sea incursions and, more recently, beach maintenance. These are unsustainable solutions, as these actions to maintain the coastline block sediment transfers. Although the issues associated with artificialisation largely overlap those of other areas, they appear to be exacerbated because of the limitation of space and the sensitivity to disturbance of coastal ecosystems.

Coastal areas of the French overseas territories are confronted with the same problems as in metropolitan France in terms of development. However, the rich biodiversity, vulnerability to climate change and societal differences require specific responses from public authorities. The artificialisation of the coastline could be better understood, both in terms of its extent, but also in its impacts.

The consequences of artificialisation are **not inevitably negative**: tourism development is a source of income for the local population, and may encourage protection of the environment and coastal landscapes, since these areas are considered a tourist resource. However, it also leads to rises in property prices that may exclude local populations.

accompanied by an integrated land management policy, and firmly supported by planning tools. Despite the national policy on ecological transition (2013), little work has been conducted on the financial and fiscal instruments that might encourage densification. This is not so much due to the technical nature of the exercise, but rather due to the lack of specialists and dedicated resources on this topic. The question was addressed in the framework of the French Committee for Ecological Taxation. Other suggestions made by this Committee include the taxation of vacant offices on the model of the taxation of vacant dwellings (which encourages their sale rather than new office constructions), and a tax on industrial and commercial wastelands to encourage the recycling of land.

Conclusions and research needs

This scientific summary highlights the fact that artificial land and the artificialisation of land in France, their impacts, their determinants and policy levers to control their expansion or impacts, remains a research topic of which many areas remain unexplored or require a renewed approach.

Many historical, socio-demographic and economic factors have made and continue to make our societies increasingly urban. This urbanization is one of the main drivers of land artificialisation. More precise distinctions between, and measurements of, the different process encompassed by the term land artificialisation is necessary in order to avoid confusion between very different situations and to enable the design and implementation of measures that are adapted to the quantitative and qualitative reduction of their impacts.

In terms of environmental impacts, it is clear that the reduction in surface permeability is the most damaging mechanism, whether as a threat to biodiversity, runoff risks or the creation of urban heat islands. Added to this is soil (and water) pollution, particularly related to mining and industrial activities and road traffic, as well as the fragmentation of landscapes by transport infrastructure. This statement argues for a renewed urban development framework that integrates green spaces, parks, and gardens as multifunctional elements of urbanization, and preserves as much as possible the functions of the land, taking into account the needs of ecological connectivity. These elements are also favorable to the creation of associated amenities that improve the attractiveness of cities. Finally, this type of development appears compatible and even inseparable from the need to preserve natural areas and lands with agronomic potential, avoiding its fragmentation on the outskirts of cities, as well as in rural areas in general.

Effective solutions exist to improve the urban environment, and this review identifies a need for strong research on themes related to the optimal density of cities, The reversibility of artificial land is a concept that, given the current situation, also requires further research, as does the concept of cost/benefit analyses of the artificialisation of land as a governance tool when assessing the overall impacts of a development project.

Collective scientific summary

This collective scientific expertise (ESCo) includes the most up-to-date scientific knowledge and its critical analysis that makes it possible to take stock of the achievements, debates and controversies that cross the scientific communities, the uncertainties that must be taken into account in the future. interpretation of the results and the gaps that will need to be filled in the future. It does not formulate opinions or recommendations. The conduct of the exercise is based on a charter whose general principles are competence, impartiality, plurality and transparency.

The group of experts gathered for this ESCo includes 55 researchers. Their disciplines are equidistributed between environmental sciences, economics and social sciences.

The bibliographic corpus was constituted after interrogation of the Web of Science-TM, Scopus and EconLit databases. The experts selected references and supplemented them according to their disciplinary skills. The final corpus includes more than 2,500 references (articles, books, book chapters, reports, regulatory texts, etc.).

Further information:

Béchet B. (coord.), **Le Bissonnais Y.** (coord.), **Ruas A.** (coord.), **Desrousseaux M.**, Aguilera A., André M., Andrieu H., Ay J.-S., Baumont C., Barbe E., Beaudet-Vidal L., Belton-Chevallier L., Berthier E., Billet Ph., Bonin O., Cavailhès J., Chancibault K., Cohen M., Coisnon T., Colas R., Cornu S., Cortet J., Dablanc L., Darly S., Delolme C., Facchinetti-Mannone V., Fack G., Fromin N., Gadal S., Gauvreau B., Géniaux G., Gilli F., Guelton S., Guérois M., Hedde M., Houet T., Humbertclaude S., Jolivet L., Keller C., Le Berre I., Madec P., Mallet C., Marty P., Mering C., Musy M., Oueslati W., Paty S., Polèse M., Pumain D., Puissant A., Riou S., Rodriguez F., Ruban V., Salanié J., Schwartz C., Sotura A., Thébert M., Thévenin T., Thisse J., Vergnès A., Weber C., Werey C., 2017, *Sols artificialisés et processus d'artificialisation des sols : Déterminants, impacts et leviers d'action*. IFSTTAR et INRA (France), 620 p. (rapport), 127 p. (synthèse).

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